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A Discovery Sourcebook for Astrobiology

ISU Design Team, SSP 2002

Pomona, CA, July/August 2002

Acknowledgments

The authors express their sincere gratitude and appreciation to the individuals and organizations that contributed their time, expertise, and facilities to assist in making this project possible.

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Foreword

The International Space University was founded to advance the exploration and use of space in the service of people throughout the world. Its central goal is to bring together those young people who are motivated and able to lead humanity into a peaceful and abundant future both on and off our planet. With personal relationships forged during an intense period of study and work as students, ISU alumni are expected to go out and create a worldwide network of friendship and achievement as they rise in the space professions. With grounding in the whole wide variety of space-related disciplines, they then can call on each other for help and counsel as they build the international space programs of the future. More than 2000 ISU graduates in more than 60 countries are already realizing this objective. ISU has two main programs: a peripatetic summer session and a Master of Space Studies curriculum at its permanent headquarters in Strasbourg. In each program students, in addition to their multidisciplinary core courses and individual assignments, carry out design projects intended to give experience in teamwork under stress and to generate influential results. The topics of these projects are deliberately selected to be difficult and important. In the 2002 summer session one project focused on space in the service of human health and the other focused on the new interdisciplinary realm of astrobiology - the study of possible universal life. This report deals with that project. Astrobiology has emerged from the world of speculation into the world of investigation because of suggestive new findings in several scientific fields: increased understanding of the fundamental processes of life on Earth, observation of life's main elements and molecules throughout space, discovery of living microbes in extreme terrestrial environments, detection of the signatures of planets orbiting many stars, and above all the realization that life may be a common, perhaps even inevitable, result of cosmic evolution. With these tantalizing hints before us, it is time for a broad attack on the question - especially one that engages talent in each of the many relevant fields and in each of the many places where skills and resources exist. The students of the ISU 2002 astrobiology team devoted their energy to defining this attack. Here is their report.

James Burke

Faculty Preface

At every Summer Session Program of the International Space University, students carry out two design projects intended to give teamwork experience under stress and to generate analyses and recommendations on topics of current interest in the world's space programs.

In 2002, the two projects were about astrobiology and the use of space systems in improving human health. This document presents the results of the astrobiology project.

Astrobiology is emerging as a new, interdisciplinary scientific field with information sources both on and off Earth. The ancient concept of a plurality of inhabited worlds has received new stimuli from recent discoveries – planets around other stars, microbes in extreme terrestrial environments, interstellar and stellar evolution involving the elemental building blocks of life.

Given the rich diversity of the subject, the first task of the student team was to narrow the scope of their inquiry. They decided to focus on likely progress over the next twenty years, concentrating on both ground-based and space-based activities that may realistically advance human understanding of the origins and distribution of Earth-like life in the solar system and around nearby stars. In choosing this focus, they deliberately excluded entities that may possibly live somewhere in the cosmos, not violating any currently known law of nature, yet being so different from our water and carbon based life that we might not even recognize them as alive.

Within this scope, the team examined ways to investigate and possibly discover other life, from bacteria to galactic civilizations, and they also considered the likely social effects of a confirmed discovery.

The focus of the report, along with the format, style, and management behind it, is the product of the participating students. The document you are reading is unique – its breadth and perspective could not be matched by a consultant, company, or national space agency. More than the results of an academic exercise, this report will be a valuable tool to scientists, educators and future mission designers.

We, the project's faculty, advisors and teaching assistant, are honored and proud to have been associated with this talented and energetic team of students.

David Miller, Co-chair	Lloyd French, Co-chair	Weng Ang, Teaching Assistant

Student Preface

How does life begin, change or evolve? Is there life elsewhere in the universe? Do we dare look for it? What is the future of life on Earth and beyond? People have pondered these questions for centuries. But now, for the first time in human history, advances in the biological sciences, the social sciences, and space technology may finally make it possible to answer these fundamental questions of human existence. The interdisciplinary study of astrobiology is a unique way of inviting all disciplines to participate in the quest of what it actually means to be alive. This report represents what can be achieved when 46 international students from 20 countries get together with some of the most dedicated scholars in the world. It was a challenging task to write the Astrobiology Sourcebook you hold in your hands. Page limitations, information technology challenges and the editing of pain staking work were some of the numerous hurdles we had to overcome. The continually shrinking timeline demanded patience and cooperation bringing about an admiration and respect for each other's unique strengths and cultural differences.

What's really out there?

"Maybe space is not about how far the eye can see
It may have so much more to do with the people around me
The differences that separate us now don't look so far
Together we can see them as they are
So maybe space is not about the things we'd like to see
It may be more about us learning to strive for what could be
I'm thankful for the time I've spent with you
Together, think of all that we might do."

What does an International Space University Summer Session Program and an Astrobiology mission have in common? Answer: The objective for both is to seek out and understand alien life.

The students of the astrobiology team would like to thank Dr. David Miller, Dr. Lloyd French, Mr. Weng Ang, Mr. Jim Burke and all the faculty and staff for their guidance and support. We would also like to thank the visiting experts who have graciously answered all of our questions, participated in strange conversations and bravely read our first drafts.

Lastly, we would like to thank whoever is responsible for creating California and the genius behind the idea of all-you-can-eat ice cream. LaTeX lives!

Message from the Editors

When the design project Editing Team was tasked with the production of a document of large magnitude in a very short period of time, which would be written by nearly fifty authors, it became apparent that a system had to be established to ensure that a single consistent and coherent document would be produced in an efficient manner.

Inspired by concept of "Concurrent Engineering", which was introduced to the International Space University Summer Students by the Jet Propulsions Laboratory in Pasadena, CA, the Editing Team was determined to create a "Concurrent Editing" environment. The concept was simple: at frequent time intervals, collect all the documents from each author and compile it into one single document with consistent formatting. The concept was carried out using a combination of LaTeX, Rich Text Format documents, Perl computer scripts, open source software, and extensive networking. The entire process was executed at 15-minute intervals on a private Linux server and then published to a web page in PDF and HTML formats. Thus, at any given moment in time, each author was able to see the current status of the *entire document* thereby promoting coherency between the chapters.

In the end, we hope the process has created a single coherent document.

The Technical Editors:
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Contents

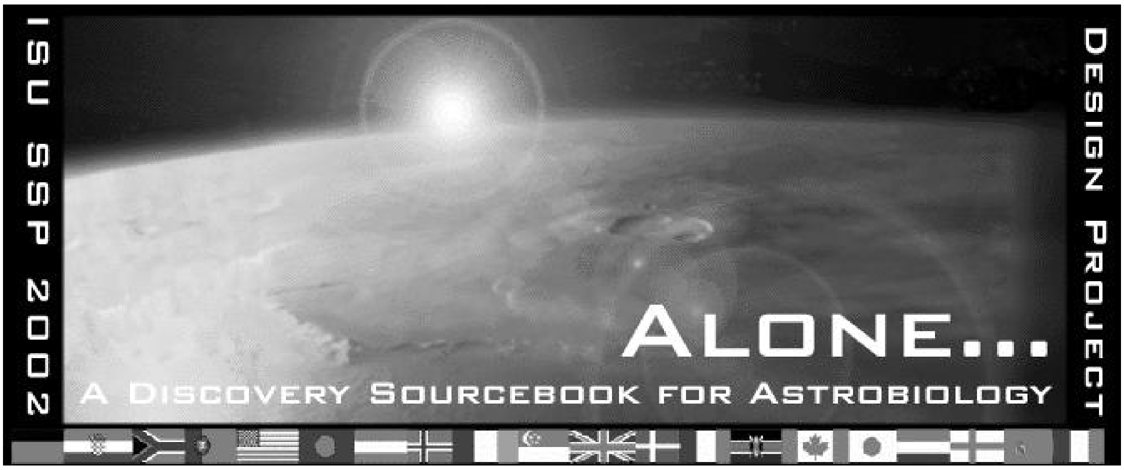
List of Figures

List of Tables

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

Alone? A Discovery Sourcebook for Astrobiology is the product of the International Space University Summer Session Program 2002 held at the California State Polytechnic University in Pomona. Forty-six students from twenty countries and a wide range of backgrounds came together to create this sourcebook, which represents an international, interdisciplinary, and intercultural approach to the topic of astrobiology.

The sourcebook combines the perspectives of many professional fields involved in space activities. These include space and society, business and management, engineering, life sciences, physical sciences, policy and law, satellite applications, and space systems analysis and design. Our target readers are both those with experience in astrobiology and those not yet schooled in its concepts.



As the field of Astrobiology continues to emerge, this sourcebook provides a consolidated, interdisciplinary viewpoint. By gathering sources from many fields, this book serves as a central resource of information. It also provides added value to guide decision makers, investigators, students, and the public at large.

The sourcebook addresses issues pertaining to the search for and discovery of non-Earth based life, extant or extinct, and not the study thereof.

The period of study is the past, the present and 20 years into the future.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

``A man that is of Copernicus's opinion, that this Earth of ours is a planet, carry'd round and enlighten'd by the Sun, like the rest of the planets, cannot but sometimes think that it's not improbable that the rest of the planets have their dress and furniture, and perhaps their inhabitants too, as well as this Earth of ours".
Christiaan Huygens, ``Cosmotheoros: or Conjectures concerning the Planetary Worlds", London, 1698

Lying at the interface among many major branches of scientific inquiry, Astrobiology has emerged over the past ten years to become an exciting, and still evolving branch of active research.

Many space missions have been performed or planned within the astrobiology context, both before and after the consolidation of the field started in the mid-1990s. This includes the search for life in extreme conditions here on Earth, the Moon, Venus, Mars, comets, and other bodies within our solar system. These missions strike out to search the solar system for answers to one of the ultimate questions of humankind.

Is Earth unique in its ability to create and sustain life? Are we alone in the Universe?

Long before the first observations of Jupiter's moons by Galileo, humanity has looked to the stars for answers, guidance, and inspiration. The impact of astronomy on humankind is unquestioned. And its ability to relate to the public's frame of mind has been enhanced with the advent of more advanced telescopes and observatories. Astrobiology is a natural extension of this line of inquiry.

The techniques used to explore astrobiology's questions are drawn from a wide range of scientific, technical and social disciplines. The advent of the space age has brought humanity closer to investigating these questions by synthesizing across disciplines.

100 years ago, the technology to carry out this investigation was unimaginable. 50 years ago, it was not possible to bridge space and time to even start an extraterrestrial investigation. 30 years ago, the first focused space-based efforts were undertaken. Today, humankind's ability to carry out a meaningful search is truly starting to emerge.

"Any sufficiently advanced technology is indistinguishable from Magic."
Arthur C. Clarke

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

The organization of *Alone? A Discovery Sourcebook for Astrobiology* follows four themes:

Current State (See Chapter 2 in the sourcebook): Discusses past, present, and planned astrobiology investigations. It identifies, references, and summarizes each activity providing an overview of the objectives, progress and present status.

The Quest for Discovery (See Chapters 3, 4, & 5 in the sourcebook): Discusses life, what we think life is, where to look for life, and the experiments to use to identify life, as we know it, either extant or extinct. We discuss future space missions by identifying destinations and mission options. Finally, we discuss planetary protection and its implications on mission protocols.

Human Elements (See Chapters 6 & 7 in the sourcebook): Discusses the impact of astrobiology on the human condition through scenarios. What happens if we do find life or what happens if life finds us? This is followed by a discussion of how education can bridge the gap between astrobiology and the public by functioning as a link among many other fields of study.

Synthesis (See Chapter 8 in the sourcebook): concludes the report with a discussion of how all of the elements in the previous chapters are inseparably intertwined. We demonstrate this in a case study of a future astrobiology mission to the Jovian moon Europa.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

Within the scope of the sourcebook, we have attempted to provide a comprehensive overview of past, present and planned missions seeking the conditions for and existence of life beyond Earth.

Exploration in the Solar System: Planets, Moons and Small Bodies. This section of chapter two documents the history of missions to bodies within the Solar System, as well as what is currently planned to explore the secrets of these worlds.

Extra Solar Planets: The search for extra solar planets has so far identified eighty-eight star systems believed to have planets, which are considered candidates for astrobiological investigation using ground and space based telescope facilities. The search has just begun.

Search for Extraterrestrial Intelligence: Radio telescopes have been scanning the skies for decades to pick up faint signals from our galactic neighbors. Several "Wow! Signals" were received, but all could be traced to natural or man-made phenomena.

Are we alone or just deaf?

Is everybody else silent?

What are the signals we should be looking for?

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

Knowing the properties of life is an important tool in the quest of finding life or the signs of life.

What is life? Simply stated, the question 'What is life?', does not have a straightforward answer. Although it is difficult to define life, it is easier to find characteristics of life as we know it.

Characteristics of Life: Seven main properties used in describing 'life':

1) Structure and Boundary
2) Thermodynamic Disequilibrium With Environment
3) Energy Conversion
4) Movement
5) Adaptability
6) Replication
7) Information Transfer

Habitable Zones and Extremophiles:
What properties of the neighborhood we live in make it a Habitable Zone.

How does the study of extremophiles on Earth further define Habitable Zones? Consider conditions required to sustain life or survival limits of life. The pertinent factors include: temperature, pressure (low or high), pH, salinity, radiation quantity and quality (e.g. UV, IR).

Finding Life or Signs of Life:
Several instruments are used in a complementary strategy in the search for life. These include search for conditions required for life (e.g. water) and characteristics of life (e.g. movement). We consider instruments used in past missions (e.g. Viking) to refine search strategy and methods.

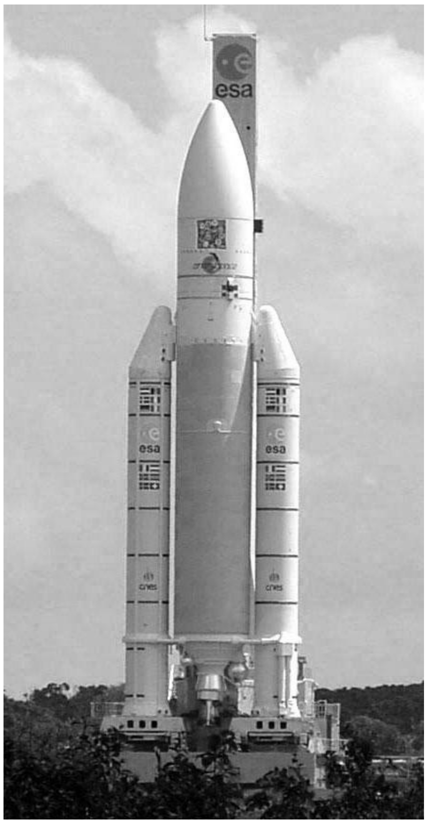
Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

We develop a mission design option tree to identify a limited suite of future missions for finding extraterrestrial life. It constitutes a limited design space that suits any future astrobiology mission to produce science data within the 20-year timeframe.

Science Objectives: We ask, ``What science on which body?'', e.g. Mars, Europa, Ganymede, Titan, or comets.

Hot Targets: We identify areas of most interest on bodies within our Solar System. Mars, Europa, Ganymede, Titan, and comets are discussed.

Missions and Technology: We describe re-application of existing technologies and identification of enabling technologies that will mature in the next 20 years.



Mission Concepts: We define new mission concepts to advance and invigorate further exploration.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

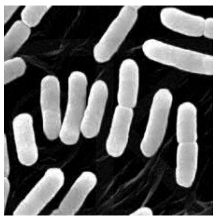
Humanity must not be reckless and insensitive in its incessant quest to explore the universe and in bringing the universe back to Earth.

Protect ANY kind of life from harm. In finding life in outer space, planetary protection dictates that we must protect this extraterrestrial form of life and also protect the Earth's biosphere from the potential harmfulness of this life form. We do not know if this situation is possible, that is why we should be prepared for any eventuality.

Forward and backward contamination definitions are fundamental in the planetary protection context.

Scientific, Ethical, and Legal reasons are motivating us in making so many efforts to avoid contamination in both ways. Science demands preventing the contamination of samples. Ethics underpins the reasons for undertaking such measures. Legal principles provide policy, to regulate our activities to have practical ways to respect the rationales that support planetary protection.

Implementation by physical means: Minimization of forward and backward contamination through bio-burden or contamination reduction methods.



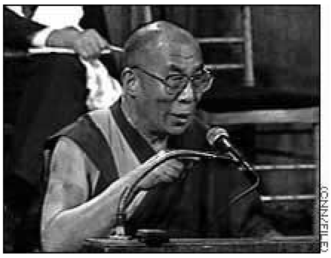
We provide guidelines after having put together all the elements that constitute what is known of planetary protection today. This will help policy makers and mission designers in future decisions.

This is absolutely necessary to obtain an agreement between public, policy, and scientific communities to ensure that future astrobiology missions continue to be funded and make it off the launch pad in support of humanity's quest to explore and search for life beyond.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

According to astronomer Richard M. West, *"The discovery of life outside the Earth will be the single, most dramatic event in the entire history of humanity, nothing less and nothing more."*

All parts of society will be influenced by such a discovery, such as religion, politics, culture, science and technology. With the help of scenarios some of the potential reactions can be analyzed and partially forecasted, but not entirely predicted.



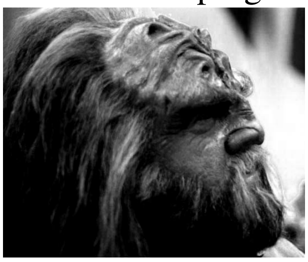
Most religions will probably adapt to this new situation, as they have done with other major changes of our worldview in past centuries. On the political level governments may want to restrict the available information to control public reaction or to strengthen their position. Will nations be able to agree on a unified response in the name of humankind?

Scientific research priorities may be shifted to further analyze the findings. Public interest might quickly decrease when the impact on daily lives is small, no new developments are reported and when the discussion is held on a complex scientific/technical level.

Recommended guidelines to mitigate any adverse effects of the first contact: First, transparency and timely distribution of information should be ensured and all media should embrace responsible reporting. Public education should be given high priority to help people deal with this radical change. An international panel of experts should be assembled to correctly assess the situation and support political leaders in their decisions.

And last but not least: **DON'T PANIC!**

It is the educator's job to bridge the gap between astrobiology and the public. What society perceives as "extraterrestrial life" and what the scientists hope to find are two different things. This is especially true since the average "astrobiology" vocabulary consists of "Klingons", "Vulcans", and "Jedi Knights". Carl Sagan made the sweeping accusation that 95% of North America is scientifically illiterate. There is a general trend towards a decrease in scientific literacy among the general population. After conducting a survey of the present astrobiology resources we made a gap analysis which pointed to a need for more of the humanities in activities for children.



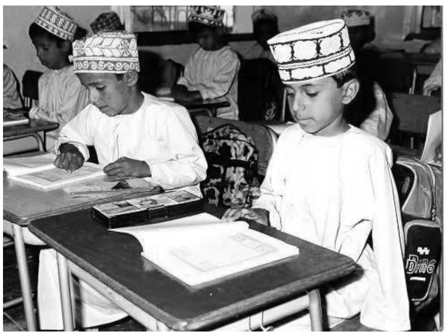
A Six-phase curriculum was developed to address a majority of the identified gaps:

Gives an introduction to astrobiology to pre-assess for present knowledge on astrobiology, misconceptions and for exposure to the basic terminology

Addresses what is needed for life on earth and beyond.

Discusses how to look for, protect and study life.

Examines which planets and bodies in our Solar System we think are best suited to contain evidence of life.



Studies what is being done on a global basis to learn more about possible life outside our planet.

Allows students to take what they have learned in the previous phases and apply it towards designing, as "life detectives", their own astrobiology mission.

Astrobiology as a common link: connecting multiple disciplines of science and humanities in a global way with emphasis on actual activities for children and implementation of a proposed curriculum.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

The case study gives an example of how the various issues addressed in our sourcebook could influence and shape a possible astrobiology mission. We performed the study with emphasis on an interdisciplinary approach and we used concurrent design processes.

The mission would investigate the Jovian system, extending science obtained through previous missions, with an emphasis on Europa. We chose the Jovian satellite Europa to be our target as it represents one of the most promising places in our Solar System where we could find at least very basic and primitive forms of life. The various aspects discussed in this study could also apply in a similar form to other potential astrobiology destinations.

We show how **currently available technology** could meet the major scientific requirements to investigate Europa, and extend our understanding of the Jovian system. Also, a mission to Europa has a scientific and educational return significant enough to give it the status of a flagship mission.

Education and public outreach plays an important role in the case study, with translation and the adaptation of educational resources representing a significant step towards promoting the global appeal of the mission.

In Summary

Current State: Many missions have been performed which investigated the properties of various bodies within the solar system. It appears that missions to Mars, Jovian moons, Titan, and comets have yielded data most relevant to astrobiology.

The Quest for Discovery: Current thinking points towards looking for life as we know it. The question of how to study and characterize life beyond life as we know it is not addressed.

There are significant opportunities for astrobiology missions in the next 20 years to investigate phenomena discovered by previous exploration missions.

Techniques for planetary protection are sufficient to support current exploration efforts; however, when issues such as sample return are considered, there are gaps to be filled ranging from technical to legal to ethical.

Human Elements: The impact of a discovery of life would have a large and irreversible effect on societies around the world. Societies would adapt to these effects. Research budgets may be re-aligned to address the new questions created and public education would become an important element in bridging the gap.

Building on astrobiology's multidisciplinary nature, education programs have been proposed to increase the public's knowledge, and skills. Students become "life detectives" in their search for understanding.

Synthesis: The Jovian satellite Europa was studied as an example target as it represents one of the most promising places in our Solar System where we could find very basic and primitive forms of life. We show that currently available technologies could meet the major scientific requirements to investigate Europa and extend our understanding. Such a mission would have a scientific and educational return that is significant enough to achieve the status of a flagship mission.

Alone? A Discovery Sourcebook for Astrobiology
An EXECUTIVE SUMMARY

This is an executive summary of *Alone? A Discovery Sourcebook for Astrobiology*, a full copy of the book is available from:

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Chapter 1

Introduction

"Science is built with facts as a house is with stones, but a collection of facts is no more a science then a heap of stones is a house." Jules Henry Poincaré, French Mathematician, 1854-1912

Astrobiology has emerged over the past 10 years to become an exciting, and still evolving branch of active research. Policy decisions by the US government, NASA and ESA in the mid-1990s [1, 2] have lead to a concerted effort by space agencies around the world to define and develop astrobiology programs. To date there have been many missions performed with an astrobiology content. Missions to Earth, the Moon, Venus, Mars, comets, other small bodies in the solar system, and the outer planets have carried out the search for life in extreme conditions in the Solar System, looking for an answer to one of the ultimate questions of humankind. *Is Earth unique in its ability to create and sustain life? Are we alone in the Universe?*

Of course, as curious minds around the globe have pondered these questions for many millennia, there are significant differences in how various societies, cultures and religions entertain the answers to these questions. Some have accepted the existence of life outside Earth as a reality, while some work to integrate these ideas into the collective thoughts of their people.

"Heaven and earth are large, yet in the whole of space they are but as a small grain of rice.... How unreasonable it would be to suppose that, besides the heaven and earth which we can see, there are no other heavens and no other earths." Teng Mu, Chinese philosopher, 13th century A.D.

The impact that the study of astronomy has had on humankind is profound. And its ability to capture the imagination of the public has been enhanced with the advent of more advanced telescopes an observatories such as the Hubble Space Telescope. Astrobiology is a continuation of humanities study of the heavens.

The techniques used to conduct this study are drawn from a wide range of scientific, technical and social disciplines. The advent of the space age has brought humanity closer to being able to make a first person investigation. The discovery of life in increasingly extreme environments here on Earth has opened up possibilities for discovery in locations never before thought possible. High powered telescopes, remote sensing satellites, landers, robotics, in situ investigation, sample return and human investigation are some of the capabilities currently under development.

100 years ago, the technology to carry out this investigation was unimaginable. 50 years ago, it was not possible to bridge space and time to even start an investigation. 30 years ago, the first focused space-based efforts were undertaken. Today, our ability to carry out a meaningful search is truly starting to emerge.

"Any sufficiently advanced technology is indistinguishable from Magic." Arthur C. Clarke

By gathering sources from the many fields that are in play, this source book serves as a central source of information. It also provides interpretation of that information for decision makers, investigators, students, and the public at large.

Definition of Astrobiology

According to ESA's 1999 report on Exobiology in the Solar System [1], the definition of astrobiology, also known as exobiology, is as follows: "Exobiology in its broad definition, includes the study of the origin, evolution and distribution of life in the Universe."

From the broad definition offered above, we have focused our study.

Sourcebook Organization, Intended Audience and Scope

Our astrobiology sourcebook combines many perspectives. These include space and society, business and management, engineering, life sciences, physical sciences, policy and law, satellite applications, systems analysis and design, and information technology management.

The sourcebook is organized into the following chapters: *Mission History, Life Experiments, Potential Missions, Planetary Protection, Impact on Humanity and Education.*

We include a summary of current knowledge pertaining to missions, science, technology, policy and procedures, present decision guiding tools and mission design proposals and document a high-level case study.

We hope to enable the reader to rapidly identify areas of interest pertaining to astrobiology missions. We target both those who are not yet schooled in astrobiological concepts and those who have some experience in the field. As a result of the very wide scope of the field of astrobiology and the varied background of our research team we have only focused on a subset of the field. Naturally, there are concepts and examples that we have not been able to treat. We hope the focus chosen provides a balanced survey of the field, a meaningful interpretation of trends, and sensible extrapolations of what might be possible in the near future.

We have bounded our sourcebook within the following constraints: (i) This sourcebook only addresses issues pertaining to the search for and discovery of non-Earth based life, extant or extinct, and not the study thereof. (ii) The period of study shall be the past, the present and 20 years into the future. (iii) We provide only a limited treatment of life forms that could exist within the laws of nature but are so different from Earth's water and carbon based life that we might never recognize them.

Current State

Past, Present, and Planned Astrobiology Investigations

Being human, we often strive to develop, build, and explore. Our expansion into the outer reaches of space is a consequence of our inquisitive nature. This section will provide a summary of past, present and planned astrobiology missions, compiled from a comprehensive literature search. These missions deal with extra-solar planets, Solar System bodies, and the search for extraterrestrial intelligence.

The Quest for Discovery

Alive

In our endeavor to find extraterrestrial life we must strive for a better understanding of the nature of life. Our knowledge of life is limited, as is exemplified by our inability to reach consensus on a definition of life. We will not resolve this issue, instead we characterize life by merely listing its properties. Having answered the question of what we are looking for, we will next discuss where we are most likely to find it. As Earth is the only planet we know that is inhabited, this essentially boils down to a search for Earth-like environments. In addition, we discuss how to find life, by what methods and instruments, and how to recognize material of biological origin.

Future Missions

Apart from Earth, there are many bodies of astrobiological interest within our Solar System such as Mars, Europa, Titan, comets, and asteroids. We can observe these from afar, but we can also visit these places or send our robot missionaries. To search for life outside our Solar System we can only train our telescopes on extra-solar planets as visiting other solar systems is currently not an option. In this section we will discuss the chances of finding life in these places and ways to do it. We will propose several mission scenarios and give an overview of appropriate onboard instruments.

Planetary Protection

Humanity must not be reckless and insensitive in its quest to explore other worlds, and in bringing samples back to Earth. The consequences of contamination of Earth or other planets could be disastrous. This chapter concentrates on the policy and doctrine frameworks, ethical perspectives, as well as the cleaning and sterilization methods used for planetary protection.

Human Elements

Impact on Humanity

In this chapter we discuss historical reactions of the public to media announcements of the discovery or presence of extraterrestrial life. On basis of past experience, we try to address the main questions and problems humanity could face if it discovers and extra-terrestrial life-form. We do this by discussing four different scenarios based on *distance* and the presence of *intelligence*, restricting ourselves to the 20-year horizon of the design project. In conclusion we discuss existing guidelines that attempt to mitigate adverse effects of contact with extraterrestrial life and provide suggestions for new guidelines.

Education Outreach

Building on astrobiology's multidisciplinary nature, we propose education programs to increase children's excitement about space. We designed six phases in the education curriculum to connect multiple disciplines of science and the humanities, with emphasis on hands-on activities. We outline a plan to implement the curriculum for use in schools and children's science museums all over the world.

Synthesis

Case Study: A Conceptual Design of a Europa Mission

In the case study, we performed a conceptual design of a planetary mission to study the 4 Galilean satellites of Jupiter, with special emphasis on astrobiology related research on Europa. The mission consists of an orbiter around Jupiter and a Europa lander equipped with a melting device, to penetrate the Europan ice layer. The case study was performed in 3 subsequent concurrent design sessions with emphasis on an interdisciplinary approach. This was realized by including the 8 different ISU Summer Session departments. This approach gave us the unique opportunity to show how the various issues addressed in this design project could influence and shape a possible astrobiology mission.

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Part I

Current State

Chapter 2

Past, Present and Planned Astrobiology Investigations

2.1 Introduction

Humankind has always asked the question, “are we alone?” Throughout the last decades of the 20^{th} century, the answer has changed from a resounding “yes” to a pensive “maybe not”. But it is our nature to explore space, searching for evidence and signs of extraterrestrial life.

This chapter forms the literature search of all past, present and planned missions seeking for clues of life beyond Earth. The surveyed missions will include:

- Satellites and probes sent to other worlds (eg: Viking, Pathfinder)
- Remote sensing of other worlds, (eg: Hubble, DARWIN and OSETI)
- Transmissions to and from other worlds (eg: SETI, BAMBI)

We will hereafter identify, reference and summarize each mission, providing the basic information about the objectives, past accomplishments and present status. Earth based searches, such as the analysis of meteorites found on Earth and sample collection using balloons will be covered in Chapter 3 of this document.

The chapter has three main sections covering:

- Extra-Solar Planets: Search & Exploration.
- Exploration in the Solar System: Planets, Moons and Small Bodies.
- Search for Extraterrestrial Intelligence.

The literature review provides statements of fact based on the information researched and obtained. This sets a background from which the Potential Missions and Case Study chapters can form an understanding of where to go next and what else is needed to forward Astrobiology. Supporting information on each individual mission can be found in Appendix A.

2.2 Extra Solar Planets: Search & Detection

2.2.1 Historical Background

The idea of the existence of worlds and solar systems other than our own is very old. It goes at least as far back as ancient times, when two groups of scientists and philosophers formed: those interested in the formation of planets within our own solar system (perhaps believing that ours was unique in the universe) and others that considered the possibility of countless worlds of infinite variety. One example of the former are the Greek atomists who suggested in the 5th century B.C. formation of other worlds. The views of the atomists were ahead of their time.

The work of the great philosopher Aristotle did much to overshadow the advancement of thought on this subject because he believed in a geocentric universe, with the Earth as the center and also the only world to contain life. Aristotle's views prevailed through much of the next two thousand years. During the Renaissance, the existence of other worlds became mainly a religious quandary and also a threat to the political and social power of the Roman Catholic church in Europe, as this idea would clearly contradict the Biblical version of the universe [see for example ref. 17]. Since there was no way to prove it either way, the scriptures became the guidebook. The reopening of science's eyes came in the 16th century when the Polish scientist Nicolaus Copernicus introduced the theory of a heliocentric universe in 1543. One of his contemporaries, the Italian philosopher Giordano Bruno professed his belief in an "infinite universe containing other stars like the Sun and other worlds like the Earth " [cf. 100]. He was arrested by the Venetian inquisition in 1592 and transferred to Rome. There, the Roman inquisition declared that his views on physics and cosmology were not theological and demanded that he retract. Giordano Bruno refused to do so and was burned alive at the stake on 17 February 1600 [100].

The first documented search for extra-solar planets was done by Christiaan Huygens (1629-1695). Although there were most likely other early attempts at this elusive goal, the documentation is extremely scarce. The first reported discoveries of extra-solar planets date to the mid-twentieth century.

As of summer, 2002, 88 planetary systems with 101 planets have been detected [116], the smallest of them (HD49674) being 0.12 Jupiter mass [10]. Recent high-precision spectrophotometric observations with the Hubble Space Telescope of four planetary transits (see Sec. 2.2.2.3) of HD 209458 indicated absorption from sodium in the planetary atmosphere [11]. This was possible not only because of important technological innovations that significantly increased the abilities of our observing tools but also because of the various sophisticated methods that we use for our hunt of other "pale blue dots" like our Earth. We will describe these methods in Sec. 2.2.2.

To go further, several questions are worthwhile to investigate: How frequent are other planetary systems? Do they resemble our planetary system? How do they form and evolve? How do features like mass, spectral type, chemical composition and age vary with the type of the central star?

2.2.2 Methods of Detection

Extra-solar planets can be detected by either direct or indirect methods. Each detection method is characterized by some observables related to the intrinsic physical parameters of the planet. These parameters are: mass M_P, radius R_P, temperature T_P, distance a from the parent star, orbital period P, brightness L_P, and distance D from the solar system. Suppose that the potential success of a given method depends naturally on its instrumental limitations. Fig. 2.1 schematically summarizes the various techniques and their capabilities. They will be explained in more detail in the subsequent sections.

2.2.2.1 Direct Imaging

Planets have generally no intrinsic emission, at least in the optical wavelength range. One can only detect their illumination by the parent star. A planet orbiting around a star with a brightness L_* acquires by reflection a certain brightness L_P which depends on its physical parameters as introduced above (i.e, R_P, a, L_*) (see App. A) The brightness ratio L_P/L_* is in general very small. For an extra-solar planet comparable to Earth and located at a similar distance from its own star the above ratio is at least 10^{-9}. This contrast can be reduced by observing at mid-infrared where the planets thermal emission peaks. But even at these wavelengths, the contrast is more than a factor of 10^6 [e.g., 31].

Unfortunately, a star seen with a telescope of a diameter Δ produces a diffraction peak with an angular radius of $\Theta = 1.2\,\lambda/\Delta$ which is in order of magnitude similar to α (λ is the wavelength of the light coming through the aperture of the telescope). The faint planet is therefore immersed in the photon noise of the rings

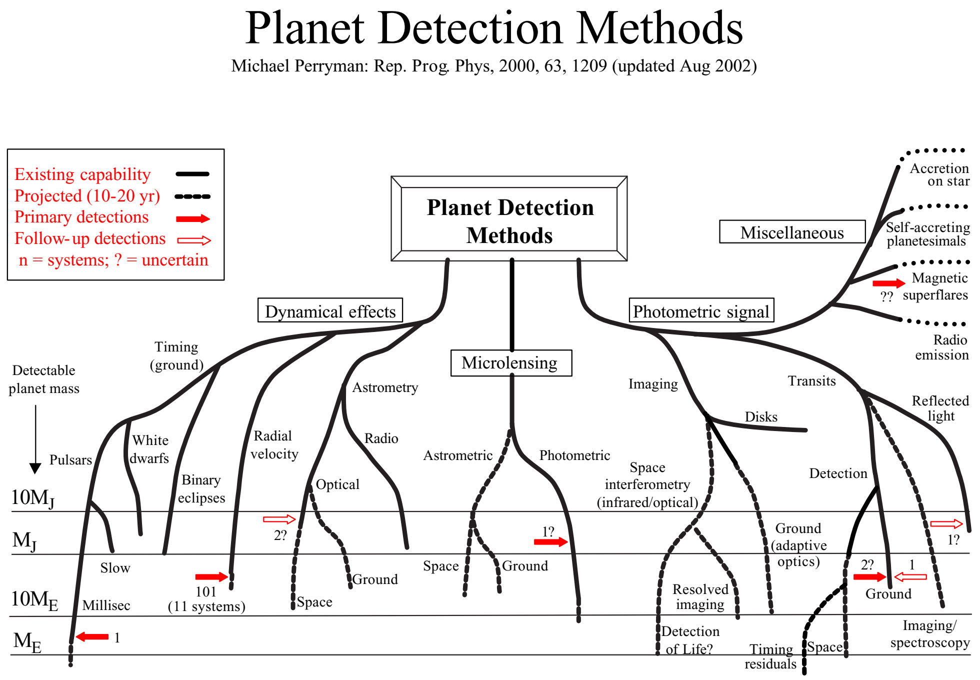

Figure 2.1: Overview of extra-solar planet detection methods and their present and future capabilities; (Courtesy of Michael Perryman, 2002)

of the diffraction spot. One can try to eliminate the effect of diffraction peak by different methods such as, Adaptive optics, Dark Speckles, Nulling, Occultation and IR/chronographic imaging. See App. A for a more detailed description of the various methods.

2.2.2.2 Dynamical Perturbation of the Star by the Planet

Because the method of dynamical perturbation of the main body is fairly simple to technically implement for both ground and space based observatories, most of the known extra-solar planets so far have been detected in this way. When the planet makes a revolution around its parent star, both objects are in orbit around their common center of mass. Thus the star makes a small circular orbit with a radius $a_* = a \cdot M_P/M_*$ and a period naturally equal to the planet orbital period P. This results in the perturbations of three star's observables: in radial velocity $\delta V_{R*} = 2\,\pi\, a_*/P_P$, in angular (or astrometric) position $\delta\alpha_* = a_*/D$ and in time of arrival of signals $\delta T_* = a_*/c$. The precision of astrometric positions and radial velocity with present observatories is high enough to detect Jupiter sized exoplanets but not high enough to detect Earth sized objects.

The time of arrival of millisecond pulsar signals can be determined with a precision of a few microseconds [133]. This high measuring precision makes it possible to detect the movements of the parent star that is caused by planets even the size of Earth (the movement of the pulsar manifests itself in a very small change of the arrival time of its emitted signal).

2.2.2.3 Planetary Transits

If a planet transits the disk of a star, it produces a drop in its lightcurve. This phenomenon has been observed (see Table 2.1).The detection of a transit in the star's lightcurve requires that the orbital plane of the planet is correctly oriented. The star must be photometrically monitored continuously over at least one entire orbital revolution of the planet. This makes the transit method very inefficient for large a and favors small a since then P is larger and the required time is shorter. The duration of the transit is $D_T = (P/\pi) \cdot (R_*/a)$, *i.e.* 25 hours for a Jupiter and 13 hours for an Earth. The depth of the transit is $\Delta F/F = (R_P/R_*)^2$. In space the photometric precision is much higher as it is only limited by the photon noise and the stellar activity noise and allows therefore to detect even Earth sized planets. On ground, however, this method is limited to Jupiter sized planets. It is important to note that the planetary transit is the only method now capable of detecting and investigating further Earth like extra-solar planets.

2.2.2.4 Gravitational Lensing

A planet can produce a gravitational amplification A_G of the light of background stars with a duration T_G depending on its transverse velocity V. The amplification is caused by the star and planet system due to the caustics in the light propagation in curved space-time. Under perfect Observer-Lens-Source alignment, the solution to the lens equation describing gravitational lensing around a point mass picks up a spherical symmetry and a whole ring of solutions are seen. The optics of the system also produce very large (theoretically infinite) amplification of the source signal on this ring, which is called Einstein ring [67]. The amplification is therefore maximum when the planet sits on the Einstein ring of its parent star. Thus the global amplification lightcurve by the planetary system has two features: a small, short duration (1 day for a Jupiter, a few hours for an Earth) planet amplification event superposed to a larger, long duration (days to month) stellar amplification event.

2.2.3 Biomarkers: Detection of Life via Remote Sensing

A major goal in the research field of extra-solar planets is not only to detect terrestrial type extra-solar planets, but also to investigate if the conditions on the planet in question would allow life as we know it to exist and if so, whether it already exists. One way of doing this is via remote sensing at interstellar distances in order to look for signatures (called biomarkers) in the spectrum of the planetary atmospheres. A possible definition of biomarkes is [42]:

> "A biomarker is any specific feature or measurable property of a planetary unit or sample which suggests that life is or was present there."

It has long been realized that the presence of life on a planet's surface can, in principle, be detected by its effect on the planet's atmosphere. [113] credits the original proposal to 1965 *Nature* paper by Joshua Lederberg, that an atmosphere that has been modified by biogenic gaseous emissions will exhibit a marked departure from thermodynamic equilibrium. Even if one could argue that all planetary atmospheres are in a perpetual state of thermodynamic disequilibrium (thermally and photochemically induced reactions), one can safely state that atmospheres that contain biogenic trace gases ought to be further from equilibrium than those that do not. [37] pointed out that the presence of life in the Earth's atmosphere was indicated by the simultaneous presence of a highly oxidized gas, molecular oxygen (O_2), along with highly reduced gases, such as methane (CH_4) and nitrous oxide (N_2O). All three of these gases are generated predominantly by biological activity. [113] were able to detect these indicators of life on our own planet using data from the Near-Infrared Mapping Spectrometer (NIMS) instrument on the Galileo spacecraft as it swung by Earth on its way to Jupiter.

Fortunately, we may be able to infer the presence of life on extra-solar planets without being able to observe oxygen, methane, or nitrous oxide. The key is to look for the 9.6 μm absorption band of ozone (O_3) [3, 62]. This band is in the middle of the infrared spectra region and is the second strongest absorption feature in Earth's atmosphere after the 15 μm band of carbon dioxide. Darwin (ESA) and Terrestrial Planet Finder - TPF (NASA) are two projects of space interferometers that will be in particular sensitive to the 9.6 μm band of O_3 [6, 32]. It should however be noted that O_2-rich atmospheres (up to 5 %) and IR absorbing O_3 layers can build up without life from H_2O and CO_2 photolysis. However, [55] could show that two photochemical sources of O_2 interfere with each other, and even when appreciable amounts of abiotic O_2 are reached, the O_3 feature is masked at a CO_2 pressure higher than 50 mbar, and the by-products of H_2O photolysis destroy O_3. As a result, whereas the unique detection of O_2 remains ambiguous, the simultaneous infrared detection of O_3, CO_2 and H_2O, provided by TPF and Darwin, is established to be a robust way to discriminate photochemical O_2 production from biological photosynthesis [55].

This, however, leads to the following important question: Is the absence of oxygen evidence for the absence of life? Here, the answer is clearly ”no”, based on what we know about Earth's history. Most geologists believe that atmospheric oxygen first rose to appreciable levels sometime around 2.0 to 2.2 billion years ago [e.g. 38]. Life on the other hand, has clearly been around for much longer than this (the microfossil record extends back to at least 3.5 billion years). So the question now is what is the spectral signature of an extra-solar planet that is an analogue for early Earth. Both CO_2 and H_2 are thought to have been relatively abundant on the primitive Earth, and methanogens probably evolved early on to take advantage of this [132]. Therefore, methane would likely have been an important biogenic trace gas in the early atmosphere, as it is today, but with a concentration orders of magnitude higher than the present level. Thus, the spectral signature of methane on an early-Earth analogue planet could be much stronger than in the present atmosphere and therefore be detected by space interferometers like Darwin or TPF [59].

2.2.4 Overview of Projects to Detect Extra-Solar Planets

Table 2.1 and Table 2.2 provide an overview on major ongoing and planned projects to detect extra-solar planets from ground and space, respectively.

2.3 Exploration inside The Solar System

2.3.1 Planets, Moons and Small Bodies

In generating this sub chapter on planets, moons and small bodies, a very concise set of information has been collated. The information will focus on the key missions and activities that we believe to be specifically astrobiology related. It can be argued that any mission does provide some value to astrobiology research, but secondary value, such as imagery, will not be discussed.

As will be seen in the tables that follow in this section, there are a large number of missions being flown to study celestial bodies within our solar system. Many of these missions have not, or are not expected to find scientific results related to astrobiology. Therefore, the missions, which have or are expected to produce astrobiology-related results, will be highlighted in bold format.

2.3.1.1 Mars

Mars has impressive surface features such as enormous volcanoes and valleys which are frequently obscured by huge dust storms. The atmosphere of Mars is much thinner than that of Earth, with a surface pressure averaging 1% that at the surface of the Earth. Surface temperatures range from -113°C at the winter pole to 0°C on the dayside during summer. The possible role in the past of liquid water in forming the dry riverbeds, which we can see, is still unknown.

Mariner 4,6,7 & 9 Many missions have been sent to Mars as it is thought to be the most likely planet to have once held life within our Solar System. The Mariner missions paved the way for the Viking landers by performing a significant amount of remote sensing and hence identifying the ideal locations for a landing. A total of 7 552 pictures we returned by the Mariner missions as well as information about the atmosphere and Mars's minuscule magnetic field. [74]

Viking 1 & 2 Vikings 1 and 2 comprised of an orbiter and lander each. They were launched in August 1975 and completed their mission in November 1982. The orbiter would take pictures and do remote sensing and the Lander would do in situ studies of the Martian soil with a goal to finding evidence of life. Figure 2.2 shows a picture taken by the Viking 1 lander on the surface of Mars.

On Viking 1, two of the life experiments were inconclusive and the third was a negative. On Viking 2, the experiments to detect life were also inconclusive. However the information about the environment was very useful, since the lander was able to last for several years returning information about the atmosphere and surface through several seasons. The composition of the atmosphere was about 95% Carbon Dioxide, 2.7% Nitrogen, and 1.6% Argon. There were also traces of oxygen, carbon monoxide and water vapor[135]. One of the most promising discoveries was that the polar ice caps were not only composed of frozen carbon dioxide, but also frozen water.

Project	Search Method	Observatory	Current Status	Org. / Country
Absolute Astronomical Accelerometry (Emilie Spectrograph)	dynamical perturbation	Haute Provence Observatory (OHP)	ongoing	CNRS/France
Advanced Fiber-Optic Echelle (AFOE)	dynamical perturbation	Whipple Observatory	ongoing	USA
Anglo-Australian Planet Search Program	dynamical perturbation	Anglo-Australian Telescope (AAT)	ongoing	UK/USA/Australia
Arizona Search for Planets (ASP)	planetary transits	Kitt Peak Observatory	ongoing	USA
California and Carnegie Planet Search	dynamical perturbation	AAT	ongoing	USA
ESO Coude Echelle Spectrometer (CES)	dynamical perturbation	ESO CES	ongoing	ESO
Southern Sky extrasolar Planet search Programme	dynamical perturbation	Leonard Euler telescope	ongoing	Switzerland
Elodie (Haute Provence)	dynamical perturbation	OHP	ongoing	France/Switzerland
EXPORT (EXo-Planetary Observational Research Team)	planetary transits	La Palma and Tenerife	ongoing	Europe
GENIE	nulling interferometer	VLT	planned	ESA
High Accuracy Dynamical perturbation Planetary Search HARP's	dynamical perturbation	ESO	ongoing	Europe
Keck Interferometer	nulling and dynamical pert.	Keck telescope	under construction	NASA/USA
MAP, MAPS	astrometry	Allegheny Observatory	ongoing	USA
PLANET	gravitational microlensing	ESO/Pert/Hobart/ CTIO	ongoing	multinational
Very Large Telescope Interferometer VLTI	nulling and dynamical pert.	VLT	under construction	ESO
UVES	dynamical perturbation	ESO, Paranal	operating	ESO
Vulcain South (Antarctic Planet Finder)	planetary transit	South Pole Telescope	under construction	NASA/USA

Table 2.1: Ground based extra solar planet search programs

Project	Search Method	Current Status	Org. / Country
BOSS (Big Occulting Steerable Satellite)	occultations	planned	USA
COROT	planetary transits	launch 2004	France/Europe
Darwin	nulling interferometry	planned for 2014	ESA
Eddington	planetary transit	launch 2004	ESA
GEST	gravitational microlensing	planned for 2005	international
HST	dynamical perturbation	ongoing	NASA/ESA
Jovian Planet Finder	coronographic imaging	proposal	NASA
KEPLER	planetary transits	launch 2006	NASA
MOST	planetary transits	launch 2002	Canada
NGST	IR imaging	launch 2010	NASA/ESA
SIM	dynamical perturbation	launch 2009	NASA
SIRTF Space Infrared Telescope Facility	IR imaging and spectroscopy	launch 2002	NASA
TPF	nulling interferometry	launch 2012-2015	NASA
UMBRAS	coronographic imaging	not specified	USA

Table 2.2: Space based extra solar planets missions

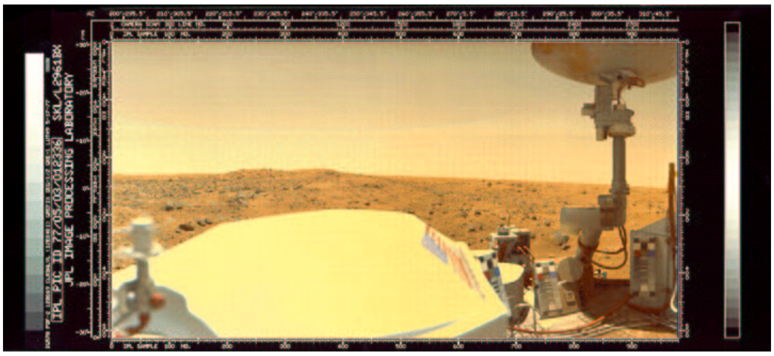

Figure 2.2: Image of Mars surface taken by the Viking Lander

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Mercury	Mariner 10		NASA	1973	100 M USD
Venus	Mariner 2	Orbiter Atmos./Mag. Field	NASA/RSA	1962	
	Mariner 5	Orbiter Space Env.	NASA	1967	
	Venera 4	Orbiter Atmospherics	RKA	1967	
	Venera 5 & 6	Orbiter Atmospherics	RKA	1969	
	Venera 7	Orbiter Space Env.	RKA	1970	
	Venera 8	Orbiter Space Env.	RKA	1972	
	Mariner 10	Orbiter Atmos./Mag. Field	NASA	1973	
	Venera 9 & 10	Orbiter , Lander	RKA	1975	
	Pioneer 1 & 2	Orbiter, Remote Sensing	NASA	1978	
	Venera 11,12,13 & 14	Landers	RKA	1982	
	Venera 15 & 16	Orbiter, Remote Sensing	RKA	1983	
	Vega	Atmospheric , Soil Sampling	RKA	1984	
	Magellan	Imagery radar & gravitational field	NASA	1989	
Mars	Mariner 4	Imaging + Atmospherics	NASA	1964	83 M USD
	Mariner 6 & 7	Imaging + Atmospherics	NASA	1969	148 M USD
	Mariner 9	Imaging + Atmospherics	NASA	1971	137 M USD (no launch)
	Mars 2 & 3	Imaging + Atmos/Magnetics	RKA	1971	
	Mars 5	Atmospherics/Surface	RKA	1973	
	Viking 1 & 2	**Orbiter , Lander Imaging**	**NASA**	**1975**	**750 M USD(no launch)**
	Phobos 1 & 2	Orbiter/Lander	RKA/Coop. Int.	1988	
	Mars Observer	Orbiter	NASA	1992	980 M USD FY93 est
	Mars 96	Orbiter/Lander/Driller	RKA/Coop. Int.	1996	
	Mars Pathfinder	**Lander/Seismology** Tech Demo	**NASA**	**1996**	**330 M in FY97** *Discovery Program
	Mars Climate Orbiter (lost September 1999)	Orbiter	NASA	1998	
	Mars Polar Lander (lost December 1999)	Lander	NASA	1999	
	Deep Space 2 (lost December 1999)	Drillers	NASA	1999	
Jupiter	Pioneer 10	Imaging, Rad., Mag.	NASA	1973	
	Pioneer 11	Imaging, Rad., Mag.	NASA	1974	
	Voyager 1 & 2	Atmos., Mag.	NASA	1979	
	Ulysses	Atmos., Mag.	ESA	1990	
Saturn	Pioneer 11	Imaging, Rad., Mag.	NASA	1973-74	
	Voyager 1 & 2	Atmos., Mag.	NASA	1977	
Uranus	Voyager 2	Atmos., Mag.		1986	
Neptune	Voyager 2	Atmos., Mag.		1989	

Table 2.4: Past Missions - Solar System Planets (No missions to Pluto)

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Mars	**Mars Global Surveyor**	**Orbiter. Mapping Remote Sensing**	**NASA**	**1997**	**330 M at EOL (expected 2004)**
	Planet B/Nozomi	Orbiter.Mag Field	ISAS/Japan	1998	
	Mars Odyssey	**Orbiter. Rad. Comms. Surface Minerals**	**NASA**	**2001**	**380 M at EOL (expected 2006)**
Jupiter	Galileo	Atmos, Mag	NASA	1979	
	Cassini/Huygens	Chem,Phy,Temporal	ESA/NASA	1997	
Saturn	Cassini/Huygens	Chem,Phy,Temporal	ESA/NASA	1997	

Table 2.5: Present Missions - Solar System Planets (No missions to Mercury, Venus, Uranus, Neptune or Pluto)

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COSTS & FUNDING
Mercury	Messenger		NASA	2004	*Discover Program of 256 M USD in FY 99
	BepiColombo		ESA	2009-10	
Venus	Venus Express	Orbiter	ESA	2003	
Mars	**Mars Express**	**Orbiter + Beagle 2 Lander**	**ESA**	**2003**	
	Mars Exploration Rovers	**Twin Rovers. H2O search + geology**	**NASA**	**2003**	**800 M USD (inc LV)**
	Athena	Seismology	NASA	2003	
	Mars Recon Orbiter	Orbiter	NASA	2005	
	Mars 2005+	**Orbiter**	**NASA**	**2005**	
	Scout	**Landers**	**NASA**	**2006**	
	SmartLander	**Landers**	**NASA**	**2007**	
	NetLander	**Landers. H2O. ICE**	**CNES/Coop Int**	**2007**	
	Mars sample return	**Orbiter,Lander Seismology**	**CNES/NASA**	**2011**	
	Scout 2		**NASA**	**2011**	
Jupiter	Inside Jupiter	Internal structure of Jupiter	NASA		296 M USD in FY 99
Pluto	New Horizons (Pluto-Kuiper belt)	Geology + Morphology Imaging, atmos	NASA	2006	

Table 2.6: Planned Missions - Solar System Planets(No missions to Mercury, Venus, Uranus, Neptune or Pluto)

Mars Global Surveyor Mars Global Surveyor (MGS) was launched on November 7^{th}, 1996. It's objective was to make a high resolution topographical map of the entire planet that could be used to plan future missions. It would also gather and return information about Mars's weather and gravity. Additionally, it would be used as a repeater to relay any signal from Mars back to Earth from a proposed future lander.

The pictures obtained by MGS showed gullies and debris flow features, suggesting that there may have been sources of liquid water, similar to an aquifer, at or near the surface of the planet. Magnetometer readings indicated that the planet's magnetic field was not globally generated in the planet's core, but is localized in particular areas of the crust. Temperature data and images of the moon Phobos, showed that its surface is composed of powdery material at least one meter thick, caused by millions of years of meteoroid impacts. The laser altimeter provided scientists with their first 3-D views of Mars' northern polar ice cap. Further details can be found on the NASA website, Ref. [50].

Mars Pathfinder Mars Pathfinder was a small lander-rover sent in December, 1996. Originally, Pathfinder was designed as a technology demonstrator to deliver an instrumented lander and a free-ranging robotic rover to the surface of the red planet at a low cost. Once there, it would take close-up surface imaging. This mission was also a test to see if a Mars rover was feasible.

The Mars Pathfinder mission was highly successful. Not only did it achieve its objectives but it also outlasted its life expectancy while returning significant amounts of data. This rover, named Sojourner, was able to take pictures and traverse the area near where it landed both under remote control and autonomously. The rover was also able to take spectroscopic measurements of several rocks near the landing site. Pathfinder returned more than 16 500 images from the lander and 550 images from the rover. It also performed more than 15 chemical analyses of rocks and soil, returned extensive data on winds and other weather factors. Results from scientific instruments on both the lander and the rover suggest that Mars was at one time warm, wet and had a thicker atmosphere allowing for the existence of life. Detailed information on the results can be found on NASA websites. [52].

Mars Odyssey Mars Odyssey, launched in April 2001, was tasked to obtain a mineralogical analysis of the planets surface. It would also measure the radiation environment to provide safety information in preparation for possible manned missions. The orbiter can also be used as a communications repeater for any other missions in the Mars area that need it. The spacecraft also contains three different spectrometers looking at thermal emissions, gamma rays and radiation. Results from the experiments can be found on the NASA websites. [51]. Significantly, Odyssey has detected that water may be present at the poles of Mars.

Mars Exploration Rovers The objectives of the Mars Exploration Rovers are to look for evidence of water and to perform in-situ experiments on rocks during its mission. Both rovers are equipped with a robotic arm that will gather soil or rocks for analysis and are fitted with a drill like attachment, so the surface of a rock can be removed and inner layers can be analyzed by microscope or spectrometer. The location on Mars, where the rovers will be sent will be chosen based upon the likelihood that it had the possibility to support life in the past. [75]

Mars Express Mars Express, together with the Beagle 2 lander, will be launched in June 2003. While the orbiter is performing analysis of the space environment around Mars, the lander will be doing in-situ experiments on the surface atmosphere and any samples it can pick up with its robotic arm. These experiments will be looking for evidence of life in the samples. The mole will be released from Beagle 2 to gather up additional samples from at most three meters away. It will also be able to burrow under rocks and into the dirt. Although the lander is not mobile, the attached drill/mole on the experiment arm, has sufficient degrees of freedom, to reach any feature of interest within the arm's length.

NetLanders Under the direction of the Centre National d'Etudes Spatiales (CNES) and ESA, four NetLanders are scheduled to be sent to Mars with an orbiter in 2007. The objective of the NetLanders mission is to survey the planet for underground water and ice, and look at the planets entire atmosphere and circulation system.

Scout NASA is currently evaluating a number of proposals towards the next generation of Mars explorers. A number of companies have submitted a variety of different ideas on how Mars will be explored. These range from the typical wheeled rovers to the more diverse ideas.

For more information on any of these Mars missions, see Ref. [76]

2.3.1.2 Earths Moon

Our Moon is a perfect example of the planetary conditions that life needs to develop: The presence of the Moon contributes to stabilize the Earth's wobble. This has led to a much more stable climate over billions of years, which may have affected the course of the development and growth of life on Earth.

There is also evidence for ice in both Poles of our Moon, as the 1998 Lunar Prospector mission announced. Looking for final confirmation of ice in the Moon, the Lunar Prospector spacecraft ended its mission crashing into a permanently shadowed crater in the Moon's south pole. There were hopes for detecting a water signature from the impact, but nothing was finally registered although the results of the impact are still being analyzed with more accuracy. The Lunar prospector data was also combined with other lunar data for conducting an integrated study of our Moon [97]. This study gives support to the existence of ice in the south lunar pole though it also points out that future missions are needed for definitely conclude the existence of ice in our moon.

2.3.1.3 Europa

There are those who hold the opinion that Europa is more likely to harbor life than even Mars itself. Europa can hold or could have held life in the past due to the existence of water. Preliminary results of Europa missions have shown evidence of surface ice, beneath which an ocean of water could exist. There is almost certainly

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Earth's Moon	Pioneer	Rad., Grav. Field	NASA	1958	
	Ranger	Imagery	NASA	1964	
	Surveyor	Test bed, Imagery Soil sampling	NASA	1966	330 M USD at eol (expected 2004)
	Lunar Orbiter		NASA	1966	
	Apollo(11,12) (13,14,15,16,17)	Soil sampling / Mapping Magnetism	NASA	1963-72	
	Zond Program	Flyby & lunar orbit	RKA	1960-70	
	Luna 16	Lunar samples	RKA	1970	
	Luna 20	Lunar samples	RKA	1972	
	Clementine	**Mapping, RS, ICE**	**NASA**	**1994**	
	Lunar Prospector	Impact on south polar crater at EOL	NASA	1998	63 M USD Low-cost Discovery Program
Phobos (Mars)	Phobos I & II	Rad., Env., Atmos.	RKA/Coop Int	1988	
	Mariner 9	Imagery & Atmos.	NASA	1971	
	Viking	Imagery	NASA	1975	
Deimos (Mars)	Viking	Imagery	NASA	1975	
Io (Jupiter)	Voyager 1 & 2	Flyby, Imagery	NASA	1977-79	
Europa (Jupiter)	Pioneer 10 & 11	Flyby, Imagery	NASA	1972-73	
	Voyager 1 & 2	Flyby, Imagery Flyby, Imagery	NASA	1977-79	
	Ulysses	Mag. & Rad.	ESA	1990	
Ganymede (Jupiter)	Voyager 1 & 2	Flyby, Imagery	NASA	1977-79	
Callisto (Jupiter)	Voyager 1 & 2	Flyby, Imagery	NASA	1977-79	
Titan (Saturn)	Voyager 1 & 2	Flyby, Imagery	NASA	1977-79	

Table 2.7: Past Missions - Solar System Moons

carbon on Europa, deposited perhaps by meteorites or crashing comets, or originating in the interior of Europa itself. Evidence from previous missions suggest this moon could also have a thin tenuous oxygen atmosphere. Both elements are necessary for the existence of life as we know it today. There is also evidence for geologic activity on Europa, possibly powering the chemical processes needed for life.

Sunlight penetrating the thick ice will be too weak to power chemical processes needed for life, so the only other possible source of energy would be from the interior of the body. Therefore, the interior of the body would need to be hot. If it is, then hot gases and molten rock, issuing from vents in the ocean floor, could create a chemical cocktail, allowing for some forms of life to exist, as does happen near hydrothermal vents on the Earth's ocean floor. Scientists have discovered marine life on Earth that thrives near these deep ocean hydrothermal vents. This discovery provides us with a model for how similar organisms might survive on Europa.

Voyagers 1 & 2 Voyager 2 was launched in September 1977 and was tasked with investigating the atmospheres, magnetospheres, satellites, and ring systems of Jupiter and Saturn. The Voyager 2 mission was then extended to become the first spacecraft to visit the giant planets Uranus and Neptune. The main exciting finds by the Voyagers, as regarding moons, include the possibility of a liquid ocean beneath Europa's frozen crust, and possible plate tectonics on the surface of another Jovian moon, Ganymede.

Galileo The Galileo spacecraft was the first to orbit a gas giant planet. Galileo helped find evidence that supports the theory that liquid oceans exist under Europa's icy surface. The same is true for Callisto, one of the other Jovian satellites, which Galileo also visited.

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Earth's Moon	Lunar A	Orbiter & Penetrator	ISAS/NASDA	2002	
Phobos (Mars)	Mars Global Surveyor	Orbiter, Imagery, RS	NASA	1997	
Deimos (Mars)					
Io (Jupiter)	Cassini /Huygens	Mag. field, dust / RS Chem.,Phy.,Temporal	ESA/NASA	1997	
Europa (Jupiter)	Ulysses **Cassini-Huygens**	Mag. & Rad. **Mag. field, dust / RS Chem.,Phy.,Temporal**	NASA **ESA/NASA**	1990 **1997**	
Ganymede (Jupiter)	Cassini-Huygens	Mag. field, dust / RS Chem.,Phy.,Temporal	ESA/NASA	1997	
Callisto (Jupiter)	Cassini /Huygens	Mag. field, dust / RS Chem.,Phy.,Temporal	ESA/NASA	1997	
Titan (Saturn)	**Cassini /Huygens**	**Mag. field, dust / RS Chem.,Phy.,Temporal**	**ESA/NASA**	**1997**	

Table 2.8: Present Missions - Solar System Moons

2.3.1.4 Titan

Titan might show us how the chemical process that led to the origins of primitive life on Earth started. Its atmosphere resembles extremely well the one of our primitive planet when life appeared.

Titan has a greenhouse-warmed climate, as does the Earth. This effect is powered by sunlight, but sustained by different gases - methane, hydrogen and nitrogen. These gasses play a vital role in the stability of Titan's climate. In particular, methane is being steadily depleted over time. If it is not replenished, or replenished only irregularly, Titan's atmosphere may occasionally thin and cool down as methane's greenhouse contribution is lost. It is suspected that the response of Titan's atmosphere to methane depletion may have been much stronger early in its history, if the sun was fainter back then than it is today. This so-called theory of a 'faint early sun, however, is discordant with geological evidence for liquid water on Mars and Earth early in their histories.

Cassini/Huygens The potential for prebiotic materials at various locations (in particular where liquid water has interacted with photochemical deposits) and the need to monitor Titan's meteorology favor future missions that may exploit Titan's unique thick-atmosphere, perform in-situ analysis of the surface and probe its interior by electromagnetic and seismic means.

Various mission concepts could be suitable for these tasks, like a Titan helicopter, a balloon or a gliding lander [63, 64]. Such missions have dramatic potential to capture the public's imagination.

Titan Explorer Titan Explorer is a mission aimed to conduct vertical distribution and chemistry of prebiotic organics in Titan. The spacecraft also aims to study surface dynamics and global winds in the moon. This mission will consist of in-situ measurements of organics in the atmosphere and on the surface; measurements of the clouds and methane abundance; infrared/visual imaging in atmospheric windows at many locations and radio altimetry for surface heights.

2.3.1.5 Pluto

Very little information is known about Pluto, and it is not expected to harbor any life, due to its far distance from the Sun.

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Io (Jupiter)	Io Volcanic Observer	Atmos., Volcanos	NASA		
Europa (Jupiter)	**Europa orbiter & Lander**	**H20 & ICE Characterization**	**NASA**	**2008**	
Ganymede (Jupiter)					
Callisto (Jupiter)					
Titan (Saturn)	**Titan Explorer**	**Organics search in Atmos.**			
Phobos (Mars)	Future sample return		RKA		
Deimos (Mars)					
Earth's Moon	SMART-1 SELENE Lunar Sat	Solar-elec. prop. tech. demo. Origin,evolution tectonics Suitability of south Pole for permanent Human presence	ESA ISAS/NASDA 50 000 young ppl EU initiative	2003-06 2005	 ESA/DLR Universities Private

Table 2.9: Planned Missions - Solar System Moons

New Horizons New Horizons is a mission designed to fly by Pluto and its moon Charon and transmit images and data back to Earth. It will then continue on into the Kuiper Belt where it will fly by a number of small objects, returning further data. The primary objectives are to characterize the global geology and morphology of Pluto and Charon, map the surface composition of Pluto and Charon, and characterize the neutral atmosphere of Pluto and its escape rate. After passing by Pluto, New Horizons will head into the Kuiper Belt where multiple objects in the order of 50-100 km in diameter are expected to be targeted for similar measurements as those made at Pluto. This phase of the mission will last from five to ten years. [77]

2.3.1.6 Small Bodies

Introduction Comets are regular members of the Solar System family, gravitationally bound to the Sun. They are generally believed to be made of material, originally in the outer part of the Solar System, that was not incorporated into the planets. It is the very fact that they are thought to be composed of such unchanged primitive material that makes them extremely interesting to scientists who wish to learn about conditions during the earliest period of the Solar System.

Many bodies have struck Earth and the Moon in the past, and one widely accepted theory blames the impact 65 million years ago of an asteroid or comet at least 10 km in diameter for mass extinctions among many lifeforms, including the dinosaurs. Other theories suggest that the chemical building blocks of life and much of Earth's water arrived on asteroids or comets that bombarded the planet in its youth.
For more information on the origins of asteroids and comets, see Ref. [90].

Interstellar dust was first discovered by German-made dust detectors on the Ulysses spacecraft in 1993 and later confirmed by the Galileo mission to Jupiter. Scientists believe that they contain heavy chemical elements originated in stars. Since every atom in our bodies came from the insides of stars, by thoroughly studying this interstellar dust, scientists hope to learn more about our cosmic roots.

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Asteroids					
Eros	**NEAR**	**Surface science**	**NASA**	**1996**	**150 M USD**
9969 Braille	DS1	Flyby Science	NASA	1998	152 M USD
Ida, Gaspra	Galileo	Flyby Science	NASA	1989	
Comets					
Giacobini-Zinner	ISEE/ICE	Interaction comet atm. Solar wind	NASA	1978	
Halley	**Vega1 & 2**	**Dust, mag. field,**	**RKA**	**1984**	
		Plasma, nucleus, Imagery	**RKA**	**1984**	
	Sakigate	UV, Solar Wind	ISAS	1985	
	Suisei	Composition	ISAS	1985	
	Giotto	**Nucleus Science**	**ESA**	**1985**	
Grigg-Skjellerup	Giotto	Flyby science	ESA	1985	
Borrelly	DS1	Comet encounter Nucleus Science	NASA	1998	152 M USD

Table 2.10: Past Missions - Solar System Small Bodies

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Asteroids					
Comets					
Wild-2	**Stardust**		**NASA**	**1999**	***Discovery Program**
Encke	CONTOUR	Nucleus science	NASA	2002	160 M USD
Schwassmann-Wachmann	CONTOUR	Nucleus science	NASA		160 M USD

Table 2.11: Present Missions - Solar System Small Bodies

OBJECT	MISSION	OBJECTIVE	AGENCY(ies) INVOLVED	STARTING YEAR	MISSION COST & FUNDING
Asteroids					
Otawara	**Rosetta**	**Flyby science**	**ESA**	**2003**	**650 M USD**
Siwa	**Rosetta**	**Flyby science**	**ESA**	**2003**	**650 M USD**
Ceres	**Dawn**	**Surface science**	**NASA**	**2006**	**271 M USD FY 99**
Vesta	**Dawn**	**Surface science**	**NASA**	**2006**	**271 M USD FY 99**
1998 SF36	**Muses-C**	**Sample Return**	**ISAS**	**2002**	
Comets					
Tempel 1	**Deep impact**	**Nucleus science**	**NASA**	**2004**	**280 M USD**
Wirtanen	**Rosetta**	**Nucleus science**		**2003**	**650 M USD**
Nereus	NEAP	Surface science	Private	2006	50 M USD

Table 2.12: Planned Missions - Solar System Small Bodies

Astrobiology and small bodies Comets are now known to contain large quantities of volatiles, including organic compounds and a rich variety of microparticles of various types. Organic compounds may have been imported to Earth by comets. Also potentially important to the abiotic beginnings of life is the complex nature of cometary particles on the microscale. Comets, being rich in water and other volatiles, have been postulated to be transporters of volatile and biogenic elements to the early Earth. Clearly, the study of cometary material is essential for our understanding of the formation of the Solar System, and most importantly to astrobiology, the interstellar contribution of pristine, early-formed organic matter from several different environmental regions.

Astrobiology missions to small bodies The following list of missions summarizes all the known past and present missions to small bodies, which produced results, that are of interest to astrobiology. A brief mention will also be made of some future missions, which are expected to produce valuable results to astrobiology.

The dust mass spectrometer on **Vega 1 & 2**, which made a flyby of comet Halley, detected material similar to the composition of carbonaceous chondrites meteorites and also detected clathrate ice. Vega 1 made its closest approach to the comet on March 6th, 1986 at a distance of 8 890 km. Further information on the Vega missions can be viewed in Ref. [72]

Giotto took the first close-up images of a comet in 1986, and instead of being bright like a surface made of ice, the nucleus was "dark", which suggests there may be a significant amount of organic material such as formaldehyde (an organic molecule) on the surface.

Figure 2.3: Asteroid Eros from NEAR: Courtesy NASA

The target of the **NEAR** mission was 433 Eros, the first-discovered near-Earth asteroid (NEA) and the second largest. As the first spacecraft to orbit an asteroid, the NEAR mission objective was to answer fundamental questions about the nature and origin of near-Earth objects, such as the numerous asteroids and comets in the vicinity of Earth's orbit.

NEAR received the first gamma-ray spectrum from the surface of an asteroid. The plot in Figure 2.4 shows a typical spectrum of Eros taken by the Near Infrared Spectrometer (NIS) on the NEAR spacecraft just before orbit insertion on February 14, 2000. Absorption bands due to the rock-forming minerals olivine and pyroxene are seen in the 1 000 and 2 000 nanometer regions, revealing information about Eros' composition.

Eros is one of the S-type (silicaceous) asteroids, the most common type in the inner asteroid belt and the subject of debate over their relationship to meteorites. NEAR also became the first spacecraft to land on an asteroid. A closeup image of Eros is shown in Fig. 2.3. For more information on Eros, see Ref. [19]

Stardust will travel into the coma of Comet Wild-2. There, it will gather dust particles and deliver them back to Earth. Enroute to the comet, Stardust will also attempt to capture interstellar particles that are believed to have entered our Solar System and interplanetary particles that exist within our Solar System. The Stardust mission will use its special formulation of aerogel, the world's lightest solid, to try to capture these small solid particles as the spacecraft travels in the same direction as the dust stream until December 9, 2002. The findings of both instruments will be sent back to Earth for further analysis. For information on this mission, see Ref. [118].

The **Deep Impact** objectives are to observe how a crater forms, measure the crater's depth and diameter, measure the composition of the interior of the crater and its ejecta and to determine the changes in natural outgassing produced by an impact on the comet surface. This will be accomplished by sending an "impactor" to the surface at several kilometers per second. This will be the first time the subsurface of a comet will be studied. Cameras and other instruments on the flyby craft, and laboratories back on Earth, will study the new crater and ejected material created by the impact.

Rosetta will study the nucleus of Comet Wirtanen and its environment in great detail for a period of nearly two years. Rosetta is due to be launched in January 2003. The Rosetta lander will land on the comet nucleus and will focus on the in-situ study of the composition and structure of the nucleus material. On its eight-year journey to the comet, the spacecraft will also pass close to two asteroids Otawara and Siwa. The closest approach is intended to be around 1 km from the surface. Ground-based observations have so far found evidence that comet Wirtanen contains water, oxygen, carbon dioxide, and various compounds of nitrogen, hydrogen and carbon.

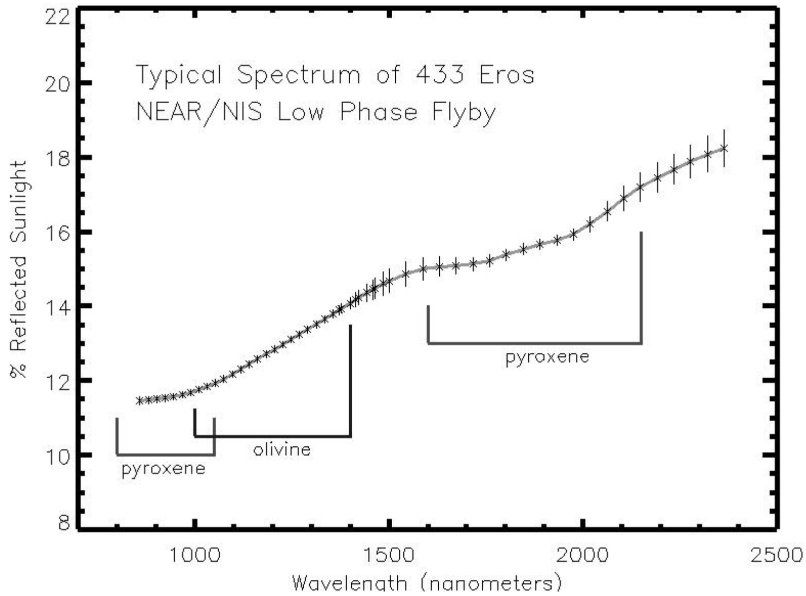

Figure 2.4: Spectrum of Eros from NEAR: Courtesy NASA

The primary scientific objective of the **MUSES-C** mission is to collect a surface sample of material from an asteroid and return the sample to Earth for analysis. The mission plan calls for a November/December 2002 launch, followed by arrival at the asteroid 1998 SF36 in September 2005. MUSES-C will initially survey the asteroid surface from a distance of about 20 km and then move close to the surface for a series of soft landings and collection of samples at three sites. After a few months in close proximity to the asteroid, the spacecraft will fire its engines to begin its cruise back to Earth.

2.4 Search for Extraterrestrial Intelligence

2.4.1 Historic background

Since 1959 humankind has been looking to the skies in search for other intelligent life. This search has been growing in complexity as more and more systems are developed to support the task at hand. The original Project Ozma, directed by Dr Frank Drake, looked at signals based on the natural frequency of Hydrogen. Today there are systems looking at all frequency bandwidths throughout the skies from radio (RF) to optical using large-scale reflectors to smaller distributed networks. The methods of processing are also dramatically varied utilizing both individual super computers as well as the Internet for distributed processing. An excellent reference detailing the full chronology of SETI can be found at [119]. There are three possible sources that may be detected and identified from Extraterrestrial Intelligence. These are seen as:

- The beacon option: Assumes that a civilization is sending out signals with the intention that it will be received by another civilization. A similar idea to that has been portrayed by Carl Sagan's novel *Contact* and the related film.
- The eavesdropping option: ET citizens might be communicating with one another and we could intercept these transmissions.
- The broadcast option: We transmit radio and television signals. Other civilizations might be picking these up and realize that there are other civilization out there.

Our focus is to summarize the projects developed to look for signals from extraterrestrial intelligence as well as those who actively try to make contact.

2.4.1.1 The Water Hole

Nature has its own way of hiding, channeling, absorbing and outputting signals in the electromagnetic spectrum. Transmissions through the Earth's atmosphere are attenuated by the atmospheric gases, the level of attenuation varying depending on the characteristic of the signal. As a result of the Big Bang, the whole universe experiences a 3 K background radiation level. These natural radiation sources limit our ability to detect artificial emissions. Fortunately, nature also provides a number of windows in this noise where signals can pass more easily, as shown in Fig. 2.5.

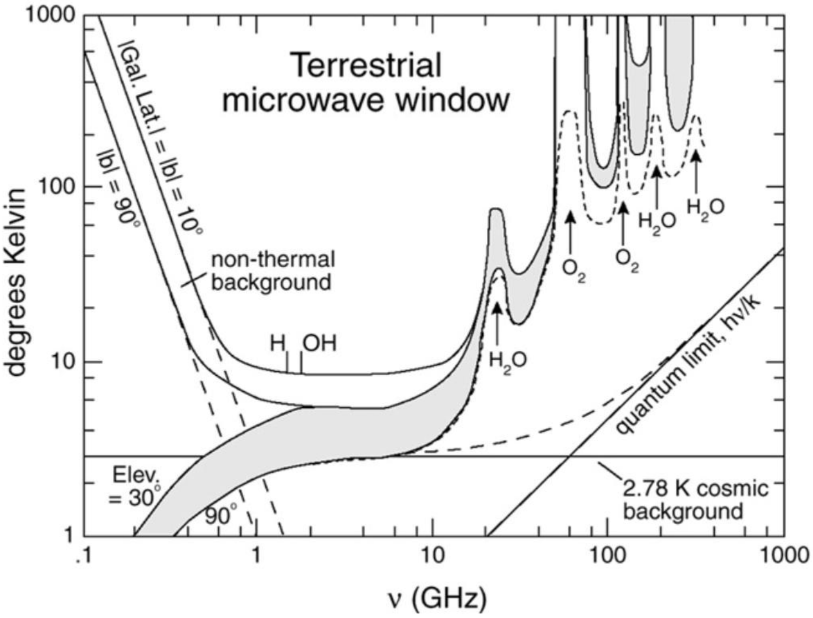

Figure 2.5: Windows in electro-magnetic spectrum

Researchers have identified that radiation from the precession of interstellar hydrogen is clearly heard in our receivers at a frequency of 1,420.40575 MHz (corresponding to a wavelength around 21 cm). Near 1,660 MHz (a wavelength of 18 cm), a cluster of radiation lines from interstellar hydroxyl ions (OH) is also present. Like the Hydrogen line, the Hydroxyl lines occur near the very quietest part of the radio spectrum [66]. It is hypothesized that an intelligent civilization would utilize this natural frequency for transmitting signals and hence it is logical to search within this range. This band of frequencies is now commonly known as “the cosmic waterhole”.

2.4.1.2 Frank Drake Equation

The Drake equation estimates the number of technological communicating civilizations that might exist within the Milky Way galaxy. It only gives an estimate of the probability of existence of extraterrestrial civilizations and not the probability that contact will actually occur.

1. $N = N_s \cdot F_p \cdot N_e \cdot F_1 \cdot F_i \cdot F_c \cdot L$

N= Number of ET civilizations able and willing to communicate N_s= Number of stars in galaxy F_p= Fraction of stars with planets N_e= Number of planets ecologically suitable for life F_1= Fraction of planets suitable for life where life has evolved F_i= Fraction of “life starts” where intelligence has appeared F_c= Fraction of intelligent species who have created technical civilizations L= Fraction of technical civilizations still in existence or estimated lifetime of such civilizations [45]

It should be noted that the accuracy of the assumptions incurs wide variations on the calculation of the results.

2.4.1.3 Major Players

- **SETI Institute**: The SETI Institute is currently the biggest organization dedicated to the search for extraterrestrial intelligence [46]. It is a non-profit organization founded in 1984, with the purpose of conducting "scientific research and educational projects relevant to the origin, nature, prevalence, and distribution of life in the universe"[46]. The SETI Institute is funded by research grants for specific projects, as well as by private donations. During the first decade, NASA was the biggest contributor but, in 1994, it stopped funding the institute. There are currently more than 100 people working for this organization. The Institute's three main programs to look for extraterrestrial signals are Project Phoenix, the One Hectare Telescope and Optical SETI.

- **The Planetary Society**: The Planetary Society is a non-profit organization dedicated to the exploration of the Solar System and the search for extraterrestrial life [120]. It was founded in 1980 by Carl Sagan, Bruce Murray and Louis Friedman and currently has 100 000 members from 140 different countries [120]. It is entirely funded by private dues and donations. The Planetary Society has participated in various SETI projects, including BETA, META and OSETI.

- **Universities** : Universities play an important role in the search for extraterrestrial intelligence. First, they provide the skilled professionals that will engage in the search for extraterrestrial intelligence, and second, they host a number of laboratories that participate in SETI projects or prepare the technology for the future ones. One of the best examples of this is Optical SETI, which is mainly accomplished by universities.

- **SETI League**: The SETI League is a non-profit, educational and scientific organization [119]. It was created in 1994, in an effort to privatize SETI after NASA cut of its SETI funding. As of May 2000, around 1 200 members were supporting the League [119]. Its main project is Project Argus, which will be presented in the next section.

2.4.2 Listening for ET signals

Pointing radio telescope toward stars and analyzing the incoming signal is the most common method used when searching for extraterrestrial intelligence. In the last decades, several projects have been proposed and implemented to try to detect an incoming signal from another civilization. This section provides the reader with a survey of those different projects.

2.4.2.1 Project Phoenix

Project Phoenix is the largest project run by the SETI Institute [106]. It has started in 1995, in New South Wales, Australia, using the Parkes 64-meter radio telescope. After this first phase of scanning the Southern Hemisphere, the project then moved to the National Radio Astronomy Observatory in Green Bank, West Virginia, where it used the 43-meter telescope to listen to the northern sky. The Phoenix Project does not try to listen to the whole sky. Instead, it is focused on about a thousand sun-like stars in the vicinity of our Sun. All of the observed stars are less that 200 light-year away from earth. The frequency range that is scanned is from 1 MHz to 3 MHz, using channels of 1 Hz. This means that the signal from each star is analyzed using two millions channels. The Project also has access to the 305-meter radio telescope at Arecibo, Puerto Rico, for 6 weeks every year. In 1999, half of the targeted stars had been studied. The project is still ongoing, doing observation at Arecibo, Puerto Rico and Jodrell Bank Observatory, United Kingdom.

2.4.2.2 One Hectare Telescope

The One Hectare Telescope is a radio telescope with an effective diameter of 100 m [105]. It will be constructed by using an array of around 350 offset Gregorian dishes of 6 m diameters. It is also call the Allen Telescope Array. The construction of this telescope will be a big step forward in the search for extraterrestrial intelligence because it will allow for a full-time scan of the sky. This new architecture also allows the system to synthesize multiple beams at the same time, thus enabling observation of multiple stars simultaneously. This will bring the number of possibly targeted stars from 1 000 to over 100 000. The Rapid Prototype Array was tested and completed in Russell Reservation, Lafayette, California. The final version is in construction. As of July 15, 2002, the first dish for the prototype array has been installed. The telescope array is supposed to enter function in 2005. It may lead the way to a One Square Kilometer Array afterward.

2.4.2.3 OSETI

OSETI stands for Optical Search for Extraterrestrial Intelligence. Using optical wavelengths to try to detect signals from extraterrestrial beings has several advantages over radio SETI. The signal gain that can be achieved in the optical band is much higher that in the radio band. Then, the equipment needed to detect the signals is less expensive than its radio counterpart and finally analyzing the signal is much easier. Taking these advantages into account, and the fact that with today's Earth technology, we would be able to send a laser signal 100 time more powerful than the sun light, a large number of scientist believe that OSETI is the best method to detect extraterrestrial signals.

OSETI projects are active a number of different universities and observatories. The goal of these projects is either to look for continuing laser beam or laser pulses coming from the stars. The five main project are **Harvard**: [107], Princeton: [110], University of California in Berkeley: [101], Lick Observatory: [99] and Columbus-Ohio: [98].

2.4.2.4 SERENDIP

SERENDIP, or the Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations, is an ongoing research effort aimed at detecting radio signals from ET civilizations. SERENDIP is currently piggybacking on the 305-meter dish at Arecibo Observatory in Puerto Rico, the largest radio telescope in the world. SERENDIP I started in 1979 and consisted of a 100-channel spectrum analyzer that was located at UC Berkeley's Hat Creek Observatory. Since that time, SERENDIP has undergone a large number of improvements. SERENDIP II ran from 1986 to 1988 and was thousands of times more powerful than its predecessor. The second-generation instrument was able to observe 65 000 channels per second and was primarily located at the 90-meter NRAO radio telescope at Green Bank and to a lesser extent on four other high-quality telescopes around the world. SERENDIP III began operations at Arecibo in April 15, 1992. The end of its 4-year survey coincided with the beginning of a major upgrade at Arecibo. The upgrade is now complete, and SERENDIP IV was installed at Arecibo in June 1997 [123].

Currently SERENDIP IV examines 168 million channels every 1.7 seconds in a 100 MHz band centered at 1.42 GHz. The SERENDIP instrument stores signals that peak significantly above the background noise. The data gathered by the instrument is transferred across the Internet to the SERENDIP lab at Berkeley. There the data is run through a series of algorithms designed to reject radio frequency interference and detect signals that have some possibility of being both artificial and extraterrestrial.

2.4.2.5 META I & II

META, or Mega channel Extraterrestrial Assay, started life in October 1989 under the guidance of Paul Horowitz, Professor of Physics at Harvard University. The project was the first million-channel search for ultra-narrowband signals and scanned 8 388 608 channels with a spectral resolution of 0.05 Hz and 400 kHz. The system corrected the observing frequency for motions with respect to three astronomical inertial frames as well as adjusting the frequency to compensate for Earth's rotation, which provides a characteristic changing Doppler signature. META I is dedicated to the northern hemisphere utilizing a 26-meter radio telescope. META II, based in Argentina and providing coverage of the southern hemisphere, partners it. META II is a 34-meter radio telescope [40][122]. META I was superseded by BETA in 1995. Up till that point, META had covered the sky five times. META II continues to search in the southern hemisphere.

2.4.2.6 BETA

Project BETA, standing for Billion channel Extraterrestrial Assay, started in 1995 and replaced META I. It is based at the Harvard Smithsonian Agassiz station and covers the entire band between 1.4MHz and 1.72MHz. The system utilizes two high gain beams separated in the east west direction plus a third Earth looking antenna to eliminate terrestrial signals. BETA also incorporates a rapid re-observation of potentially artificial radio signals and candidate events [39][121]. BETA was rendered inoperative owing to storm damage in 1999. It is currently under repair.

2.4.2.7 SETI@home

The SETI@home system uses a receiver on the Arecibo radio telescope to scan the skies. It collects radio data on a frequency band of 2.5 MHz around the central frequency of 1 420 MHz. This raw data is then delivered on tapes to SETI@home headquarters in Berkeley, California. There it is chopped up into small "work-units", which are 107 seconds long and about 10 KHz wide. These work-units are then distributed to SETI@home users around the world, who analyze the data on their PC's.

The computer program is designed to look for very narrow band signals, which would most likely be artificial. It does so by scanning each work unit for signals at bandwidths ranging from 0.075 Hz to 1 200 Hz. It uses a mathematical algorithm known as a Fast Fourier Transform (FFT). Since a signal is likely to drift during the transmission because of the Doppler effect, SETI@home also repeats its scan of each bandwidth many times over, each run corrected for a different drift rate [102].

To distinguish a signal coming from space, from one based on earth, the SETI@home program looks for a unique characteristic: a signal that will appear, grow stronger and then fade away in the span of 12 seconds. This is because it takes 12 seconds for the Arecibo dish beam to cross a given point in the sky. The curve representing this type of signal is known as a "gaussian", and the program is designed to look for signals that closely approximate this shape. SETI@home also runs a test called a "fast folding algorithm" which searches for pulsed patterns, and an additional test looking for three equally spaced pulses, or "triplets."

Once the PC program finishes analyzing its work-unit, it sends its results back to the Berkeley headquarters, and receives a new one in return. All interesting and promising narrow-band signals, gaussians, triplets, and pulses, are automatically saved for further analysis and review. Any one of them, just might be the "real thing…". The current status can be verified at `http://setiathome.ssl.berkeley.edu/`

2.4.2.8 BAMBI

Project BAMBI is an amateur SETI and radio astronomy project carried out from two sites, California and Colorado. Observations are made using off-the-shelf parabolic antenna operating at a frequency of about 4 GHz. The project has concluded that it is possible to achieve reasonably respectable frequency coverage of a search spectrum using amateur equipment. The project hopes to encourage other amateurs to join in the search. BAMBI has demonstrated that it is possible for amateurs to obtain sensitivities comparable to larger more expensive systems. The next phase of project BAMBI will be to run a high resolution FFT spectral analysis on the output of the spectrum analyzer in a search for narrow band carriers not found from natural radio sources.

2.4.2.9 ARGUS

The SETI League manages project Argus. This project's goal is to scan the sky using a large number of small amateur radio receivers. They want to achieve "the first ever continuous monitoring of the entire sky, in all directions in real time"[60]. To achieve this goal, around 5 000 small radio telescopes will be needed. Each of these stations is built and paid for by the individual member, for a cost of between a few hundreds to a few thousand dollars. Observation started on April 21st, 1996, with 5 radio telescopes. The number of active telescopes crossed the 100 milestone in November 2000. You can find more information on project Argus on the SETI League web site at [60].

2.4.3 Sending signals to ET

2.4.3.1 Pioneer10

Along with its sister ship Pioneer 11, Pioneer 10 carries a plaque with messages designed to make contact with possible alien civilizations. The late Dr. Carl Sagan helped devise the plaques that bear the illustration of a man and a woman as well as a diagram identifying Earth's location in the galaxy (see Fig. 2.6). Like a message in a bottle, these plaques will journey out into interstellar space possibly to be found one day by an extraterrestrial civilization. Currently Pioneer 10 is 80.98 AU from the Sun and has a relative speed to the Sun of 12.24 km/s.

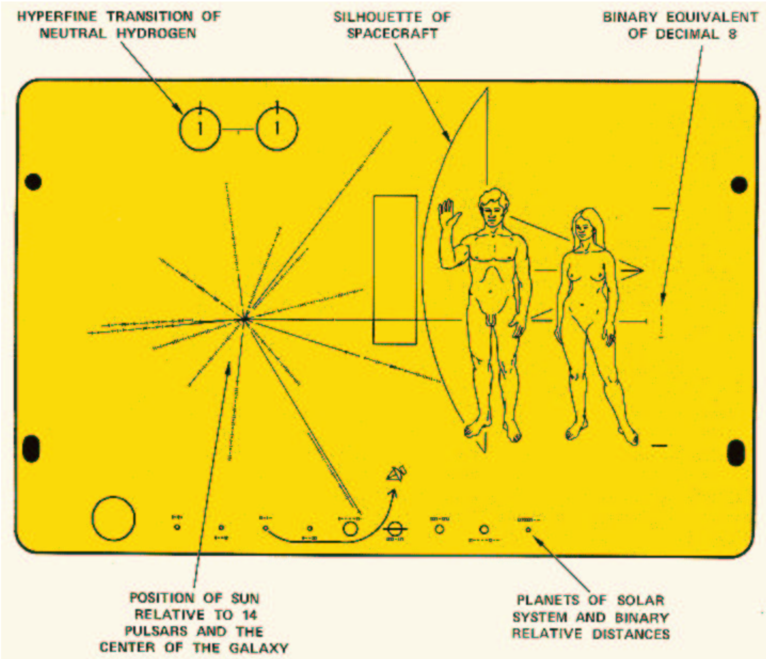

Figure 2.6: Pioneer 10 Plaque

2.4.3.2 Voyager

After the success of Pioneer 10 and 11, Voyager 1 and 2 carried a more ambitious message. This message had the mission of presenting humanity and its world to any other being that would find it. The message was carried by a 30.5 cm gold-plated copper disk containing "sounds and images selected to portray the diversity of life and culture on Earth"[49]. 115 images were included in analog format, as well as natural and human-made sounds, and greetings in 55 different languages. More detail can be found on the following NASA web pages [49]. Voyager 1 and 2 are now both more than 10 billions km away from Earth, and they are pursuing their journey toward interstellar space. Voyager 1 backup position-sensing system has been successfully activated in April 2002, in response to increasing sign of trouble in the main unit. The Earth base team should be able to continue monitoring both probes for another 20 years.

2.4.3.3 Team Encounter Spaceship

Team Encounter is a private venture created with the goal of creating *Humanity's First Starship* [24]. Anybody can become a member of this group by buying a Space Flight Kit that allow one to send a text, a picture and a DNA sample onboard the starship or during a Cosmic Call (see section 2.4.4.1). The starship is scheduled to launch in 2004 on the Ariane 5 rocket[128]. It will use solar sail as a propulsion system and will travel to the outer Solar System. Tests are being conducted on the solar sail deployment system. For more information on Team Encounter, see their website at [24].

2.4.4 Frank Drake message

In 1962 Frank Drake constructed a two-dimensional "pictogram" similar to one we might some day receive from extraterrestrials. As a clue to decoding the message, it consists of 551 bits of information. The only factors of 551 are the prime numbers 19 and 29, which are the lengths of the sides of the message. When properly formatted, the message shows-among other things-a picture of the hypothetical species sending the message, a diagram of its solar system, and pictorial representations of carbon and oxygen atoms to indicate elements important for this extraterrestrial biochemistry. In 1974, Drake actually transmitted a message (see Fig. 2.7) from the Arecibo radio telescope. The transmitted image was similar to the earlier pictogram, but with more emphasis on terrestrial biochemistry.

Figure 2.7: Message transmitted from Arecibo in 1974

2.4.4.1 Team Encounter Cosmic Calls

A basic description of Team Encounter is given in section 2.4.3.3. In addition to its starship project, Team Encounter are also sending radio signal toward the star. A first signal, named Cosmic Call I, was sent from the Evpatoriya Radio Astronomy facility in Crimea, Ukraine, from May 24 to July 1st, 1999. It included personal messages from Team Encounter participant, as well as a scientific message. Dr. Yvan Dutil and Stephane Dumas, from the Defense Research Establishment Valcartier in Canada, wrote this scientific message. They used the Lincos logical language developed by Professor Hans Freudenthal in 1960. Figure 2.8 shows a page of the message that was sent [128].

Team Encounter is currently in the last phase of preparation to send the Cosmic Call II. The signal was supposed to be sent from the Mir space station, but this option is no longer available. The new equipment that will be used to send the message has yet to be defined. This second message will again contain personal and scientific messages, in audio and written format. For more information refer to [30].

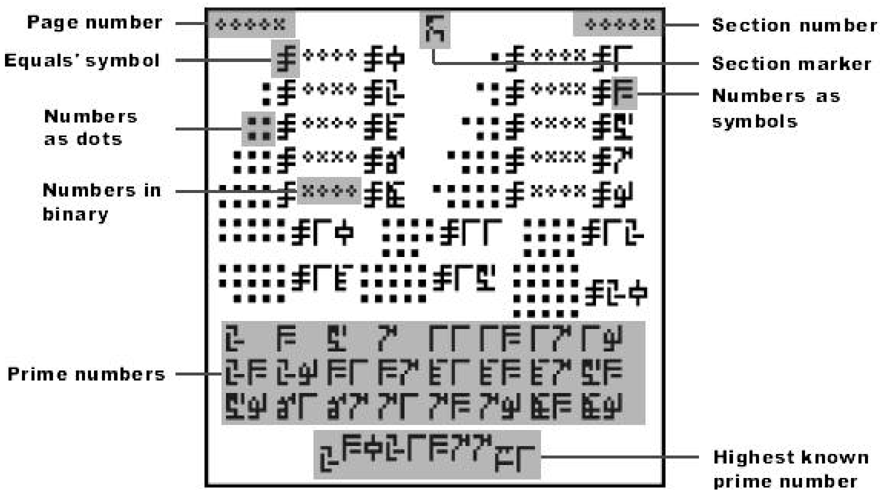

Figure 2.8: First page of the Dutil-Dumas Lincos message

2.5 Conclusions

In this chapter we have looked into and categorized the three main areas of where and how we have been searching for life; Intersolar, Extra-Solar and SETI. To date, none of these searches has provided conclusive evidence that we are NOT alone. This does not mean we are alone, but more to the point we just have not found the evidence yet.

The search of the extra-solar planets using powerful ground and space-based telescopes has identified eighty-eight bodies to date. Although life is unlikely to exist on these planets, their existence motivates a continued search for other planets that may be suitable for life. The continued development of other search methods such as DARWIN will help with the ever-intense search, by broadening our horizons and improving our eyes and ears to space.

The search within our own Solar System has proved more interesting, though this is mainly because of easier access. Many missions have been sent to Mars and Venus. Europa and Titan have also shown promise. The missions that have traveled there to date have identified the presence of water. The surface features also indicated that some sort of liquid flows were once present. But have they had the opportunity to undergo some form of biological evolution? As a civilization, we have gathered a large amount data on the objects within our Solar System. However, the more we find, the more we realize that we have only begun to explore and understand.

Using radio telescopes, we have been scanning the skies in search of transmissions from other civilizations. These have not yielded any signals that prove the existence of extraterrestrial civilizations. Though some spurious signals have been infrequently received, at no point have the candidate measurements been repeatable. Hence this cannot be considered as conclusive scientific proof of extraterrestrial transmissions.

It is theorized that the chemical building blocks of life, and much of Earth's water, arrived in asteroids or comets that bombarded the planet in its youth. This theory has yet to be confirmed by the science community. Comets are now known to contain large quantities of volatiles, including organic compounds and a rich variety of micro particles of various types. Evidence suggests there may be a significant amount of organic material such as formaldehyde (an organic molecule) on the surface on comets, which would support the building block theory. Evidence has raised the probability that impacts of asteroid-sized bodies with the Earth have greatly influenced the course of biological evolution. If true, biological evolution, like prebiotic chemical evolution, is connected in a fundamental way with the dynamical evolution of small bodies in the Solar System.

Although the chance of finding a unique elemental signature in captured, cometary coma material may be slight, such a discovery would be of enormous value in distinguishing between an asteroidal and a cometary impactor. Dust mass spectrometers, which have examined comet nuclei, have detected material similar to the composition of carbonaceous chondrites meteorites. This evidence supports the impactor theory. More evidence is needed for a conclusive result. This requires either a successful sample return mission, or a very heavily instrumented orbiter mission.

Exploring the composition of small bodies in our Solar System will help us to understand the required conditions for the formation of complex molecules such as sugars and amino acids - the latter being the building block of proteins- necessary for the existence of life as we know it on Earth.

So where should we be looking for life? How should we be searching? And what should we be looking for?

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Part II

The Quest for Discovery

Chapter 3

Alive

In this section, we discuss properties of extant and extinct life, the limits of life and requirements for a planet or body to be habitable. The number of instruments to search for life is also reviewed.

3.1 Definitions and Characteristics of Life

3.1.1 Introduction

The task to define life is at the present time an impossible one. But how could one look for life without knowing what it is? As Rachel Nowak [205] pointed out, we are in a similar situation as scientists were in the 18th century when they tried to define water as "an odorless, colorless, thirst-quenching liquid" which was true, but insufficient. Only the development of a molecular theory - understanding water as H_2O - rested this argument once and for all.

A general theory of life is yet to be found. Still, astrobiology has to move on using the descriptions and common patterns of life we have. In this chapter we will present not one, but five 'definitions' for life. They come from guest speakers at ISU, namely Penelope Boston (Complex Systems Research Inc.), Chris McKay (NASA AMES), Pamela Conrad and Ken Nealson (both from NASA JPL), as well as the book "Life everywhere" [145], the online NASA Astrobiology Roadmap [214] and the astrobiology website on ibiblio.org [172].

3.1.2 Definitions of Life

In the following descriptions, we attached one or more characteristics of life to every scenario.

3.1.2.1 Life on Earth

Let us begin to define life on Earth. It is the only example we have ever examined, and every definition has to be based on what we learned from our home planet. More important, we know what life on Earth is not like. Although ever more extremophiles are still discovered and in need of a lot of research to be understood, all Earth life has one common feature: it stores its biological blueprints in DNA double helices (apart from viruses, their classification as life is still controversial). All life will have to store information about its composition; this general principle can be substantiated to using DNA and even some universal DNA sequences common to all life on Earth.

3.1.2.2 Almost Earth-Like Life

What about life that is very closely related to Earth, but not identical? In order to build a rather complex life form without skyrocketing needs to store the information about it, all life forms must use a set of building blocks to assemble structures. Life on other planets may not use the same blocks, and it may store and assemble information in a different way (although alternatives to DNA are limited [145]), we might expect our closest relatives to use a similar set of amino-acids, proteins and sugars. Given the similar composition of several objects in our solar system, and the fact that they have all been bombarded by comets probably bringing the same basic organic material, it is not far fetched to assume life (e.g. on Mars) to be a close relative of ourselves, even if it originated independently.

3.1.2.3 Life in the Solar System: Still Carbon-Water Based

When we look at objects in our solar systems with different composition or physical parameters (gravity, pressure, temperature etc.) than Earth, we should widen our definition of life to carbon and water based life forms. Water is the most important material for all life on Earth. Playing a role in many different processes it is probably unique in its appearance as a polar basis for ion solutions. It is hard to think of any other liquid (even in other temperature and pressure ranges) that has the same ability and abundance as H_20, with hydrogen being the most abundant element and oxygen also being relatively common. But should other life forms really use different ways to arrange building blocks, what would be an examinable attribute to use for a definition? Replication and growth is imperative to sustain or enlarge populations and to recover from natural disasters. All of this requires energy, of course, so the ability to free, transform and store energy will also be a distinguishing mark of life.

3.1.2.4 Different Life – a Wider Perspective

We should also consider life that arose in our solar system using the same materials we used, but which is simply different in its composition and appearance from what we expect life to be. When we talk about primitive life forms, we usually think about tiny bags of water – microbes. But why couldn't extraterrestrial life be huge? Why couldn't it be gaseous things floating in the Jovian atmosphere? Seeking life on very odd locations, we have to keep in mind that we could literally plunge into life, having a hard time finding anything because we keep looking through the microscope where we should use a wide-angle lens. Also should we think about the possibility of non-biological life forms, since humanity itself is working hard to build ever more 'intelligent' computers and doesn't hesitate to implement robotic features into human bodies – so artificial life has to be considered as well. Finally, considering Jim Lovelocks Gaia hypothesis [183], a whole planet could be viewed as a life form and should therefore be examined in such a way.

If we continue our discussion to think about extra solar life, or even life in other galaxies, it might be totally different to our expectations. To find a suitable definition to include all life we can think of, we should approach the problem from a thermodynamic point of view.

3.1.2.5 Bizarre Life – What We Cannot Even Imagine

How should we define life that is unknown and beyond humanities imagination? For the most general definition (and the least practical) we will have to consider a philosophical viewpoint. Peter Russell showed how the whole history of the universe could be looked at as general evolution [211]. Starting with cosmic evolution, where elements where formed and stars arose and passed, leading into chemical evolution with ever more complex molecules, going from biological evolution to conscious evolution of humanities ability to reflect upon itself. In this scenario, life would simply be the step on the ladder between chemical and conscious evolution.

3.1.3 Characteristics of Life As We Know It

Every mission requires its definition of life, based on expectations of different life forms and based on a search of environment conditions. Trying to give a general definition of life must fail, because it either fails to really pinpoint life that we know or it fails to include all possible forms of life that might be out there. But we can study life on Earth and collect a list of characteristics that will help to look for life in outer space. These are our seven common features of all life that we know so far:

3.1.3.1 Structure And Boundary

Life needs structure to perform its various tasks. Known life is built upon basic cells that specialize in specific purposes. Cells themselves are composed of basic building blocks as for example amino acids. Cells are complex structures with a clearly defined, yet permeable, boundary to its exterior.

3.1.3.2 Thermodynamic Disequilibrium

Structure and complexity are the fundamental opposites of a state of high entropy. The second law of thermodynamics says that entropy in closed systems will tend to increase, where entropy is a way to measure the disorder of a system. In a system at its maximum entropy, no more energy is available to be used (that does not mean there is no more energy, but there are no more energy differences). When something dies, its entropy increases because its organized structures are decomposed. Inversely, life is a system that maintains a state of low entropy, far away from a thermodynamical equilibrium. Apart from being a detectable characteristic feature of life, it also feeds into the next issue, because maintaining low entropy necessitates using energy to export high entropy byproducts to the environment.

3.1.3.3 Energy

Energy is crucial to life, being needed for basically every process in every cell. The ability to ingest nutrients, convert their energy to usable forms, store that energy and to free it on need is thereby unavoidable.

3.1.3.4 Movement

To get to the nutrients, and to get away from its own byproducts, life needs some form of mobility. This can mean movement of life forms themselves (e.g. jaguar), but can also be achieved by resting in a moving environment (e.g. trees, corals). Movement is surely something detectable, although it will be hard to distinguish life-driven movement from ‘natural’ (geological) movement.

3.1.3.5 Adaptability

Life responds to stimuli. Although quite easy to conceive, this principle is very hard to pinpoint. Everything responds to stimuli in some way. Trying to define purposeful responses means getting on very thin ice, since purpose is a very subjective concept. Still, the ability to respond to changes in a way that allows self preservation is one of life’s main properties. This can be done individually (e.g. getting away from hazardous conditions) or as a species by adapting the genome to changing environments (evolution). Evolution, however, is based on replication and information.

3.1.3.6 Replication

In order not to die out, replication is essential to life. Something can always kill life, so non-replicating life forms, even if they did not die naturally, would be doomed to extinction. Replication means building similar units of oneself. Thereby it requires metabolism, the systems ability to produce and assemble its own building blocks. Reproduction also implies growth, which basically requires the same metabolic features. Building similar units is due to the inability to perfect the reproduction process, it is also essential to evolution and thus highly desirable.

3.1.3.7 Information

Buildings need blueprints. Reproduction needs some sort of information about the basic elements of life. The ability to physically store this information, to allow the right amount of mutations, to read it and to transform it into building blocks for life is the final necessity that describes life as we know it so far.

3.1.4 Conclusion

A universal definition of life is not now possible. Astrobiology will have to start with what we learned as basic principles of life here on Earth until it finds other examples and a general theory of life becomes possible. Thinking only about life as we know it, we came up with seven basic characteristics of life: structure, disequilibrium, energy, movement, adaptability, replication and information. Looking for a definition of life, one should bear in mind that different mission scopes require different definitions of life. Finding extraterrestrial life would be the best contribution to a general theory of life. Until that time, Astrobiology can contribute to sharpen those conditions and definitions into a more precise form. Life on Earth leaves many mysteries to be solved, and studying extremophiles in unfamiliar environments must be conducted with the same effort as looking for life in outer space.

3.2 Traces of Extant and Extinct Life

Terrestrial life is the only form of life that we know, and it appears to have arisen from a common ancestor. Life is found on the Earth anywhere liquid water is present, including extreme environments as the interior of nuclear reactors, ice-covered Antarctic lakes, suboceanic hydrothermal vents, and deep subsurface rocks. To understand the possible environments for life on other worlds, we must investigate the full range of habitable environments on our own planet, both today and in the past. [209]

If life arose on other bodies than Earth, there are two possibilities. First, an extinct form of life can be found in inactive form preserved on those planets in rock or ice. This means that we search for a fossil record. The current surface environment of Mars for example is hostile to life as we know it, thus an ancient biosphere might have become extinct.

A second option is that an extant form of life can be found. For the extant life there are two distinct types of evidence. First, growing life could be recognized directly for example via the detection of metabolic activity. The second type of evidence involves dormant life, which may be spatially or temporally separated from a hospitable niche and in a nongrowing, but surviving stage, from which it could in principle be resuscitated for detection.

In the detection of both extant and extinct life, the possibility of nonliving indicators should be considered which would be found as geochemical tracers (organic or inorganic remnants or products) in environments that are hostile to life, but which would be indicative of life existing in other places or in other times (e.g. biogenic gases, biogenic minerals, complex organic molecules indicative of living systems and footprints).

3.2.1 Where to Search for Extant and Extinct Life

Of great importance in the search for life is the location of sites that are most likely to favor finding life or an indicator of it. These will include both protected environments, niches favorable to life, or those places where evidence of hidden life or extinct life may be found near to the surface of the planet. Perhaps the most valid critique of the Viking experiments is that they were conducted at the wrong place. Life's fundamental requirements for liquid water, energy and nutrients form the basis of a search for sites which are most prospective for locating a fossil record.

Subsurface Features: There may even be small surface features, like vents or fumaroles, where subsurface volcanic sources may be releasing water and reducing gases into the local environment, and therefore providing sources for metabolic activity. In future missions, discovery of such surface features will require very-high-resolution imaging and thermal-mapping capabilities. Also, if methods with high spatial resolution could be developed for the identification of gaseous atmospheric constituents from orbit or at the surface, this technique could be extremely useful in delineating regions that might support the kinds of metabolism.

Aquifer Systems Another class of potentially suitable environments is represented by more widespread groundwater or aquifer systems that would be maintained in liquid form by core geothermal heat, but not be involved with surface or near-surface geothermal activity.

Desert Rocks An additional potential niche for extant life is illustrated by an ecosystem containing bacteria and algae that can be found within certain rocks found in the cold and dry valleys of Antarctica. The habitat for these organisms consists of porous and translucent rocks. Here the growth of organisms occurs a few millimeters below their surface when sufficient water is absorbed by the rocks from surface ice and snow as a consequence of warming during sunlit portions of the day.

Salt Crystals Still another class of potential sites for extant life consists of those where organisms continue to survive, although growth or metabolism is not apparent. These organisms are distinguished from the temporally dormant organisms by longer-term separation from an environmental niche hospitable to growth. For example, it is known from terrestrial samples that, as evaporites crystallize out of solution, halophilic bacteria can be entrapped within developing salt crystals. It has also been suggested that active metabolism may occur within brine inclusions that are sometimes found in such crystals. Furthermore, viable micro-organisms have been isolated within salt crystals that are thought to be 200 million years old. A strategy with the objective to search for such halophilic organisms must begin with global reconnaissance aimed at locating sites with potential for evaporite deposits.

Permafrost Another scenario for extant extraterrestrial biology is based upon the microbiology of permafrost regions on Earth, where there is found evidence that organisms can remain viable for very long periods in ice obtained from these sources. Thus, permafrost and ground ice on other planet might be possible sites for extant biology.

Atmosphere Routine monitoring of key atmospheric gases indicative of life may pay high scientific dividends. In atmospheres that are otherwise oxidizing in nature some reduced gases such as sulfide or methane are almost exclusively indicators of either living ecosystems or hydrothermal activity (volcanism). Detection of any of these gases would then argue for further monitoring of possible spatial and/or temporal fluctuations in their abundances. Furthermore, analysis of gas inclusions in polar cores could yield data on such reduced gases that would point towards future analyses of their sources and sinks. Analysis of stable-isotope ratios might discriminate between biological and chemical sources for these gases.

3.3 Conditions Required for Earth-Like Life

In this chapter two important aspects of life are analyzed. The first one deals with the extreme conditions that life can tolerate. This is a very important aspect as it sets the physical boundaries of the conditions within which life could have evolved and within which life can be sustained. The second part of the chapter deals with the emergence of life provided the conditions for the emergence of life are satisfied. In addition the Sun-Earth and Sun-Moon connections are closely investigated.

3.3.1 Limits of Life

Two aspects need to be investigated when considering the limits of life. The first one deals with the conditions that Earth like organisms can live in and looks at extremophiles-organisms that live in extreme environments. The second part deals with survival, which is crucial in the search for fossilized life. It is noted that the first topic is covered in the sections pertaining to limits; the second topic is covered in the sections pertaining to survival.

Temperature Limits Temperature limits are imposed by the intrinsic properties of chemical bonds as life on Earth is based on the chemistry of carbon in water. The temperature variances in which living organisms can thrive within are small. Noting that some prokaryotes (archea or bacteria) organisms without a nucleus, can grow at temperatures from –12 degrees Centrigrade to 113 degrees Centigrade. However for other organisms the temperature range is narrower citing that Eucaryotes, organisms with a nucleus, thrive from around 0 degrees Celsius to 60 degrees Celsius [157]. An example of extremophiles can be Tardigrades which are 1mm size organisms that can live in cold or hot regions. They were submerged in a liquid helium for hours and lived upon returning to normal conditions.

Pressure Limits Currently the extreme pressure limit for life on Earth is unknown. Thus far, organisms living in the deepest parts of the oceans under pressures of 1100 bar have been found. It is plausible for the pressure limit to be much greater than 1100 bar as it is believed that macromolecules and cellular constituents only begin to denature at around 4000 bar [157].

Acidic and Alkaline Environment Limits Some organisms have been found to be living in a extreme pH conditions, from pH of nearly 0 (extremely acidic) to pH of 12.5 (extremely alkaline). However, these extremophiles are able maintain their intracellular pH of between pH 4 and 9. For the topic of organisms living below a pH of 4 (acidophiles) see [204] in regard to organisms living above a pH of 9 (alkaliphilus) see [169].

High-Salt Environment Limits All organisms are salt dependent. However, due to the fact that high salt concentrations disturb the networks of ionic interactions responsible for shaping macromolecules and holding together macromolecular complexes the tolerated salt concentrations are typically low (below 0.5%) [166]. However, salt loving extremophiles referred to as halophilic microorganisms (both prokaryotes and eucaryotes), are able to tolerate a wide range of salt concentrations ranging from 1-20% NaCl.

Subterranean Limits It is acknowledged that bacteria actually thrive in the terrestrial crust in the depths of up to 750 meters [157]. Subterranean microorganisms are usually discovered during drilling experiments in subterranean oil fields [216].

Survival in Vacuum Most experiments involving microorganisms have been done in low Earth orbit where pressure of around 10^{-4} Pa – 10^{-6} Pa are prevalent [157]. It has been found that certain microorganisms can survive exposure in the vacuum of space for extended periods of time - equal to or greater than 6 years- if provided shielding against the intense UV radiation the sun generates [175]. Cellular damages do occur, however, and these are probably due to the dehydration of spores.

Survival in Radiation environments Constituting only 7% of solar radiation received at one astronomical unit, UV radiation has been found to be the most detrimental factor of space as demonstrated when tested with dried preparations of viruses, bacteria and fungal spores. For example, upon incidence of the full spectrum of solar UV radiation, 99% of *B. subtilis* spores were killed within seconds [174]. In regard to ionizing components of the radiation-experienced in space, the heavy particles (HZE particles) are the most effective species and present a formidable obstacle to survival in space because they penetrate even heavy shielding [173].

3.3.2 Emergence of Life

3.3.2.1 Introduction

Although the focus of this section is the connections between our Sun, Moon, Humanity, and how we have adapted and evolved to the conditions provided by our surrounding, it is appropriate to discuss some of the events that preceded the formation of our solar system. The Big Bang created light elements, hence at first the universe was made up entirely of hydrogen and small amounts of helium, lithium and beryllium. However, gravity influenced these gases and collected them together into massive clouds that formed simple galaxies. These galaxies became denser and hotter which then triggered the chain of events that led to the creation of stars, which created heavier elements that now compose solar systems, planets and eventually, billions of years afterwards life on Earth [225].

We will now explore the connections that exist between each one of us and our universe. . . Enjoy!!!

3.3.2.2 Are We Really Made Out Of Stardust?

Every single atom in our body was literally once part of a star. In fact some of the elements found on Earth are from a third generation star. Which means that part of our bodies has been in at least three stars before forming each one of us! As we mentioned earlier, shortly after the Big Bang there was almost nothing but hydrogen. It was not until galaxies and stars where formed that we started having heavier elements in the universe.

Heavy stars (with mass greater than 25 solar masses) are the ones responsible for us! The temperature in the cores of these stars can reach nearly 3 trillion Kelvin by the time iron is formed. When every other element in the core has become iron, fusion ceases. The star will try to shrink to increase pressure and temperature as it usually does. However, at this point it is dealing with iron (the same iron that today flows though our blood), which happens to be a very peculiar element. Iron doesn’t fuse like the lighter elements so it keeps trying to fuse iron by increasing it’s temperature more and more until the result is catastrophic explosion known as supernova.

If the star that caused the supernova explosion was not massive enough to create a black hole, elements heavier than iron are created. The matter that is released by these massive explosions, are then spread out into the star’s galaxy. Part of this dust will again come together because of the gravitational pull of matter and form new stars and sometimes planets around them. In conclusion, “*We are star stuff*” Carl Sagan (1994).

3.3.2.3 Sun-Earth-Humans Connection

"*It is true that from the highest point of view the Sun is only one of a multitude - a single star among millions - thousands of which, most likely, exceed it in brightness, magnitude, and power. It is only a private in the host of heaven. But it alone, among the countless myriads, is near enough to affect terrestrial affairs in any sensible degree; and its influence upon them is such that it is hard to find the word to name it*." Charles Young (1896).

This quote made over a century ago is still one of the best descriptions of the sun’s influence on Earth. Our planet receives half of one-billionth of the Sun’s total energy output! Yet this is enough to nurture and power the whole planet. The sun’s energy triggers photosynthesis, which in return produces carbohydrates, which via the food chain, nourishes herbivores, carnivores and humans [170]. Generally speaking, our Sun hosted hospitable conditions for the emergence and sustainability of life nearly 3.8 billion years ago and since then life has only needed to adapt and evolve to the conditions provided by our star and surroundings.

Biochemistry There are 114 elements in the periodic table of which 92 are naturally occuring. 90% of the cosmos consists of hydrogen, 9% of the remaining matter is helium, which leaves mere 1% of the universe to the remaining 112 elements! So, what does this have to do with humans? The best theories of the formation of the solar system predict that there are great similarities in the composition of the Sun, planets, asteroids, comets, and dust in space. For instance, on Earth, many minerals contain hydrogen but it is mainly held locked in water, which is hydrogen and oxygen. The third most abundant element on the sun, is oxygen, which happens to be the most abundant element by weight in our bodies and also is the most abundant element on the earth's crust when accounted for weight (the rocky crust of Earth is made of silicate minerals containing oxygen). We breathe oxygen, we drink it (in water), and it supports the stems of plants, trees and is essential for the bio-combustion in our bodies (metabolism). In addition, the second most abundant element in our bodies is carbon, which happens to be the next most abundant element after oxygen in our star as well [143].

Physiological Adaptations The Sun's surface, is brightest in the visible region of the electromagnetic spectrum. Visible light is the only part of electromagnetic radiation that our eyes can see. If we look at the curve of absorption coefficient of water, we would notice that what we call "visible light" is precisely the window in which the absorption coefficient drops to a minimum (in other words, the light can go through). This explains why we are water-based creatures; our eyes are mainly made of water!

Another peculiar example is our skin color. Anthropologist Nina Jablonski has found a strong correlation between skin color and the strength of sunlight across the globe. Humans in the lower latitudes on earth, have developed dark skin to block out the sun and protect their body's folate reserves. Mean while, people far from the equator, where the incidence of sunlight is weaker have developed fair skin to absorb the sun and produce adequate amounts of vitamin D during the long winter months [181].

3.3.2.4 Moon-Earth Connection

Have you ever wondered what Earth without a moon would be like? Would life have emerged on planet Earth if the moon did not exist? In fact it would not take very much for our history to have turned out in a very different way. Scientists now believe in the theory that the moon was formed when a Mars-sized planetesimal collided with our young Earth, ripping up a huge chunk of Earth's crust and hurling it into orbit. After this matter cooled down the particles united by gravitational forces and finally created our moon in orbit around the Earth [144].

The moon is primarily responsible for the stable 23.5 degrees tilt which gives seasons on our planet. Without our moon this tilt would dramatically change over short periods of time causing unpredictable climatic changes. In addition, over time, the moon's tidal drag has acted as a brake on the earth's rotation, without the moon's drag, it has been estimated that the earth would spin as much as three times faster than it currently spins. It is thought that if this was the case, then a year on earth without our moon would consist of approximately 1,095 eight-hour days. If Earth rotated faster wind patterns would likely be stronger and longer-lived. It is also thought, that the earth's core would generate a stronger magnetic field, hence deflecting more of the solar wind. Add it all together, and you get an environment and an ecosystem, radically different from the one we are familiar with [144].

3.3.2.5 Final Remarks

Life would be very different if our star would have a different mass or if Earth would be located further away from the Sun. In general the slightest change would definitely lead to a different evolution path. It is possible that life exists elsewhere in the universe. By studying life as we know it, we can have a general idea of what to expect of extraterrestrial life by means of studying their solar systems and the conditions provided by their star.

3.3.3 Habitable Zones

3.3.3.1 Habitability of Planets

We find that planets are common in other solar systems, at least in our solar neighborhood. Most of the planets detected so far are gas giants, which, as far as we know, are unlikely to harbor life. There is no reason to believe that terrestrial planets are rare, and thus we may investigate the habitability of such planets. In this section we discuss this important issue. What makes a terrestrial planet habitable? Habitability is usually discussed in terms of advanced (non-microbial) life and this inevitably leads us to search for conditions which are Earth-like. Therefore, we need liquid water and some dry land, or, in other words, oceans and continents. We need an atmosphere, preferably with an oxidizing agent such as molecular oxygen (O_2). We would like to have climatic stability, which requires a low eccentric orbit, an ocean, a stabilizing moon, a low impact rate, and a central star that does not show periodic outbursts or flaring behavior. And, as will be explained later in this section, we need a global carbon cycle. For this, plate tectonics seems to be essential, which in its turn requires a heat source in the planets' interior, a sufficiently thin lithosphere, and a lubricant such as water. Furthermore, a protective layer in the atmosphere against radiation would certainly be advantageous (on Earth we have the ozone layer). In the next subsections we discuss all these requirements in terms of the concept of the Habitable Zone. The theory of the Circumstellar Habitable Zone (CHZ) has been around for a while, and recently we have seen the emergence of the concept of the Galactic Habitable Zone (GHZ).

3.3.3.2 The Circumstellar Habitable Zone

The Original Model Huang [177] was the first to propose the concept of the Circumstellar Habitable Zone (CHZ), which he defined as a circumstellar circular shell in which liquid water would be stable if present on a terrestrial planetary surface. As planets are thought to form in a plane the CHZ is generally referred to as a ring. The rate of energy received per unit area from the central star must lie between two limiting values. This rate is called the flux F, and it relates to the luminosity L of the star (energy output per unit time) and the distance to the star R as

$$F = \frac{L}{4\pi R^2} \tag{3.1}$$

The HZ requirement is $\epsilon_1 < F < \epsilon_2$, with ϵ_1 and ϵ_2 being constants that refer to the physical properties of water on a particular planet, and which are independent of the nature of the star. The radius of the CHZ is then constrained as:

$$\sqrt{L/(4\pi\epsilon_2)} < R < \sqrt{L/(4\pi\epsilon_1)} \tag{3.2}$$

from which it follows that the area of the CHZ ring is proportional to the stellar luminosity.

Assuming that the formation of terrestrial planets is not restricted to specific stars, from the previous argument we can determine which stellar types are most suitable for life. Early type stars (O B A) have a large CHZ, whereas late type stars (K M) have a small CHZ. Now, if we assume that planets are formed at an equal spacing, the likelihood of finding a planet within the CHZ of a late type star is relatively small. Unfortunately, we do not know how terrestrial planets are distributed around their parent star, simply because we have yet observed just a single solar system with terrestrial planets, other than our own (pulsar PSR 1257+12) [224]. If we take the distribution of the planets in our own Solar System as representative, the decrease of the size of the CHZ with stellar type would be countered by the increase of the planetary density. Although early type stars have a large CHZ, their associated planetary systems may not be suitable for life, most importantly because these stars have very short lifetimes of less than 1 Gyr. Now it appears that life on Earth did not need much time to develop. Research by Mojzsis et al. [188] suggests that life emerged already 3.8 Gyr ago, which is a mere 700 Myr after the formation of the earth, but this value still exceeds the average lifetime of an early type star. As multicellular life did not appear until 600 Myr ago (the Ediacaran fauna), which is 3.9 Gyr after the formation of the earth, it is safe to say that advanced life can only develop around stars of a later type than early F. Europa seems to threaten this theory. Although it lies outside of the CHZ it still might harbor life as the required energy might come not from the Sun but from the tidal pull of Jupiter.

Greenhouse Effect The conceptually very simple CHZ model presented by Huang [177] has since been improved by several authors. The most important addition is the inclusion of a global carbon cycle. On Earth, Venus and Mars, atmospheric carbon is present predominantly in the form of carbon dioxide (CO_2). Now, CO_2 is a greenhouse gas − as is water vapor − thus its presence in an atmosphere increases the surface temperature of a planet. Let us take the Earth as an example. If the Earth were a perfect blackbody, its surface temperature would be equal to the effective temperature T_{eff} defined by $F = \sigma T_{\text{eff}}^4$ with F the energy flux the Earth radiates into space and σ the Stefan-Boltzmann constant. The rate at which the Earth radiates energy into space must be equal to the amount it receives from the Sun. This requirement leads to the Arrhenius equation [138]

$$(1 - a)S_\odot = 4\sigma T_{\text{eff}}^4 \tag{3.3}$$

in which we have introduced the albedo of the Earth a (the fraction of light reflected off the planet) and defined $S_\odot$ to be the Solar energy flux measured at the distance of the Earth from the star. If greenhouse gases are present in the atmosphere, the surface temperature of the Earth is $T_\mathrm{s} = T_\mathrm{eff} + \Delta T$ with ΔT some parameterized function of the atmospheric partial pressure of CO_2 (P_atm) and other greenhouse gases.

Global Carbon Cycle We can outline (part of) the carbon cycle as follows. Transport of atmospheric CO_2 to the sediment takes place through weathering of rock and biological activity. When sedimentation takes place on the ocean floor, carbon is returned over geologic time to the Earth's interior by subduction. Outgassing by volcanic activity pumps CO_2 back into the atmosphere, completing the cycle.

Walker et al. [221] proposed that the global carbon cycle acts as a negative feedback mechanism. If the surface temperature of a planet rises, for example as a result of an increase in luminosity of the central star, the rate of weathering will increase, since it is temperature dependent. This will increase the rate at which atmospheric CO_2 is removed from the atmosphere, reducing the greenhouse effect and decreasing the surface temperature. CHZ models need to take this scheme into account as stellar models indicate that the luminosity of a star increases over its lifetime due to the gradual depletion of hydrogen in the core.

A Recent CHZ Model Recent CHZ models attempt to model Earth-like planets [221] [140] [165], which implies the occurrence of plate tectonics. Central in these is the rate of weathering, denoted as F_wr. It is a function of the activity of H^+ in fresh soil water a_{H^+} and the surface temperature T_s. As the relative rate f_wr it is expressed in terms of its present value $F_\mathrm{wr,0}$. The activity is a function of the CO_2 concentration in the soil P_soil and the soil (surface) temperature. P_soil is a linear function of the biological activity Π and atmospheric CO_2 concentration P_atm. The process of weathering removes CO_2 from the atmosphere, while volcanism adds it. The Geodynamic Model by Franck et al. [165] defines $f_\mathrm{A} \equiv A_\mathrm{c}/A_\mathrm{c,0}$ to be the continental area normalized by its present value, and $f_\mathrm{sr} \equiv S/S_0$ to be the spreading rate of the tectonic plates normalized by its present value. Then

$$\frac{dP_\mathrm{atm}}{dt} \propto f_\mathrm{sr} - f_\mathrm{wr} \cdot f_\mathrm{A} \tag{3.4}$$

The time dependent input variables in this model are the Solar energy flux as measured at Earth distance $S_\odot(t)$, continental area $A_\mathrm{c}(t)$, and spreading rate $S(t)$. These act to change the output variables surface temperature $T_\mathrm{s}(t)$ and atmospheric CO_2 pressure $P_\mathrm{atm}(t)$ of the planet over time. Assuming that changes take place gradually, we only need to consider the state of equilibrium: $f_\mathrm{sr} = f_\mathrm{wr} \cdot f_\mathrm{A}$. Note that the presence of life (Π) has a direct influence on the habitability of a planet $-$ it is part of the carbon cycle $-$ creating a circular argument.

The results from the Geodynamic Model (GDM) of [165] show that the CHZ of our solar system shifts outwards in time and decreases in size. Currently, the inner and outer radii are at 0.94 and 1.2 AU, respectively, with an optimum distance of 1.08 AU for an Earth-like planet. In 600 Myr the inner radius will reach Earth distance, which then may no longer be able to support life. Concerning our neighboring planets, Venus was never in the CHZ and will never be. Interestingly, although Mars is currently outside the CHZ, the model indicates that it was inside up to about 500 Myr ago.

Habitability of Moons What about the habitability of moons orbiting giant planets? If these are located within the CHZ, liquid water may be present on their surface, and, if outside under the surface (e.g. Europa). Generally, moons do not provide a very habitable environment for the following reasons. Moons would face the rapid loss of an atmosphere (inside CHZ) or would be very cold (outside CHZ, e.g. Titan). Moons have no plate tectonics, and are more prone to collisions due to the strong gravity of the giant planet (many crater chains have been detected on Ganymede and Callisto). And finally, the planet could be a source of intense radiation (e.g. Jupiter, but not so much Saturn).

3.3.3.3 The Galactic Habitable Zone

Metallicity Already, Huang [177] pondered on the question of habitability within a galactic context, wondering whether a planet orbiting a star close to the galactic center can support life. This leads us to the concept of the Galactic Habitable Zone (GHZ), explored in detail by Gonzalez et al. [167]. A key parameter in this concept is metallicity. Astronomers rank all elements which are not hydrogen (H) and helium (He) − the two most abundant elements in the universe − under metals. The metallicity of an object denotes the constituent abundance by number of these elements with respect to H and He and is usually expressed as a percentage or fraction. Terrestrial planets are primarily composed of metals (O, Si, Fe etc.). The formation of terrestrial planets and their respective mass is governed by the composition of the cloud of Interstellar Matter (ISM) from which their solar system has condensed. A high metallicity is required to form terrestrial planets of sufficient mass.

Our Galaxy The Milky Way is composed of three distinct stellar populations: the central bulge, the disk, and the halo. These populations, which partially overlap, differ with respect to the rate of star formation, the age of the stars, their metallicity, and their kinetics. Halo stars, primarily present in globular clusters, are generally ancient and metal-poor; the chances of finding terrestrial planets orbiting these are slim. The disk harbors our Sun and is expected to harbor terrestrial planets. In the central bulge we find stars of all ages that show a large range in metallicity. Here, Earth mass planets should be common. However, we think that the bulge has a low habitability as high energy events are more likely to happen (supernovae, gamma ray bursts) and the high stellar density may lead to frequent gravitational perturbations of orbits of planets and comets, causing collisions etc. (Gonzalez et al. refer a discussion to a forthcoming paper).

Chemical Composition A recurrent theme in our discussion of the habitability of planets is plate tectonics. Apart from the presence of water (which acts as a lubricant), plate tectonics requires a certain chemical composition of the planets' interior and an internal heat source. The radioactive isotopes U^{235}, U^{238}, Th^{232} and K^{40} are the most important sources of heat within the Earth [180]. Gonzalez et al. [167] calculate that if a terrestrial planet with a mass equal to that of the Earth presently forms at the same radial distance from the center of the galaxy as our Sun, it will have much less radiogenic heat production after 4.5 Gyr due to a decrease in abundance in the ISM of these long-lived radioisotopes. This may prevent plate tectonics from operating on this planet. These results suggest that there exists a window in time in our galaxy during which terrestrial planets with long-lasting geological activity can form. Currently, this window is slowly closing on a time scale of Gyr.

Gonzalez et al. conclude that there exists a zone of enhanced habitability within our Milky Way: the Galactic Habitable Zone. It is an annulus within the disk, which edges are constrained by the existing metallicity gradient in our galaxy (decrease outward). It slowly migrates outward as stellar evolution continues to enrich the ISM with metals. Not surprisingly, our Sun is located within the GHZ. As to whether other galaxies may harbor habitable planets, more luminous galaxies appear to be more metal-rich (the Milky Way is among the 1.3% most luminous galaxies). The earliest galaxies (e.g. Hubble Deep Field) were very metal-poor, and we do not expect they formed terrestrial planets.

3.4 Finding Signs of Life

3.4.1 Introduction

To maximize chances of unambiguous results pertaining to the existence of either extinct or extant life, it is imperative to choose a suite of instruments that would reduce the number of alternative interpretations. At the same time, each instrument needs to be chosen in such a way as not to form a weak link in the chain of observations across the instruments array. It turns out that the main strategy for finding life is to provide, set of instruments that will give concrete evidence for either for or against the existence of life.

In Appendix B a number of existing and proven instruments are described that can be used with various space missions. To facilitate the best choice of required instruments, it has been decided to subgroup them according to the area where they will consequently be used. First, there is a set of instruments that can be used for Remote Sensing. These can be further divided into three categories, namely Remote Sensing from the Earth's surface, Remote Sensing from the Earth's orbit and Remote Sensing from orbit around the target body. 3.1 describes these cases.

The most important set of instruments, pertain to the in situ analysis which can be used for the atmospheric, surface or subsurface investigation. In situ analysis instruments can also be part of the interplanetary spacecraft,

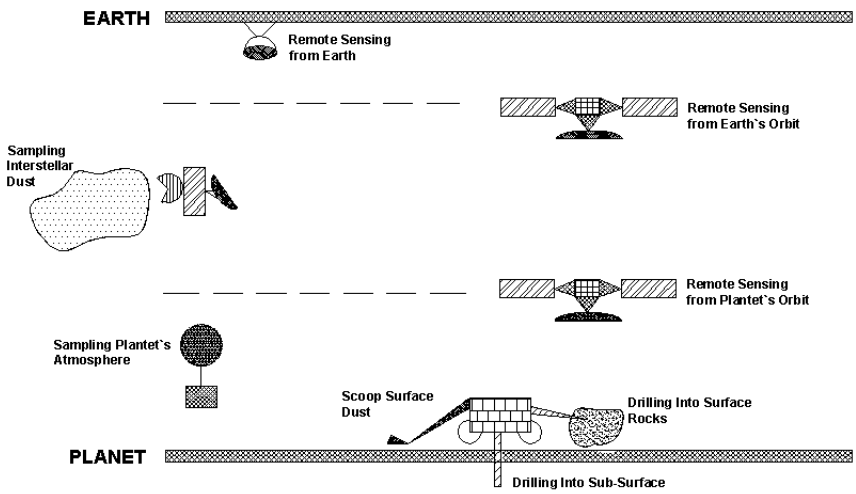

Figure 3.1: Grouping of instruments relative to the areas of investigation

whose mission might be to capture interplanetary dust, or comet's tail.

3.4.2 Remote Sensing

This section will survey remote sensing instruments that could aid in the search for bodies conducive to life. Instrumentation will be assessed as pertaining to the electromagnetic spectrum and parameters that can be determined by remote sensing in spectral ranges applicable to the conditions required for life.

3.4.2.1 Conditions Required For Life

Due to the nature of the search (life similar to earth life) the parameters will be based on biomarkers contrived from life as we know it. In a paper by G. Wald in the US National Academy of Sciences four general requirements for life were set forth (1) the presence of liquid water, (2) Elements needed for reproduction and metabolism, (3) an energy source, and (4) suitable environmental conditions [178]. From these requirements this paper will focus on detecting liquid water and elements life requires. Therefore the search parameters for remote sensing are the existence of liquid water, chemical non-equilibrium, oxygen, carbon, nitrogen, and hydrogen, among other elements [179].

The most universal requirement for earth life is the existence of liquid water; this condition necessitates temperature and pressure constraints pertaining to the phase diagram of liquid water. Thus in conditions of low pressure as seen on the phase diagram of water, water goes from solid ice to vapor with increasing temperature without becoming a liquid. This is of concern with planets that have less dense atmospheres; liquid water would not exist on the surface of such a planet. However the search for liquid water will not be limited to the surface of a planet, as subterranean water may exist.

3.4.2.2 Electromagnetic Spectrum and Remote Sensing

Remote sensing in space is limited to the electromagnetic spectrum since there is no medium for other waves to propagate through. The electromagnetic spectrum refers to the continuum of electromagnetic waves organized according to wavelengths and frequencies. The spectrum contains gamma rays, x-rays, ultraviolet, visible, near infrared, infrared, microwave, and radio waves refer to table 3.1.[1]

[1] `http://imagine.gsfc.nasa.gov/docs/science/know_l1/spectrum_chart.html` is the URL for the table.

	Wavelength [m]	Frequency [Hz]	Energy [J]
Radio	$> 1 \cdot 10^{-1}$	$< 3 \cdot 10^{9}$	$< 2 \cdot 10^{-24}$
Microwave	$1 \cdot 10^{-3}$ - $1 \cdot 10^{-1}$	$3 \cdot 10^{9}$ - $3 \cdot 10^{11}$	$2 \cdot 10^{-24}$ - $2 \cdot 10^{-22}$
Infrared	$7 \cdot 10^{-7}$ - $1 \cdot 10^{-3}$	$3 \cdot 10^{11}$ - $3 \cdot 10^{14}$	$2 \cdot 10^{-22}$ - $2 \cdot 10^{-19}$
Optical	$4 \cdot 10^{-7}$ - $7 \cdot 10^{-7}$	$4 \cdot 10^{14}$ - $7.5 \cdot 10^{14}$	$3 \cdot 10^{-19}$ - $5 \cdot 10^{-19}$
UV	$1 \cdot 10^{-8}$ - $4 \cdot 10^{-7}$	$7.5 \cdot 10^{14}$ - $3 \cdot 10^{16}$	$5 \cdot 10^{-19}$ - $2 \cdot 10^{-17}$
X-ray	$1 \cdot 10^{-11}$ - $1 \cdot 10^{-8}$	$3 \cdot 10^{16}$ - $3 \cdot 10^{19}$	$2 \cdot 10^{-17}$ - $2 \cdot 10^{-14}$
γ-ray	$< 1 \cdot 10^{-11}$	$> 3 \cdot 10^{19}$	$> 2 \cdot 10^{-14}$

Table 3.1: Bands in the Electromagnetic Spectrum

Gamma rays Gamma ray spectroscopy can be used to map near surface water and elemental abundances on a body [141]. Elemental abundances could indicate locations where hydrothermal processes might have played a role in the surface evolution of the planet. The gamma ray spectrometer on board the Mars Odyssey is designed to map the distribution of near surface water and the elemental abundances on the surface. This instrument has a spatial resolution of 300 [km] for elements such as Oxygen, Silicon, Chlorine, Potassium and Iron [206]. The Gamma ray spectrometer on the Mars Odyssey is supplemented with two neutron detector systems to detect hydrogen. The instrument is designed to detect hydrogen on the surface and up to a depth of approximately one meter. [207] The gamma ray spectrometer uses 32 W of power and has a mass of 30.5 kg.[139]

Ultraviolet spectrum Ultra violet spectrometry can be used to determine the atmospheric composition of a planet [195]. Examples of instruments that operate in this spectrum are Cassini's Ultraviolet Imaging Spectrograph (UVIS), Galileo's Ultraviolet Spectrometer and the SPICAM instrument on the Mars Express. The Ultraviolet Imaging spectrometer subsystem on the Cassini spacecraft has the hydrogen-Deuterium absorption Cell instrument to measure hydrogen and deuterium in the Saturn System [196]. Galileo's Ultraviolet spectrometer will be used to study the composition and structure of Jupiter's upper atmosphere. This instrument weighs 9.7 [kg] and uses 5.9 [watts] of power [197]. The Ultra violet sensor in the SPICAM instrument on the Mars Express mission will measure ozone in the Martian atmosphere.

Visible spectrum The Visual spectrum can be used to observe topography necessary for defining drainage patterns. Other applications can include cratering chronology to date a specific location on a planets surface. This information could then be used to search for extant life at younger locations and extinct life at older locations [141].

Infrared spectrum Examples of specific instruments that operate in IR are the OMEGA (Infrared Mineralogical Mapping Spectrometer) on board the Mars Express orbiter, THEMIS (Thermal Emission Spectrometer) onboard the mars Odyssey, the Infrared sensor of SPICAM (UV and IR) Atmospheric Spectrometer on board the Mars Express, and the Near- Infrared radiation mapping spectrometer (NIMS) on board the Galileo Orbiter. The OMEGA instrument will search for clues to the history of water on Mars and investigate its possible past habitability. [154]. The instrument will map the intensity variances in the (3.6 [μm]-3.9 [μm] Infrared wavelength band) searching for carbonates. It will also search for water in the 3 [μm] Infrared wavelength to show variances in hydration to determine where water was. Searching for carbonates in sedimentary rocks is vital; if found it would provide evidence for the existence of liquid water on Mars in the past, as carbonates are formed when carbon dioxide dissolves in water and reacts with metals.

The thermal emission imaging system will be used to determine mineralogy of the surface of Mars and elevated near-surface and surface temperatures that could be an indication of a hydrothermal system. [156]

The infrared spectrometer will measure water vapor in the atmosphere.

The PFS on the Mars Express is capable of identifying molecules in the Martian atmosphere. This device is capable of searching for methane, which if found in large quantities could be an indication of life. [155]

The near-infrared radiation mapping spectrometer (NIMS) on board the Galileo Orbiter measures the thermal, and structural composition of the Galilean satellites. It is capable of detecting ammonia, water vapor, phosphate, methane and germane. The NIMS weighs 18 kg and uses 12 Watt of power. [212],[145]

Midrange infrared observations are of interest as water molecules, carbon dioxide and ozone have absorption features detected in this spectral range. Remote sensing from Earth orbit would most likely search in this range. [158].

Radio waves An example of specific instrumentation that utilizes this spectrum is the subsurface sounding radar/altimeter to be flown on the Mars Express mission. The Mars Advanced Radar for subsurface and Ionospheric Sounding (MARIS) instrument will attempt to detect subsurface water (liquid and solid). This instrument is capable of penetrating the surface at a depth up to 5 [km] below the surface [160],[161]. It has been proposed to use this technology at Europa to detect subsurface liquid water to a depth of approximately 20 km. [187]

Remote sensing from Earth is limited due to the earth's atmosphere that results in opaque regions. 2.5

3.4.3 In-Situ Analysis

Remote sensing provides a first step in identifying extraterrestrial bodies where conditions that can or could support life exist or existed. Once these bodies are identified the next step is to actually send a spacecraft there and obtain a sample for analysis.

Visual sample investigation should be the first analysis performed on any solid sample. Very often, visual analysis can give the indication of the rock or mineral type and decision can be made in the early stage to either go ahead and do further analysis or to discard the sample.

In situ analysis is not limited to the solid samples, but can also include liquid and gas. Thus we can divide in situ analysis into three main components. These are analysis of the interstellar dust including comet's tail or coma, analysis of the extraterrestrial body's atmosphere including particulates suspended in the air, and analysis of samples on the surface of the extraterrestrial body. The latter one could be further divided into subsurface and surface analysis. Each of the above missions can have a wide range of instruments on board, and the only limiting factor on the number of different instruments that could be incorporated into the payload is the mass of the spacecraft and in turn, cost.

There are many indicators that could be used to find life. However, in the analysis all the indicators need to be taken into consideration and not just one or two of them. These indicators are listed below [157].

3.4.3.1 Evidence of Extant Life

Structural indicators are for example cells and sub cellular structures. The analysis can be achieved via using selective dyes to identify specific cellular components and various microscopic observations.

Culture Indicators involve isolation and successful culturing, with subsequent biochemical analysis of nucleic acids, proteins lipids etc.

Metabolic Indicators involve observation in culture or in situ of the chemical products of metabolism using isotopic traces. Direct analysis using for example gas chromatography can also be used. Such experiments were conducted by Viking and were based on testing of carbon assimilation, catabolic activity and respiration.

Isotopic Indicators involve discrimination of ^{13}C relative to ^{12}C during enzymatic uptake of carbon in photosynthesis.

Chirality Indicator is based on homochirality of life i.e. preference for either left or right handed molecules. Analysis include observing of the optical activity.

Spectral Observations can detect a variety of organic compounds involved in living systems and are based on vibration spectroscopy like Raman spectroscopy.

Spectrum	Instrument	Wave length [m]	Information obtained	Location of operation	Mass[kg]/ Power [w]
Gamma ray	Gamma ray spectrometer (Mars Odyssey)		near surface water elemental abundances	Orbiter	
Ultra violet	Ultra violet Spectrometer Cassini's (UVIS) (HDAC) (EUV) Galileo's (UVS) Mars Express (SPICAM)	 55.8[nm]-190[nm] absorption (121.5 [nm]) 55.8 [nm] - 118 [nm] 118[nm - 320[nm]	Atmospheric composition Atmospheric composition Hydrogen-Dueterium Atmospheric composition Atmospheric composition Vertical distribution of Ozone and CO_2 in Atmosphere	Orbiter Orbiter Orbiter Orbiter	 14.46 [kg] 9.7[kg]/5.9[w]
Visible	Visible Observations	400[nm]-700[nm]	Surface Topography	Orbiter	
Infrared					
Infrared (Near)	Galileo (NIMS)	0.7-5.2 [micron] starts at near infrared and overlaps with mid IR	Surface mineral mapping capable of detecting water vapor,oxygen,methane	Orbiter	18[kg] / 12[w]
Infrared(Mid)	Mars Express (OMEGA) (SPICAM) (PFS) Interferometer	 1.0-5.2 [microns] 1-1.7 [microns] 1.2 [microns] 5 - 20 [microns] Overlap with other IR	 carbonates,hydration water vapor capable of detecting methane ozone, water carbon dioxide	 Orbiter Space based Observation	 29[kg]
Infrared(Far)	Mars Odyssey THEMIS	6.5-14.5 [micrometers]	Mineralogy of surface	Orbiter	
Radio	Mars Express (MARIS)		Subsurface water	Orbiter	

Table 3.2: Table of Instrumentation

3.4.3.2 Evidence of Extinct Life

Structural Indicators include observations of groups of possible microfossils structures including petrological analysis of the associated minerals and the study of the residual carbonaceous matter. Analysis can use various microscopes to observe microfossil structures as well as Infra Red or Raman spectroscope to confirm the mineral and carbonaceous constituents.

Biogeochemical Indicators include determination of the elemental abundances in reduced (organic) carbon remnants using a Gas Chromatograph/Mass Spectrometer and Alpha Proton X ray Spectrometer. In addition volatile (hydrocarbon) component of the reduced carbon constituents can be analyzed using Pyrolysis/Gas Chromatography/Mass Spectroscopy.

Isotopic Indicators are based on conversion of inorganic carbon to organic i.e. the retainment of biogenic carbon residues due to the enhancement of the ^{12}C isotope to ^{13}C. In addition earlier biological activity can be indicated by the $^{34}S/^{32}S$ isotope composition change between sulphides and sulphates. The Pyrolysis /Gas Chromatography/Mass Spectroscopy is used for these analyses and in addition Ion microprobe can be used for microstructures.

Molecular Indicators can be used thanks to the fact that certain biochemical compounds as for example lipids may withstand degradation over long periods. Later they may be extracted by organic solvents from residues and analyzed using chiral and isotopic analysis to obtain an indication of the nature of the original body.

Chirality Indicator is based on the fact that the homochirality structure is retained upon the death of the organism. Racemization can be very slow depending on the surrounding conditions.

Spectral Observations utilize vibrational spectra of organic compounds to provide nature of carbonaceous samples of biological and abiotic origin. For this analysis Infra Red and Raman spectroscopies are used which in addition provide mineralogical contents of the sample.

3.4.3.3 Analysis Based On The Conditions Required For Life

Instruments and experiments can be divided into three main subsections. These are experiments and instruments to analyze geochemistry, to perform isotopic analysis and to perform molecular analysis.

Geochemical and Petrological Analysis Geochemical, Petrological and Mineralogical analysis provides information on the local environment and traces of biological activity. It gives the information on the biologically significant elements such as C, H, N, O, S and P and their distribution between organic and inorganic matter. It also provides oxidation states of various elements and major, minor and trace elements abundances. In addition, it gives the indication of the possible sites where biomarkers or fossils can be found. Search for biogenic minerals can also provide valuable information on ongoing or past activities of life.

In general, two types of samples will be encountered, namely soil or particulates in the air, and hard rocks including subsurface rocks. Hard rock can be either ground to get fine particulates for the chemical analysis or can be core drilled and sectioned for the microscope investigation. On the other hand, particulates can be size sorted and ground into fine dust to expose the interior and for chemical analysis.

A representative suite of instruments is listed below. [157]

Panoramic Stereo Camera Panoramic Stereo Camera can be used for investigation of rock types and relatively large bio features and fossils. Approximate mass is 2.5 kg and power requirement is 8 Watts.

Low Resolution Microscope LRM has a resolution in the range of 0.1mm/pixel and is used for examination of samples before viewing them under high-resolution microscope. Approximate mass is 0.2 kg and power requirement is 2.5 Watts.

Optical Microscopy – Low Magnification (20-80x) OM-LM is used for color analysis, texture, fossils, grain size and grain shape analysis. Approximate mass is 0.3 kg and power requirement is 4 Watts.

Optical Microscopy – High Magnification (100-500x) OP-HM is used for viewing minerals, surface of grains and microfossils. Approximate weight is 0.3 kg and power requirement of is 4 Watts.

Atomic Force Microscope AFM is used for imaging of pre-selected surfaces in the nanometer range. Field of view is in general 1micron by 1 micron. Approximate weight is 1.5 kg and power requirement is 5 Watts.

Scanning Electron Microscope/Environmental Scanning Electron Microscope SEM/ESEM in the backscatter mode can give the elemental analysis and in the secondary electron mode can give the topographical information of the specimen. Resolution is on the order of 1 micron. ESEM as opposed to SEM does not require coating of the sample before viewing and thus it is simpler to use.

Ion Probe Analyzer IPA is used for surface analysis, including major and trace elements of rock forming minerals, organic matter, isotopic imaging, biogenic matter. It can analyze specific regions on the sample that is associated with fossils and can give $^{13}C/^{12}C$ ratios for organic traces.

Alpha Proton X-ray Spectrometer APXS is used for elemental analysis of all elements except for Hydrogen and Helium. It can also give absolute abundances of these elements. In turn APXS can give absolute oxidation state of the subsurface material as a function of depth. APXS can also analyze Carbon down to 0.1%wt. And does not require sample preparation apart from removing of surface dust. Approximate mass is 0.5 kg, Power requirement is 0.4 Watt.

X-ray Analysis XA is used to identify minerals by X-ray diffraction. Fine grain particulates or ground up minerals are required for the analysis.

Differential Thermal Analysis DTA is used to identify and analyze of H_2O- ; OH- ; CO_2- bearing minerals. Volatiles which are released could be also analyzed by a mass spectrometer.

Infra Red Spectrometer IRS is used for identification of minerals and organics. Molecules such as CO_2, H_2O and CO have characteristic absorption bands in the Infra Red. IRS is excellent for detection of polar molecular groupings such as –O-H and –C=O. Approximate mass is 1 kg and power requirement is 3.5 Watt.

Thermal Infra Red Spectrometer TIRS is used to investigate specific absorption and emissions of carbon bearing molecules. It can provide a direct test for the presence of organics and can determine whether geothermal or hydrothermal activity is occurring.

Raman Spectrometer RS is used for molecular analysis of organics and minerals. It is complementary to Infra Red Spectrometer. It is especially good for non-polar groupings –C-C- and –C=C-. It also covers full range of spectrum for the characterization of the signatures of minerals, crystals and inorganic species simultaneously unlike Infra Red instrument. Approximate mass is 1.5 kg and power requirement is 1 Watt.

UV Spectrometer UVS is used to determine volatilized rare gas content, production rates of water, carbon dioxide and carbon monoxide and atomic measurement of C, H, O, N, S. In addition it can give photometric properties and ice/ice/rock ratio of small grains.

Mossbauer Spectrometer (MS) MS is used for analyzing iron bearing minerals and compounds. Oxidation state and the ratio of Fe^{2+}/Fe^{3+} can be determined. The Mossbauer parameters are temperature dependent and the average information depth is in the range of 200mm. Approximate mass is 0.5 kg and power requirement is 1.6 Watt.

Isotopic Analysis Isotopic ratios can serve as a valuable indicator of chemical biomarkers. For example depletion of ^{13}C is a clear signature of biological activity. Similarly determination of $^{15}N/^{14}N$ and $^{34}S/^{32}S$ can also provide very important information on possible biological activities in the analyzed samples.

Gas Chromatography-Isotope Ratio-Mass Spectrometry (GC-IR-MS) GC-IR-MS is used for carbon species that are sufficiently volatile to be chromatographed. It is compatible with Pyrolisis-Gas Chromatography-Mass Spectrometry (PYR-GC-MS).

Secondary Ionization Mass Spectrometry (SIMS)/ Ion Microprobe In studies requiring determinations of isotopic and/or trace-element abundances with very high spatial resolution, the ion microprobe remains the premier. It allows measurements of isotope ratios for both major and minor elements. Both custom-built and commercial ion microprobes have been employed in geo/cosmochemical research for approximately 15 years. [219].

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) Laser ablation ICP-MS is incredibly versatile and can provide the greatest accuracy. It needs minimum sample preparation and could be done directly from the microscope. LA-ICP-MS could be utilized for isotopic analysis of inorganic and organic matter. LA-ICP-MS cannot rival SIMS for the determination of isotopic ratios across the mass range, however, LA-ICP-MS has been used to accurately determine the heavier isotopes [218].

Molecular Analysis In this chapter instruments are selected to find both organic and inorganic molecules. Inorganic molecules include water (H_2O), carbonate (CO_2), nitrates (N_xO_y), sulphates (SO_x) and phosphates. Correct mapping of the abundance of inorganic molecules and determination of their concentration gradients with depth, whenever applicable, is essential for developing models of evolution of organics. However, the discovery of organics is of prime importance for astrobiology. For example, discovery of CH_4 or H_2S, could be a sign of current biological activity.

Gas Chromatograph Mass Spectrometer (GC-MS) Gas Chromatography is used for analyzing complex mixtures of gasses or volatilisable constituents. It is usually coupled with the Mass Spectrometer, which analyses the resulting ions, depending on their mass to charge ratio. GC-MS thus provides elemental, molecular and isotopic abundances and compositions. An example of such a system is the Viking 1 Landers Gas Chromatograph/Mass Spectrometer with a mass of 19 kg and power requirements of 60 W [223].

Pyrolysis Pyrolysis is a technique for the analysis of non-volatile compounds of low thermal stability, in particular organic compounds of high molecular weight. During the process, non-volatiles are converted into gaseous species. This method can distinguish for example between sulphides and sulphates and because it is quantitative, it gives absolute abundance of elements of biological significance like for example C, H and N and in addition gives bulk isotopic compositions. Also nature of the source of volatiles for example C from CO_2 can be inferred.

Pyrolisis-Gas Chromatography-Mass Spectrometry (PYR-GC-MS). Pyrolysis technique can be used together with Gas Chromatography-Mass Spectrometer to analyze organics and inorganics. Depending on the Mass Spectrometer type, PYR-GC-MS can weigh 3.5 kg if the MS uses ion trap technique or 4.5 kg if the MS uses Time of Flight technique. Power requirement for the Time of Flight type PYR-GC-MS varies between 8-16W.

Laser Ablation-Inductive Coupled Plasma-Mass Spectrometer (LA-ICP-MS) LA-ICP-MS is used for the determination of major and trace elements of both organic and inorganic phases. Analysis is very fast. It can also do isotopic abundance measurements.

High Performance Liquid Chromatography (HPLC) This instrument can be used for analyzing complex low volatility compounds of high molecular weight. However, it uses a liquid solvent, which makes it difficult to qualify for space activity. However, if developed for space application it can be of tremendous value in the search for life.

UV Fluorescence UV Fluorescence is used for analysis of hydrogen peroxide H_2O_2 and have a very high sensitivity of up to few parts per trillion. However, due to the liquid transfers and enzyme storage it is not suited for space application yet and needs to be developed further for use in space.

Table 3.3 summarizes instruments that can be used to analyze different types of organics and inorganic molecules.

3.4.3.4 Analysis Based On The Properties Of Life

Introduction Visual inspection is the first method of analyzing a newly acquired sample. Then, methods of detecting life might vary as scientists disagree about non-visual observation methods.

Homochirality Homochirality can be a crucial signature of life both extinct and extant. Biological systems use only one mirror image form of molecules, for example proteins are made up of only Left Handed Amino acids. On the other hand non-living system are normally racemic i.e. contain equal numbers of Left Handed and Right Handed molecules. Both direct measurement of the optical activity and the measurement of the ratio

		Instruments
Organics	Low molecular weight (RH RCO_2H, RCO_3H, ...)	GC-MS, MS
	Higher molecular weight hydrocarbons, including PAH, amino acids and purines	GC-MS, MS
		PYR-GC-MS/PYR-MS
	Macromolecular weight (kerogens and oligopeptides)	PYR-GC-MS/PYR-MS
Inorganics	Volatiles can be released by light heating (if adsorbed in the soil) or by pyrolysis (if chemically bound in minerals)	PYR-GC-MS

Table 3.3: Analyzing Instruments

Characteristics of Life	What to look for?	How to look for it?
Boundary	Cytoplasmic Membranes	1-anilinonapthalene 8-sulfonate (ANS)
Metabolism	Enzymes - Electron Transport System	5-and 6-sulfofluorescein diacetate (SFDA, CFDA-AM)
Reproduction	Nucleic Acids	ethidium bromide (EB)

Table 3.4: Fluorescent dyes

of Right to Left handed molecules would be very powerful indicator of life that would be difficult to mimic abiotically.

Homochirality detector can be an optical instrument for detecting optical activity such as SETH Cigar [184],[185].

In order to obtain the ratio of right to left handed molecules, a separation technique using Chiral GC columns such as COSAC GC-MS needs to be used. Thus GC (chiral columns) together with optical rotation measurement and Mass Spectrometer should provide the separation of enantiomers, their quantitative analysis and Right to Left isomers ratio [220].

Fluorescent Microscopic System Fluorescent Microscopic System (FMS) can be used to detect living and extinct organisms and organic compounds. The method is based on the special fluorescent dyes, which have affinity for enzymes, nuclei acids and cell membranes.

Table 3.4 is based on the paper published by [213] and it summarizes three characteristics of life and selected Fluorescent dyes that can be used for analysis and detection of each.

DNA probes DNA probe arrays are used to decipher genetic information. It consists of glass wafers on which high density arrays of DNA probes (short segments of DNA) are placed. Each of these wafers holds approximately 60 million DNA probes that can be used to recognize longer sample DNA sequences. The recognition of sample DNA by the set of DNA probes on the glass wafer takes place through the mechanism of DNA hybridization. When a DNA sample hybridizes with an array of DNA probes, the sample will bind to those probes that are complementary to target DNA sequence. By evaluating to which probes the sample DNA hybridizes more strongly, one can determine whether a known sequence of DNA is present or not in the sample DNA. [215].

Polymerase Chain Reaction (PCR) The central scientific fact that makes PCR so useful is that the genetic material of each living organism-plant or animal, bacterium or virus-possesses sequences of its nucleotide building blocks (usually DNA, sometimes RNA) that are uniquely and specifically present only in its own species. Indeed, complex organisms such as human beings possess DNA sequences that are uniquely and specifically present only in particular individuals. These unique variations make it possible to trace genetic material back to its origin, identifying with precision at least what species of organism it came from. Such an investigation requires, however, that enough of the DNA under study is available for analysis-which is where PCR comes in. PCR is a common method of creating copies of specific fragments of DNA or RNA and rapidly amplifies a single DNA or RNA molecule into many billions of molecules.

Metabolism Viking experiments were inconclusive, although idea of feeding certain gas and looking at any changes was very good. The ideas behind a metabolic processes and how to detect them comes down to knowing what to feed the sample with. In turn, an experiment can be conducted by which a series of chambers can be assembled to test the sample. However, unlike the Viking experiment, each reaction chamber should be supplied with only one kind of the gas or a substance. By identifying which chambers recorded any changes in temperature or pressure for example, one can identify a set of gasses or substances that affected the sample. By knowing which of the substances affected the sample one can try and identify the sample with the Earth analogs.

Summary of Instruments Tables 3.5 and 3.6 summarize most of the instruments that can be used in the missions that aim to find life. [157].

3.4.4 Sample Return

Sample return missions are described in the Future Mission chapter. The major benefit from returning samples back to Earth is that they can be analyzed by the entire suite of scientific instruments. However, sample return missions are very costly. Thus all the effort needs to be made to bring back to Earth only those samples that are most interesting from the scientific point of view. In general each sample that is acquired should be divided into two fractions. First fraction should be used for different chemical and biological analysis, while the second fraction should be stored. If the analyses of the first fraction gives a positive result pertaining to the finding of life, then the second fraction could be sent back to Earth for further analysis.

	Volatiles					Geology				Oxidant
	Absorbed / Chemically Bound (H_2O, CO_2,O_2)	Liquid Water	Ground Ice	Saturated / Unsaturated Frozen Ground	Gas Hydrates (CO_2, H_2S, CH_4)	Lithology	Mineralogy (Elemental, Chemical)	Physical Properties (Density, Particle Size)	Stratification	Characterization
Neutron/γ-Ray Detectors (Passive)						x	x			
Pulsed Neutron Activation GRS						x	x	x	x	
Set of Distributed Thermistors										
Radiation Detector/Dosimeter										
Seismometer										
Subsurface Sounder/Ground Penetrating Radar		x	x	x						
APX/XRF						x	x			
IR/Raman Spectrometer	x	x	x		x	x	x			
DSC/EGA/TDL	x	x	x		x					
XRD						x	x			
Moessbauer							x			
GC/MS	x	x			x					
Organic Detector										
Oxidant Detector										x
Microscope						x	x	x		

Table 3.5: Instruments used to search for life

Type of Analysis	Instrument	Mass	Power	Notes
		kg	Watts	
Elemental	APX, Alpha-Proton-X-ray	0.5	0.4	Mars Pathfinder, ATHENA Payload,
	Gamma Ray Spectrometer (passive)	25		Mars Observer
		2	1	Lunar Prospector
		27	31	NEAR (Near Earth Asteroid Rendevous), XRS/GRS
	Neutron Activated GRS (active source)	5	5	
	Laser Induced Breakdown Spectrometer	1.5	3	
	X-Ray Fluorescence	4	5	Viking (1977)
		27	31	NEAR (Near Earth Asteroid Rendevous)
Mineralogy	UV-VIS Spectrometer	0.3	2	Clementine Mission
	FT-IR Spectrometer	2.5	5	ATHENA Payload
	Imaging IR Spectrometer	2	10	
	Raman Spectrometer	2	10	
	X-Ray Diffraction Spectrometer	4	3	
	Differential Scanning Calorimeter Evolved Gas Analyzer	4	35	Mars Polar Lander, 98
	Moessbauer Spectrometer	0.5	1.6	ATHENA Payload
	(Iron Phase Mineralogy)			
Organic & Volatiles	Mass Spectrometer	17	20	Galileo-Huygens Probe
	Organic Detector	2.5	24	
Oxidants	Oxidant Detector	1.5	10	
Particle/Crystal Size	SEMPA (Scanning Electron Microscope and Particle Analyzer)	12	22	
Density/Porosity/Permeability	γ-ray spectrometer	1.5		
Thermal Conductivity/Heat Capacity	Set of Thermistors	0.5		
Radiation	Radioactivity Dosimeter	0.5	6.5	
Atmosphere	Dust Detector	1.5	6	
	Sensors for Pressure/Temp./Wind speed/ Wind direction/Water vapor /CO_2	3	5	
	Isotopic Ratios (TDL, ^{1}3C/^{1}2C, ^{1}8O/^{1}6O, D/H)			
Imaging Microscopy	Microscope	1.4	10	
		0.2	3	ATHENA Payload

Table 3.6: Instruments that can form part of the payload

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Chapter 4

Future Missions

4.1 Introduction

Astrobiology encompasses not only the search for life itself, extant or extinct, but also the determination of the conditions necessary for life, the specification of its required building blocks, the way life can spread over different environments, and even the future and destiny of existing life. The purpose of this section is to establish mission concepts that can meet the different faces of Astrobiology.

The celestial bodies of interest for astrobiology missions within this section include Mars, Europa, Ganymede, Titan, comets, asteroids, as well as interplanetary and interstellar dust. All of these objects are unique and interesting astrobiology targets, each with extensive rationales for astrobiology exploration.

Mars is interesting because it shows evidence of past volumes of surface water and is in the habitable zone of the solar system. The Galilean moons such as Europa are thought to have liquid water oceans and an oxygen atmosphere whilst Ganymede is assumed to have oceans, a magnetic field, auroras, and a complex geological history. Titan is a place to study how the pre-biotic conditions for life might have evolved. Comets and asteroids are studied because they may harbor chemicals and materials that comprise the building blocks of life, and even life.

In this section, our goal is to determine the science objectives and potential targets for each mission and then to determine the science packages to use for different scenarios (possibly requiring the development of new enabling technology). Possible mission scenarios will also be discussed.

4.2 Astrobiology Mission Design

4.2.1 Scope

This section deals with the mission design process. For in-situ science missions, design considerations are given regarding sample acquisition.

To define a limited suite of potential missions for finding extraterrestrial life, a mission design option tree is developed. It constitutes a limited design space which suits any future astrobiology mission producing science data within the 20 year timeframe of this sourcebook. Further confinement of this design space requires an actual astrobiology mission statement, i.e. “what science to which body?”, accompanied with mission constraints.

As this section outlines the design space for astrobiology missions, subsequent sections will describe missions to selected targets in the solar system.

4.2.2 Mission Design Process

Mission design brings together payload, spacecraft, launcher, orbital mechanics and ground infrastructure to create a consistent, end-to-end (pre-launch to payload disposal) space mission[323].

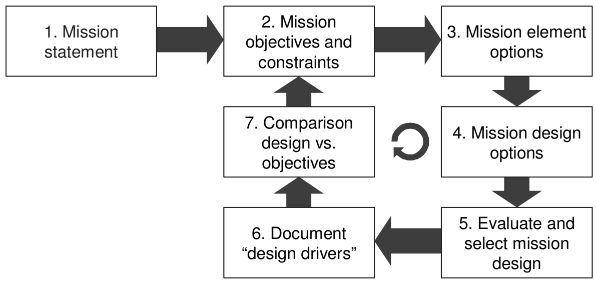

Figure 4.1: Scheme of Mission Design Process

Mission design is an iterative process, as indicated in figure 4.1. A mission design process starts with a mission statement. It states the mission objectives in general terms.

Objectives are directly derived from the mission statement and bounded by constraints such as funds and schedule. Objectives and constraints are translated into technical requirements (e.g. on mass, volume, power consumption) by means of a requirements discovery process. The different mission elements are identified by functional analysis. For a sample return mission to Mars a simplified example is shown in figure 4.2.

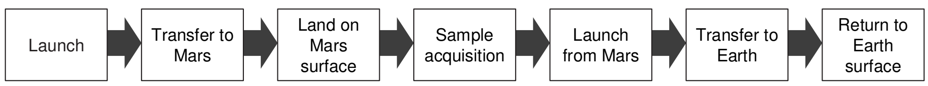

Figure 4.2: Scheme of Mars sample return mission

For each mission element, options are identified. This set of options is translated into a mission design option tree (MDOT), which has the following properties: it includes seemingly odd or unusual options, it stimulates “thinking-out-of-the-box” and it is a pure *or* tree (logical OR). Each branch represents a decision: e.g. manned or unmanned, controlled or uncontrolled descent

Feasible mission designs need to be evaluated in terms of e.g. mass, cost, risk, power and data volume. A trade-off is made between different apparently feasible designs. Critical elements of the finally selected mission design are marked as “design drivers”. During finalization of the mission design, compliance with mission requirements is verified for all mission elements.

In subsequent sections, each step of the mission design process will be tailored to astrobiology missions.

4.2.3 Constraints

A design space that accommodates any future astrobiology mission within a 20 year timeframe is by definition infinite (figure 4.2.3). First, the known constraints are dealt with. Then the defined constraints will be addressed.

4.2.3.1 Known Constraints

The scope of this astrobiology sourcebook limits its outlook to missions with the potential to be performed within 20 years limited to looking for water/carbon life and its supporting environments.

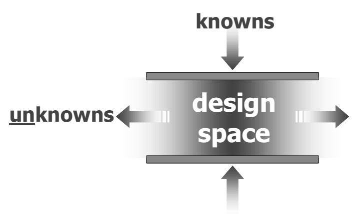

Figure 4.3: Mission design space

However, additional constraints can be derived from a common science mission imperative:

Science shall determine the mission, not vice versa.

4.2.3.2 Defined Constraints

As this is a sourcebook for future astrobiology missions, its scope is not constrained to a particular celestial body or mission type. Essentials for defining an astrobiology mission are targets: Mars, Moon, Europa, Titan, Phobos, Ganymede, Calipso,comets; hotspot: exact location of interest, budget, schedule, sample return, robotic or crewed.

4.2.4 Mission Element Options

4.2.4.1 General

Basically, any astrobiology space mission fits in one of the four categories:

- in-situ, sample-return
- in-situ, non sample-return
- remote-sensing fly-by
- remote-sensing orbiter

For each of these four mission types, a simple break-up into mission elements is presented in table 4.1. It shows that a sample return mission requires many more functions than, for example, a fly-by mission, and will, as consequence, be much more expensive. Landing is not an absolute necessity for sample return:

- A gas sample can be collected without landing;
- Ballistic impact of a celestial body causes scattered matter that can be collected in-flight.

Figure 4.2 shows a more extensive list of mission elements that are typical for an astrobiology mission.

Only the following mission elements that are of particular interest to astrobiology missions will be discussed in detail: sample acquisition and in-situ science experiments.

4.2.4.2 Sample Acquisition

In-situ science experiments are of particular interest for astrobiology missions, especially for discovery of extant or extinct microbial life. In-situ science experimenting requires a strategy to acquire a sample. Development of such a strategy requires prerequisite knowledge of the following items:

- The type of sample to acquire: gas, fluid, dust, rock, ice or other.
- The location of the sample:
  - sub-surface: in the soil, rock, ice, fluid underneath the ice or other.
  - surface: on a solid / liquid / gaseous surface.
  - above the surface (or super-surface): in dust close to the ground, in atmosphere, in clouds, other.
- The type of science experiments to which the sample is subjected. Note that in-situ science experiments will always have to deal with contamination issues (cf. sec. 5.5).
- The need for sample selection vs. random sample acquisition.

mission element	in-situ		remote sensing	
	SR	no SR	fly-by	orbiter
launch from Earth	X	X	X	X
transfer to celestial body	X	X	X	X
insertion to orbit around celestial body	X	X		X
remote sensing data acquisition and transmission			X	X
pinpointing landing spot	X*	X*		
descent from orbit to celestial body	X*	X*		
deploy lander	X*	X*		
sample acquisition	X	X		
sample investigation, data acquisition and transmission		X		
launch from celestial body	X			
rendezvous with orbiting S/C	X**			
transfer to Earth orbit	X			
return to Earth surface	X***			

*Landing is not required for sample return
**or direct insertion into transfer orbit
***or sample delivery at earth orbiting station (ISS)

Table 4.1: Astrobiology mission elements - simple breakdown

- The need or not for sample return.

The next question is: how to bring the science instruments and the sample together. In general, a vehicle is required to accomplish this or a special device as an arm and a scoop. Some exceptions are:

- Dust attracted by a charged plate.
- Collecting scattered material as a result of ballistic surface impact or explosion in or at the surface.

Figure 4.4 shows typical vehicle functions related to the location of the sample. In general, a vehicle has to perform a variety of functions to bring the sample and the science instruments together.

There are two main ways of bringing the sample and the science instruments together:

1. Get science instruments to the sample
   This option requires a vehicle that carries the science instruments to the sample location. Depending on the type of sample to acquire, the vehicle digs, drives, floats, melts etc.
2. Get sample to the science instruments
   This option requires some means to transport the sample to the science instruments. Examples are:
   (a) Robotic arm grabs sample and brings it to the science instruments;
   (b) Liquid sample underneath an ice crust can be collected by a melting or drilling probe and returned to a science station on the surface of the ice;
   (c) Small rover collects sample and returns it to a larger immobile surface science station;
   (d) Small lander collects sample and returns to orbiting science station.

Remarks:

- Generally, acquisition of a sample requires a mix of both options.
- Contamination issues have to be dealt with while collecting a sample.
- Preprocessing the sample could be needed before in-situ analysis.

The functions of the vehicle depend on the type of sample that is to be acquired. Table 4.3 together with figure 4.4 (*sample location*) limits the number of possible vehicle functions.

	description	options	
inputs	Celestial body of interest	Mars … Europa … Moon … Ganimede …Calisto … comet/meteorites	… other
	Mission rating	robotic … crewed	… other
	Science mode	In-situ … remote sensing	… other
	Sample return (SR)	no SR … SR to Earth orbit(ISS) … SR to Earth	… other
Mission elements	launch from Earth	Shuttle … Ariane-V … Proton … Delta II	… other
	Power infrastructure	solar … nuclear(reactor) … nuclear(RTG,DIPS) … fuel cell …	… other
	Communications infrastructure	direct to Earth … comsat … combination direct/comsat	… other
	Earth staging location	none(direct injection) … LEO … LEO(ISS) …HEO	… other
	Staging location near celestial body	no staging … low orbit … L1 … L2 … L4/L5 …	… other
	transfer to celestial body: propulsion type	Chemical(storable,cryogenic) … electric(ion)	… other
	transfer to celestial body: trajectory type	minimum energy … free return … fast transit … gravity assists	… other
	insertion into orbit around celestial body	no insertion(direct entry,fly-by) … equatorial … polar … landing site inclination	… other
	remote sensing	No remote sensing … imaging … spectroscopy … magnetic field measurement … sounding radar … radiometry	… other
	pinpointing landing spot	before launch … during mission	… other
	landing on celestial body: mode of descent	no landing … controlled … uncontrolled	… other
	landing on celestial body: braking	no braking … thrusters … aerobracking(heatshield,parachute) … airbags … crumple zone	… other
	Surface infrastructure	no infrastructure … predeployed redundant systems … predeployed selected systems	… other
	deploy lander	no deployment … autonomous … remote control	… other
	Surface stay duration	90 days … <month … <week …< day … <1 hour	
	sample acquisition: acquisition strategy	no acquisition … local(grab) … mobile(select sample)	… other
	sample acquisition: range	No range (local grab) … > 10m … > 100 m … > 1 km	
	sample acquisition: type	gas … liquid … dust … ice … rock	… other
	sample acquisition: location	sub-surface … surface … super-surface(atmosphere)	… other
	sample acquisition: method of acquisition	pick … drill … dig … melt … dive … sink … drive … walk … jump … hover … fall … fly … float … sail	… other
	science to conduct on sample	no science … chemical derivation … mass spectrometry …spectroscopy … tomography … atomic force microscopy … chromatography(liquid, gas) … Acoustic sounding(echoscopy)	… other
	launch from celestial body: method of launch	no ascent … thruster … release of energy in preloaded springs	… other
	launch from celestial body: ascent propellant	storable … cryogenic … manufactured on-site … combination	… other
	rendezvous with orbiting spacecraft	direct entry(no rendezvous) … rendezvous	… other
	transfer to Earth orbit: propulsion type	chemical(storable,cryogenic) … electric(ion)	… other
	transfer to Earth orbit: trajectory type	minimum energy … free return … fast transit … gravity assists	… other
	return to Earth surface	No return … Direct entry … capture/phasing/entry … capture/ISS rendezvous	… other

Table 4.2: Astrobiology mission elements

4.2.4.3 In-Situ Science Experiments

Important considerations for choosing science instruments are mass, volume, power consumption, required structural infrastructure and data infrastructure to support the science instrument. They are detailed in chapter 3.

4.2.5 Mission design options

For astrobiology missions, the number of mission design options is large because of the defined constraints (see section 4.2.3.2). However, some limitations to the design space can be easily made.

Consider the general mission design option tree presented in figure 4.5. It defines the design space for any astrobiology mission that produces science within 20 years. Some design options are not expanded:

- Bold arrow indicates a principal consequence of a mission constraint
- Connectors ending in a dot instead of an arrowhead indicate that this option is not expanded further (only one example is shown).

Figure 4.5 shows that a celestial target for an astrobiology mission can be within or outside our solar system. Within the solar system, there are essentially two possible mission types: missions that conduct in-situ experiments or remote sensing science experiments.

For missions beyond our solar system, in-situ science experiments are not feasible, given the requirement to produce science data within 20 years. Therefore, the bold arrow creates a shortcut from *extra solar system* to *remote sensing*.

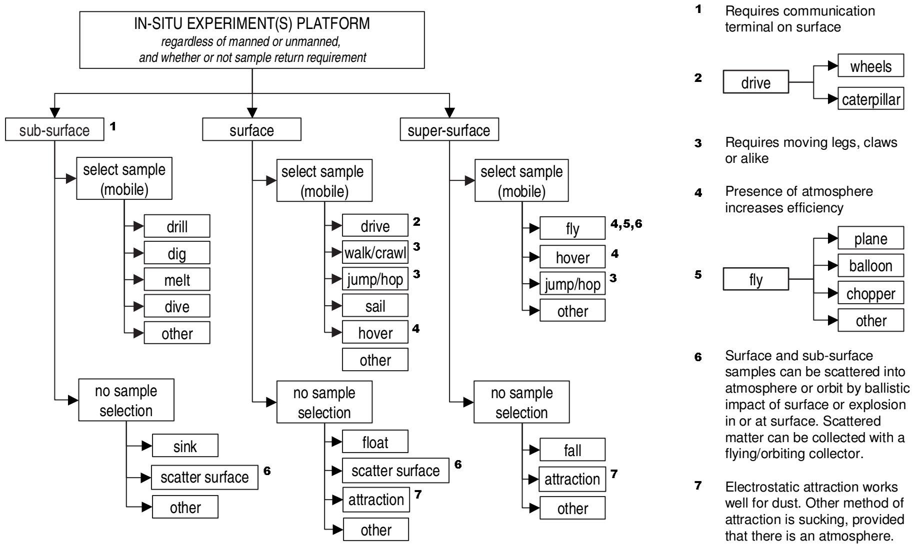

Figure 4.4: Vehicle functional options for sample location and destination

Remote sensing can be done from Earth (e.g. Very Large Telescope Interferometer,*VLTI*, in Chile), from Earth orbit (Hubble Space Telescope), or by sending a spacecraft (Pioneer, Explorer, Mariner, Voyager, Surveyor). The spacecraft can produce remote sensing data during a fly-by, or from an orbit around the celestial body of interest.

Because of the limited timeframe, in-situ investigations are considered to be of more interest than remote sensing. In-situ missions can be crewed or robotic. Crewed missions will always be sample return missions, provided that it is the intention to return the crew to Earth. This is indicated by the bold shortcut arrow from *crewed* to *sample return*(sample return can be to Earth orbit or to Earth surface). For a robotic mission there is a principal choice whether or not to return a sample.

Regardless of whether or not a sample is returned, one of the main options is to design a probe with the ability to select a sample: when landed on Mars, one can "blindfolded" pick a sample at the landing spot, or go out (autonomously or commanded) and look for a really interesting sample. For a crewed mission it is likely that the astronauts have means at their disposal to screen and select the samples they have collected.

We have chosen to expand the mission design option that it collects a gas sample without selection, using a probe that sits on the Martian surface and accommodates a mass spectrometer and a gas chromatograph to determine its chemical composition.

Considerations regarding mission design are:

- A mission can be redundant: separate launch of identical spacecrafts (Voyager 1 & 2 spacecraft);
- A mission can comprise more spacecrafts, each with specialized tasks. For example, an orbiter for communications, a landed stationary science platform that communicates with the orbiter, and a rover to select samples;

4.2.6 Mission Design Options Trade-off

A trade-off is made against requirements (or constraints). Since some constrains are unknown (see Section 4.2.3.2) a final mission design cannot be selected.

However, astrobiology missions with the potential to produce scientific data within 20 years will be identified for Mars, Europa, Ganymede, Titan, and other bodies, such as asteroids and comets. The identified missions are found at the end of the sections that deal with these bodies.

	Function	Sample Type				
		Gas	Liquid	Dust	Ice	Rock
Sample Selection	Drill	x	x	x	x	x
	Dig			x	x	x
	Melt		x		x	
	Dive		x			
	Drive	x		x	x	x
	Walk	x		x	x	x
	Jump	x		x	x	x
	Hover	x	x	x		
	Fly	x		x		
	Sail	x	x	x		
No Sample Selection	Sit on Surface	x		x	x	x
	Sink		x			
	Scatter Surface	x	x	x	x	x
	Float	x	x	x		
	Attract	x		x		
	Fall	x		x		

Table 4.3: Sample type related to vehicle functions

4.2.7 Mission design drivers

Funding will be the major design driver for future astrobiology missions. Other design driving issues are scientific return, technological development, finding life itself, public interest.

4.3 Mars

4.3.1 Science Objectives

Searching for extinct and extant life on Mars is a major part of missions, planned and underway to Mars. In chapter 3 geochemical and biochemical signs and environmental conditions for life have been identified. This defines our science requirements. Any search strategy should be based on these criteria to select a site of interest. The geological and geophysical histories and aspects of Mars need to be understood to asses the possibility of life arising. What happened to the water and to the carbon is probably the most important questions any astrobiology mission can address.

4.3.2 Hot Targets

In this section we have focused on a small group of possible sites and a rationale for choosing these sites. The science achieved, the types of missions, the number of missions, and the instruments flown will be constrained by technology, policy, funding and the public support for future Mars exploration.

The surface of Mars now is extremely dry, oxidizing, bathed in UV-radiation, and cold for much of the time. This implies that life is either extinct, or it hides in protected environments like the endoliths on Earth. A search for extinct life should focus on areas where organisms are most likely to be buried, i.e. standing water with regular inflow from other areas or dried-out riverbeds. Some of the dried-out riverbeds and lakes should have formed when life was still present.

The Gusev Crater, 14.6 °S, 184.6 °W, 160 km diameter, is very promising from a scientific point of view.

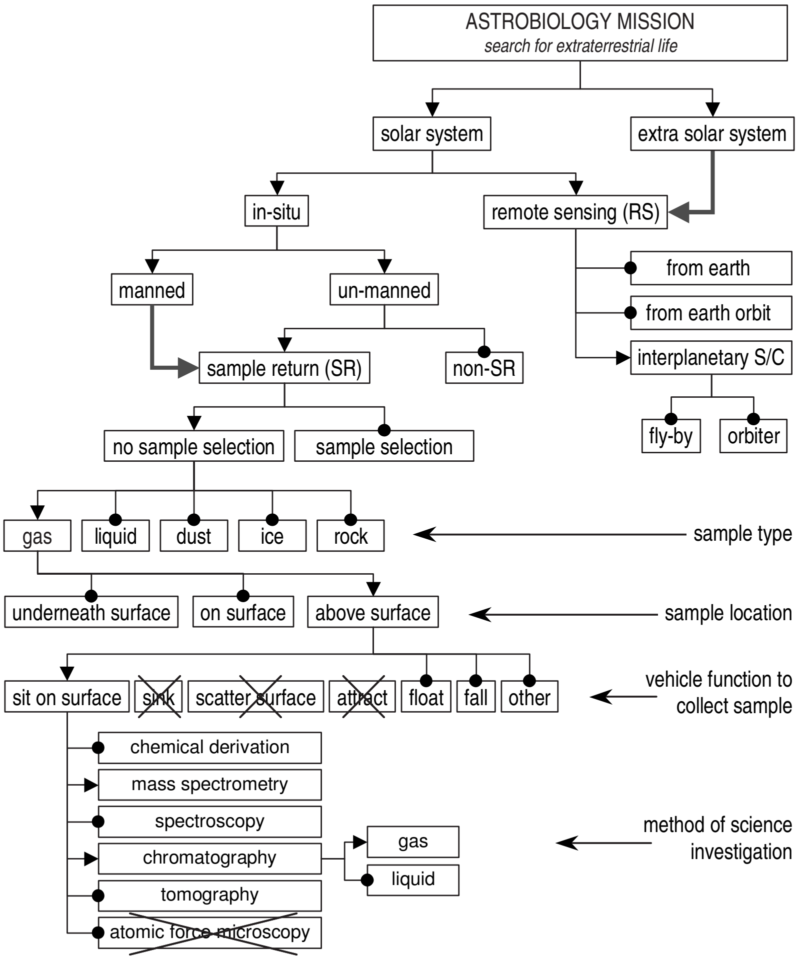

Figure 4.5: Astrobiology Mission Design Option Tree

It has been suggested as a target area by several researchers, and features as number 112 and 138 in NASA's Center for Mars Exploration (CMEX) catalogue. It will be a source of information on the hydrology over geological periods of time, climate changes and its biotic and fossilization potential.

A flood channel, Ma'adim Vallis, with its adjoining channels, is passing through the crater into the Elysium Basin region. If we only consider the elevation of the rims, the old lake might have been 1 km deep. Data from the Mars Orbiter Camera (MOC) and the Mars Orbiter Laser Altimeter (MOLA) show that the crater has periodically been filled with liquid to a depth of 300-400 m. The latest lake might have been 30 m deep. This is also supported by what appears to be shorelines, terraces and evaporates according to N. G. Barlow et al, [258]. Sediments and evaporates in such environments are likely to preserve fossils, kerogens, permineralised organic structures, minerally replaced organisms and bacterial moulds, [322].

The preflight estimated landing area of Mars Pathfinder was roughly an ellipse of 100 km x 200 km. We need higher precision to ensure a landing within the crater. The depth of the crater, 1600 m [258], also complicates the landing. Ideally, samples should be taken from several locations. This implies either a long-range rover or enough fuel in the lander to take off and land in a different location within the crater.

Valles Marineris, the largest canyon in the solar system, is really interesting, not only for an astrobiology mission, but also for hydrology and geology. There might be sediments laid down in ice-covered lakes in the canyons of Candor, Ophis and Hebes Chasmas[239]. A large area is drained by the only channel leading from the canyon to the northern plains and where Aureum Chaos, Gangis and Eos Chasmas (5-12° S, 31-41° W) flow together, must be considered for a future astrobiology mission. Given the evidence of large flows of liquid through the area, a lake covering 5×10^4 square kilometers with depth of several hundred meters must have existed. This lake had to be an efficient trap for sediments and debris originating further west in the canyon, since standing water must have existed for a long time in this area. In these surroundings, it should be possible to obtain samples of some of the oldest rocks on Mars [239], since landslides from the canyon walls have brought samples from many different geological layers.

Figure 4.6: The Gusev crater with the flood channel Ma'adim Vallis to the south – Malin; Space Science Systems/NASA

If we assume that life existed on the surface of Mars, the polar regions demand attention. We can imagine that Martian spores have been carried by the wind from more habitable areas and frozen in the polar ice as on Earth. It has also been suggested that below the icecaps on Mars, there might be areas with pockets of liquid similar to those found in Antarctica. Active organisms (extant life) may be found in those environments. Life could also have retreated to protective environments inside rocks (endoliths). These life forms could be protected from the harsh environment of the surface and may be the most likely extant life form. The assumption that life was prevalent on the surface might not be valid. Mars lost its atmosphere about 3.5 billion years ago, and this may have been too early to allow for the development of life[322].

Subsurface environments might be the best place to look for signs of either extinct or extant life, because of the UV-radiation on the surface. Areas with periodical subsurface liquid water might be the last refuge for life on Mars. Other signs of extinct life than fossils may be preserved much better there, than on the surface. Therefore, we should look at sites where water has recently emerged on the surface. Some promising sites are the gullies in Nirgal Vallis (28.4° S, 41.7° W) and meandering, banked channels in a crater east of Gorgonum Chaos at 37.4° S, 168.2° W. These two sites appear to be particularly young, because (1) the gully aprons cover surrounding landforms including windblown (eolian) dunes, (2) the channels cut through the surrounding terrain, and (3) extremely few craters have been found covering these structures. It has been suggested that these sites represent runoff of liquid water, because water is the most chemically likely substance[288]. The clustering of the gullies and their confinement to distinct geological layers imply aquifers similar to those on Earth. Nirgal Vallis appears to have formed from groundwater sapping, which also supports the assumption that the gullies are formed from water outflows.

Most gullies are found in clusters between 30° and 70° on both hemispheres, although they are more common on the southern hemisphere. The southern hemisphere has more craters and troughs, and hence provides porous areas where permafrost might accumulate. The gullies are usually also found on pole-facing slopes, which spend most of the Martian year in shadow. Malin and Edgett suggest that this might be because the low soil temperature in the shade causes a buildup of ice at the exit of the water conduit. When the pressure builds up enough to breach such a plug, high volume outflow would be produced. William K. Hartmann, [259], suggests that minor random geothermal events might melt the underside of the permafrost and thus produce aquifers. This scenario is also consistent with the lack of obvious geothermal or volcanic features.

Possible liquid water and thermal energy sources are areas where life might be present even today. The assumed sporadic outbursts might bring biological material to the surface and hence the problems associated with (deep) drilling can be avoided. Since the gullies of Nirgal Vallis and Gorgonum Chaos seem to be reasonably young, we might look for organic molecules usually considered unstable on the Martian surface in addition to stable organic molecules. The valley is only 6 km wide at this point [315]. This is much smaller than the landing ellipses for current missions to Mars. Hence, either a long-range rover that is capable of negotiating extremely inclined slopes or pinpoint-landing techniques must be developed.

What is the best place to search for signs of life? To look for fossils, the landing site should be in the proximity of dried-out lakes. With a long-range rover, the confluence of Aureum Chaos, Gangis and Eos Chasmas might be the best place. There are several possible targets in this area. If the desire is to find biomarkers and/or organic materials, sites where such materials have only been on the surface for a short time are needed. Nirgal

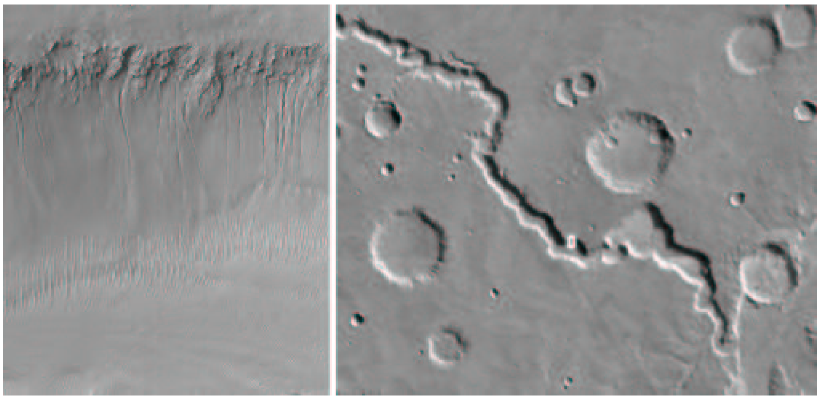

Figure 4.7: The gullies in Nirgal Vallis - Mars Global Surveyor Image MOC2-240 to the left - and a Viking overview image to the right[287]

Vallis appears to be such a place, and the gullies might recently have brought material to the floor of the valley.

4.3.3 Science packages

Theses packages are dedicated to find life and are defined thanks to the instruments described in the Alive chapter with respect to Mars environment and potential condition to find life on Mars.

- **fossil+**: an atomic force microscope, a carbon dating package and a camera.
- **water way I**: a Raman and Mössbauer spectroscopy, a carbon dating package, a mass spectrometer, an optical microscope and a camera
- **water way II**: a Pyrolitic Gas Chromatograph, a Raman and Mössbauer spectroscopy, a carbon dating package, a Mass Spectrometer, an Atomic force microscope and a camera.
- **water way III**: a ground looking radar tuned to find ice and liquid water.
- **Discovery**: a gas chromatograph & mass spectrometer, a Raman and Mössbauer spectroscopy, an Atomic force microscope, an optical microscope, carbon dating, and a PCR to replicated DNA.

4.3.4 Scenarios

4.3.4.1 Paradigm

The past, present and planned Mars astrobiology missions are described in the chapter “Past, Present and Planned Astrobiology Mission” of this report. Although the planned Mars missions are mainly composed of NASA missions, the paradigm developed in this chapter will try to stay on a global level.

This future Mars program has been completely reorganized on several occasions, which means that it is and is likely to stay fragile and uncertain. Two past examples have to be underlined. After the failure of Mars Climate Orbiter & Mars Polar Lander, a new program has been developed by NASA based on one Orbiter every 4 years and 4 months (one launch opportunity is skipped), and one Lander/Rover every 4 years and 4 months (scheduled between the Orbiter launches). The old Mars Sample Return mission is also an example. Leading goal of NASA Mars astrobiology program, has been postponed, now out of the ten years plan. However this mission is still the ultimate objective. The last example is the French Mars program. Its 2005 mission, which was part of the old Mars Sample Return mission has been postponed to 2007. It is now subject to scientific and cost uncertainties. In the same way, the long term strategy that ESA is now developing in its AURORA program could be modified due to the possible success of 2003 Mars Express/Beagle II mission. To sum-up,the

2005 mission is known, uncertainties are the current state for 2007 missions and some proposals are known for the 2009 opportunity.

The paradigm of Mars astrobiology exploration includes public interest, which seems to be underestimated. Since the Mars Pathfinder mission in 1997, public interest has risen due to worldwide distribution of images and of scientific data. Since that, the number of automated Mars missions has increased. Some long term human exploration plans, have also caught public attention. This interest could one day reach the threshold effect, and catch unawares sooner than one could foresee.

Although the high cost and long term nature of these missions act as barriers, could public interest serve to initiate such missions? There is no right answer, just assumptions. But we can also believe than one day, the “Pathfinder generation” will have an influence on a politic level with a big support from the public interest. What about limited cost funding? Today, the international program for ISS, even with its cost overruns, is an example that attention and funding can be joined to elaborate a big program, which is in fact a new step for humanity.

In the beginning of this new millennium three break through scenarios are discussed below. Two of them are short-term scenarios, the other one is a long-term scenario:

- A discovery of evidence or extinct leads to an international Mars Program fueled by public as well as scientific interest.
- The technical success of low cost Mars Express/Beagle II mission (with some non-redundant system) leads to a Mars race.
- With Chinese Human flights, a moon program on the way and a permanent base foreseen, NASA could try to turn away attention from these new Chinese missions by initiating a new challenging Mars Program, with or without international collaboration.

The roadmaps shown in the next subchapter have been developed keeping these scenarios in mind.

4.3.4.2 Mission Roadmaps

Scenario 1 We made the following assumptions:

1. A long and sustained effort will be required to reveal whether Mars carries, carried, or ever carried life.
2. The missions planned until 2009 [238][289][246] will be carried out as foreseen.
3. Point landing technology will be demonstrated by the Mars Smart Lander (MSL) in 2009[246].
4. In 2010, radiothermal generators(RTG) have an efficiency of 20% - 30% as projected in [297] rather than 6.7% as on Cassini.
5. Rechargeable battery technology will further advance. In the last decade, the communication and computer industry pushed improvements. In this decade, also the car industry will have a high demand for batteries with increased power density and reduced mass[236].
6. Microsystems[318] and in particular micro-chemical systems,[317] [319] continue to evolve. Consequently, size, weight, and power requirements of measurement devices such as gas chromatographs are greatly reduced.
7. Advancements in machine vision, image interpretation/understanding, and artificial intelligence will give a great deal of autonomy to the mission. Currently, there are many research projects undertaken in these fields [228][229][230][231][232][233][234][235]. These efforts are not only driven by the space community or the military, but also by internet commerce.
8. To support machine vision and artificial intelligence algorithms, more computing power is needed. In terms of technology, radiation hardened hardware currently lags about 10-15 years behind the state of the art. However, Sandia Labs is working on the next generation of processors suitable for space by hardening an off-the-shelf Pentium chip[303].

To support a long term mission of 10 years, we imagine a modular and scalable program for Mars exploration as shown in the roadmap in figure 4.8. In this scenario, two rockets will be launched each capable of delivering 250 kg mass to Vallis Nirgal. This location is tempting for its gullies (see section 4.3.2) that might indicate recent outflows of water. The first one carries a base station, while the second one carries 5 rovers of about 35 kg each. The rationale for having 5 rovers is not only to have the ability to cover large areas, and increase reliability by redundancy, but also for undertaking experiments that mutually exclude each other or need to be spatially separated.

Each rover is equipped with a science package of 15 kg. The launch configuration would include 2 science packages “waterway I”, “waterway II”, and “waterway III” each (see section 4.3.3). This not only replaces the science package “fossil”, but also increases reliability by introducing redundancy. The remaining science package slots would be given to other experiments that are not directly related to the search for life.

The rovers are equipped with batteries, a mount for a science pack, a manipulator that is also capable of drilling holes into stones, a telescope camera for spotting sights of interest, and a mount to carry the base. The rovers interact with each other, and the base. Using artificial intelligence, they are able to complete their science objective (search for life) autonomously without human intervention from Earth, either as a group or as individual rovers. Once a place of interest is identified, e.g. a conspicuous discoloration of a stone, they send a message to Earth via a communication satellite, and move in to explore it further. A human operator can then decide to either resume control and send them (high level) commands, or to let them finish their job in the way the mission planning agents of the rover software laid it out. Broadband data connections should be easily possible as the Italian Marconi satellite [242], and possibly an Amsat satellite [243] will be orbiting Mars from 2008 onwards. Thereby the science data return is maximized while at the same time the cost for using communication facilities on Earth such as NASA Deep Space Network (DSN), are lowered.

The base station is powered by two radioisotope thermoelectric generators (RTGs) weighting about 110kg total. Given an efficiency of 20%, the RTGs will deliver power between 1.8 KW at the beginning of life(BOL) and 1.2 KW at the end of life(EOL). This is enough energy to support the rovers for at least 10 years. Science packages can either be carried on a rover or they can be stored in a storage facility on the base. A load mechanism will allow the exchange of the science packages or the rovers’ batteries. The batteries will then be recharged using the electricity generated by the RTGs. The base is prepared to saddle up a drilling package that is sent in 2014. Once a site is fully explored, 4 rovers connect to the base via the transport mechanism, and move on to a new location. The fifth rover acts as a redundant spare.

The rovers as well as the base are constructed from modular building blocks. That might add some mass overhead, but it makes the components serviceable: A later mission might be restocking the supplies and send replacement parts to Mars. Using their manipulators, the rovers can then exchange defect parts.

In 2014, a drill package of about 35 kg and maximum drilling depth of 10 meters will be lifted to Mars. Furthermore, additional science packages will be delivered. The rovers will meet up with the lander and add the new components into the base. The selection of the science packages will largely depend on how the mission will have come across until the launch slot in 2014. If traces of existing life are found, then a science package “discovery” (see section 4.3.3) will be sent on its way to Mars. A second launch will bring an orbiter into Mars orbit. To support the ground activities and identify new target areas, the orbiter will carry a high resolution multi-band imager. This instrument could detect subsurface life announcing its presence by traces of methane[322]. Methane would occur very localized and close to the surface as it is not stable in the Martian atmosphere. Instruments not related to the quest for life would take other payload slots.

If the orbiter does not reveal other interesting target areas, we would send an additional swarm of rovers to Vallis Marineris in 2016. As for the first colonies of rovers, the swarm would carry 2 packages of “waterway I”, “waterway II”, and “waterway III” each, while the remaining slots will be taken by science packages from other disciplines. The search for fossils that could be hidden in the sedimentary layers of Vallis Marineris (see section [322] and section 4.3.2) will be the main objective.

The slot in 2018 will be used to equip both swarms with updated science packages. As in 2014, the selection of the packages will very much depend on the returned science data. In addition, the second swarm will receive a drilling rig that weights about 180-200 kg, and a drill depth of 50 m.

In-situ programs at Mars, as this scenario, fall into planetary protection COSPAR category 4b. We favored in-situ analysis over sample return mission because they are not only cheaper, but also allow employing a lower planetary protection level. Planetary protection is described in chapter 5. Guidelines for planetary protection sorted by category are listed in appendix D.

The estimated costs for the program over a timeframe of almost 20 years are roughly 890 M$ (see appendix C.1. Relying on Russian hardware reduces the launching, and transport costs. Autonomy, and high level control of the rovers decreases the operational cost.

In comparison with today's missions, the described has an increased complexity. We think that this is justifiable because in 10 years time we will have the technology to deal with that. The benefits of having a scalable and reconfigurable mission outweigh the costs for the increased complexity.

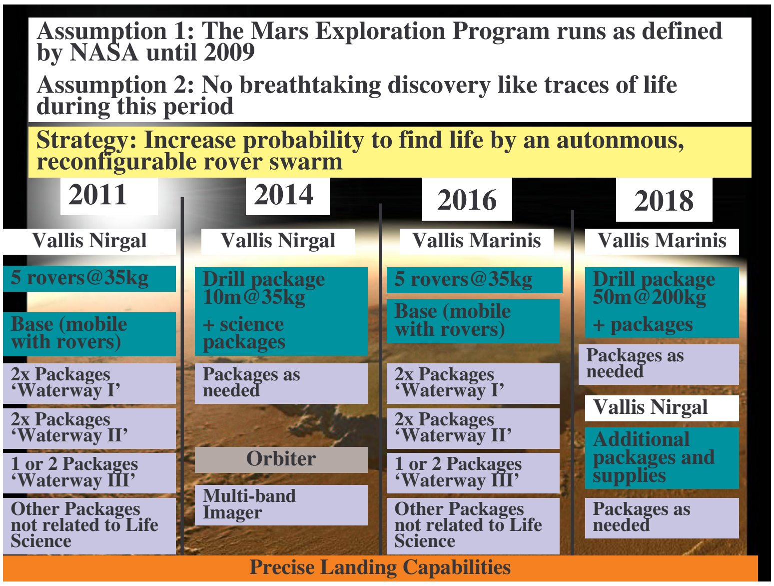

Figure 4.8: Roadmap for sustained search for extinct or extant life

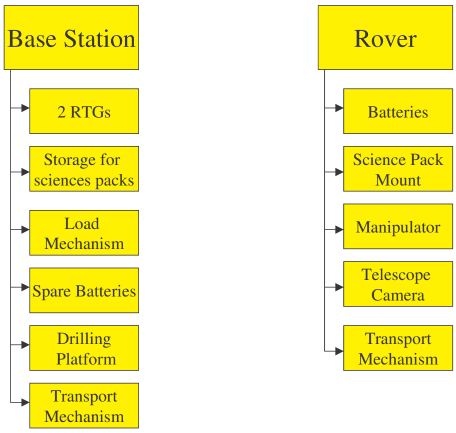

Figure 4.9: Mars Rovers

Scenario 2 We made the following assumptions:

1. Point landing technology will be demonstrated by the Mars Smart Lander (MSL) in 2009[246]. For the 2007 rover, we have a smaller landing ellipse than today (Tens of kilometers) but not point landing

capabilities yet.

2. In 2007 and 2009, radiothermal generators (RTG) have an efficiency of 15% (see also [297]).
3. Breakthroughs in battery technologies are projected within the next 10 years, but not within the next 5 years.
4. Microsystems[318] and in particular micro-chemical systems [317][319] leave the labs, and are available for applications in space missions by 2009. Consequently, size, weight, and power requirements are reduced.
5. Semiautonomy is available by 2007.

We think that the discovery of a fossil by either Mars Exploration Rover or by the Beagle 2 mission would constitute a break through scenario. A greater interest for Mars exploration, and a list of questions to answer, would arise. How old is this fossil? Does life still exist on Mars?

To answer these questions, a new strategy could be integrated, but not before the 2007 launch opportunity. The first idea is to try to return to the same place (Precise landing capabilities needed), with a rover and a package of instruments named “fossil+” (see 4.3.3 for details). If precise landing capability are not available, the rover would need to be able to cross large distances. A rover purely relying on solar cells and batteries has a operating time of about 3 months. Major breakthroughs in the field of battery technology are projected in 5 to 10 years. That might not be good enough, so we suggest to use 1 radiothermal generator (RTG) for the power supply. It would provide power from 450 W(EOL) to 675 W(BOL).

We would redirect the Scout mission in 2007 and bring it into the gullies as Nirgal Vallis or Gorgonum Chaos to try to answer the second question (Does life still exist on Mars?). The radar deep sounder of the Mars Reconnaissance Orbiter in 2005 will determine the depth and distribution of ice and liquid water and help to determine the rover landing and drilling sites for 2009 and 2011.

Furthermore, we would send an orbiter into Mars orbit in 2007 that is equipped with a high-resolution multi-band imager. The imager would look for organic molecules outgassing from the surface that indicate the presence of a living metabolism. To have a contingency in case the orbiter in 2005 fails, the orbiter would also have a high resolution deep sounding radar on board. Advances in radar technology will allow to probe for water even deeper than the Mars Reconnaissance Orbiter.

The rover in 2009 would be equipped with a drill (5 m) and science packages “waterway I” and “waterway III” (see also 4.3.3) containing a Raman and Mössbauer spectroscopy, a carbon dating package, a mass spectrometer, an optical microscope, and a ground looking radar to look for water.

The mission in 2009 would be followed by a rover in 2011 with a deeper drill (15 m) and more precise sciences packages “water way II” and “water way III): a Pyrolitic Gas Chromatograph, a Raman and Mössbauer spectroscopy, a carbon dating package, a mass spectrometer, an atomic force microscope, and a ground looking radar.

Both rovers would be powered by RTGs , and have a weight of 230-250 kg, and a life time of 5 years. We estimated about $1B for this scenario (see C.2). Since there is some autonomy already available we assumed operating costs that are lower than today but higher than in the first scenario. It assumes a higher level of autonomy as it starts 8 years later. We also assumed there would be a small increase of money devoted to Mars exobiology. The design of the instrument packages and drilling will be a challenge. The technology for miniaturizing chemical sensors on semiconductors might not yet mature for the mission in 2007. Weight, and energy requirements, and reliability are the main design challenges for the drills.

This mission falls also into COSPAR category 4b. Procedures need to be implemented to avoid forward contamination (see 5.1 or D).

Scenario 3 If the Mars Exploration Rovers discover organic molecules, another break through scenario could be envisaged. It is based on a great increase of money devoted to Mars exobiology program, perhaps thanks to an international cooperation, and money from private initiatives. The idea is to build two big laboratories with the instruments package named “discovery” to better understand this potential extant life. If metabolism is found, one of the first questions would probably be: “Is this life related to us ? Do we have common roots?”.

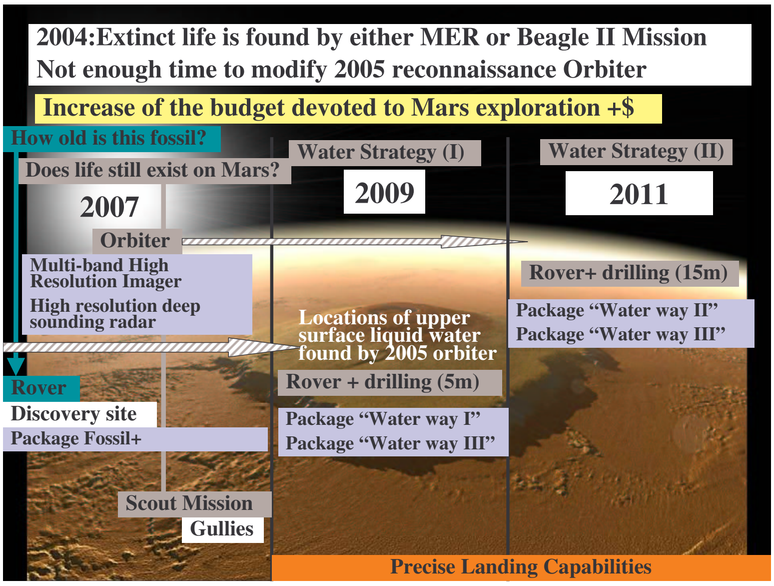

Figure 4.10: Roadmap after finding proof of extinct life

In order not to overtake budget constraints, a remote sensing subsurface liquid water with an orbiter is proposed. The cost for the 2 rovers and the orbiter would sum up to around 570 M$ (see also C.3)

We decided not to specify the following missions deeper. We think that a discovery of life would have far reaching consequences on the existing Mars program, and consequences are difficult to predict today. Probably, there would be a desire among scientists to undertake a sample return mission that helps to understand the life we found. Despite the technical challenges, there would be also issues with the public perception, and planetary protection issues as a sample return mission no longer falls in COSPAR category 4b, but 5 (see 5.1 or D). We think a sample return could take place as early as 2011. More likely, it would take place much later.

4.4 Europa

Is Europa chewy or crunchy? The state of Europa's oceans is going to be vital for the presence, or not, of life. This is one of the most fundamental questions we need future missions to address [309].

4.4.1 Science Objectives

The primary science objectives are two fold:

1. Determining whether liquid water has existed in substantial amounts subsequent to the period of planetary formation and differentiation, whether it exists now, and whether any liquid water that is present is globally or locally distributed; and
2. Understanding the chemical evolution that has occurred within the liquid-water environment and the potential for an origin of life and for its possible continuation on Europa.[293]

These primary objectives were established by the National Academy of Sciences soon after Galileo confirmed the existence of an Oxygen rich atmosphere on Europa during a flyby in 1999. These missions, along with observation of Europa from Earth, have established many facts about the bulk composition of Europa. It is clear that the upper surface comprises a thick layer of water ice. However,there is a great deal of uncertainty about what lies beneath this layer.

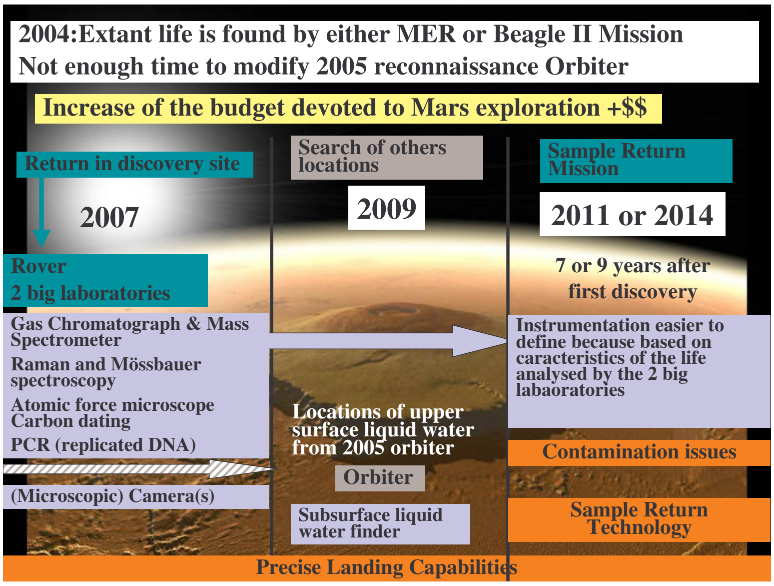

Figure 4.11: Roadmap after finding proof of extant life

The current model of Europa suggests a large liquid water ocean, maybe up to 100 km deep underneath a thick water ice layer. Due to the consequences regarding possible Europan life in this ocean, it is important to determine this fact well and to design missions to effectively explore, characterize and conduct life experiments if this model is true.

Evidence supporting the possibility of a liquid ocean is:

1. As a consequence of its vicinity to Jupiter, Europa experiences large tidal forces due to the large gravity gradient. This force stretches and deforms Europa during its orbit. This phenomenon creates friction within the rock that may heat up and melt the ice enough to maintain a liquid ocean beneath the icy crust. This process is called "tidal heating."

2. Another source of heat might be the decay of radioactive elements.

3. During the 350 km flyby of Galileo, a magnetic field on Europa was measured and found to be consistent with magnetic induction of a rotating conductive (salty) ocean. In this model, Jupiter's large magnetic field induced currents within the conductive ocean. Measurements of the variability of this induced magnetic field are consistent with this.

There are also some secondary scientific objectives. Before we can even begin to look for life on Europa, we must observe the following, through a series of missions that would lead up to an ultimate search for life:

1. "Obtaining measurements of the time variations of Europa's global topography and gravity field over a period of several tens of orbits of Europa around Jupiter, with a precision and accuracy of 2 meters to uniquely distinguish between tidal distortions of several meters (expected for a completely solid ice cover) and several tens of meters (expected if a global layer of liquid is present). The results of these efforts will allow a unique conclusion regarding the present-day existence of a global liquid-water layer;

2. Imaging Europa's surface, with resolution of at least 300 m/pixel for global coverage and with higher resolution (< 50 m/pixel) for selected regions, to understand the global geologic history and identify regions where liquid water may be readily accessed;

3. Performing radar sounding of Europa's subsurface structure to a depth of 5 to 10 km, to identify possible regions where liquid water might exist close to the surface. If the ice is less than 5 to 10 km thick, use of

ice-penetrating radar may allow determination of the vertical extent of the surface ice layer (and possibly a direct detection of any underlying liquid water), as well as the local structure of the ice;

4. Mapping the near-infrared reflectance spectrum of Europa's surface materials globally at kilometer-scale resolution, supplemented by 300-m resolution in selected areas, and using the results to identify the bulk composition of the surface materials, their abundances, and their spatial distributions. A spectral resolution of 10 to 15 nm will be required;

5. Measuring the magnetic field to a precision of 0.5 nT under a variety of different background conditions (i.e., at different Jovian longitudes), combined with coordinated measurements of the plasma environment, to determine whether there is an intrinsic magnetic field and what the properties of either the intrinsic or induced field are. Such measurements may provide important information about the structure and dynamical processes operating in Europa's deep interior; and

6. Determining the composition and properties of the atmosphere using both in situ and remote-sensing experiments." [293][1]

Once these observations are made, we can begin to look for life using the experiments described in section 3.4

4.4.2 "Hot" Targets

4.4.2.1 Energy Sources

The two main energy sources on Europa are thought to be solar and geothermal in origin. Solar energy could support life near the top of Europa's icy surface layers only. At the distance of Jupiter (0.78 billion km), the solar constant is a roughly 27 W/m^2 less than that of the Earth, 50.7 W/m^2. The amount of energy therefore derived from the Sun is very small but may be enough to support life near the surface and below, depending on the transmissivity of the ice. There may also exist "thin ice" areas caused by up springs of water due to possible geothermal activity that may also receive enough of this solar energy.

Life may also exist within cracks near the surface fed by nutrients washed down from the surface. This would not require sunlight, as we know of terrestrial bacteria that feed solely in iron or other minerals, but would require the presence of nutrients near Europa's surface layers created by the action of intense radiation. This radiation ionizes water molecules forming molecular oxygen and hydrogen peroxide. Irradiation of carbon-based molecules could also lead to simple organics. These oxidant and organics can be transported downwards through cracks. This can be measured using exploratory lander missions once suitable sites have been identified via remote sensing. [299] [300]

Life in these areas may also go through various phases depending on their environment. For example, the life may be dormant once the water freezes but may spring back to life during times of thaw, perhaps when surface cracks form.

Another abundant source of energy may be geothermal heat. Europa could possibly have enough internal geothermal heat to drive its ecosystem and this heat would be concentrated on the bottom of Europa's ocean. On Earth, certain areas on the ocean bed are found to have hot geothermal vents caused by Earth's volcanic activity. Water flowing through such vents may get enriched in chemical nutrients, thus, constituting a target for the settlement of biological communities.

4.4.2.2 Life "Hot" Targets

Although geothermal vents are energy sources independent of solar energy, on Earth life in or around these vents still relies on oxidants originating from areas dominated by solar energy. Since these areas may be very limited on Europa, life near Europan geothermal vents may be restricted to single celled organisms that do not require much energy. Although we cannot rule out the presence of large complex life in Europa's oceans, we

[1] `http://www.nas.edu/ssb/comp-europaes.htm`

would require a new energy source or physical process not yet understood at present to explain their presence. This is one rationale behind astrobiology missions to Europa.

Depending on the chemistry and physics of the Europan oceans, life may exist that takes advantage of both the solar and geothermal energy. This may include plant like life near the surface, which once dead, may sink to the ocean floor providing important nutrients to the other forms of life near the bottom. In this scenario life may be present at all ocean depths as energy from below and above may interact to provide suitable conditions in many places. Submarine missions would be vital to understand the chemistry of the oceans at various depths.

Some concerns regarding the energy sources on Europa include issues such as the amount of sunlight required for photosynthesis, do cracks occur regularly on Europa, and are the oceans exposed to the surface to a degree consistent with large scale mineral exchange. In addition, can we think of ecosystems that can exist with absolutely no solar energy?

Our own Earth can help us providing clues for addressing these issues as some extreme environments in our own planet show that even life can exist and persist there. Our Earth tells us that life can proliferate in regions of extremes, examples of this include:

- Extreme heat – geothermal vents with temperature in excess of 112°C and hot water geysers.
- Extreme cold – bottom of lake Baikal in ancient ice, and Siberian permafrost, lakes in Antarctica, and deep (>2km) in Antarctic ice. Bacteria found in such places have been shown to be metabolic
- Extreme radiation – life has been found within nuclear reactors.
- Toxicity - Hydrogen sulfide is a naturally occurring compound in many different environments. Biologically it is highly toxic on the same level as cyanide. There are a number of animals that are tolerant of sulfide and can live in sulfide rich environments.

[286]

We should however be cautious in comparing the Earth to Europa as many of the best analogs on Earth for Europa are actually very different in many ways, and trying to determine the effects of these differences will be extremely hard.

4.4.3 Missions & Technology

To address both the primary and secondary science objectives listed it is clear that both remote sensing missions and lander missions will be required. An initial orbiter mission would address the primary science objective regarding Europa's possible ocean. These initial missions would also be able to study Europa's icy surface in detail, both its dynamics and chemical composition.

A combined orbiter/lander/cryo-hydrobot scenario would follow the initial orbiter mission to address any questions that could not be answered by the orbiter alone.

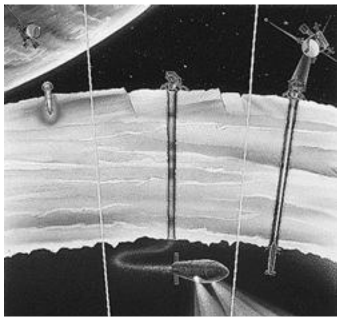

Figure 4.12: Artist Impression

Two approaches can be utilized to determine the existence of liquid water in Europa: the first consists of using radar to penetrate the ice and perhaps measure its thickness. The second is to use very precise gravity and altimetry measurements to observe the tides raised by Jupiter on Europa; these tides will be much larger, as great as 40 meters or so, if there is a liquid layer than if the water is all frozen.

Missions that involve landing on Europa would need to follow a program of detailed remote sensing to both identify good landing sites for in-situ surface experimentation. They will also identify areas of Europa's surface best suited to land robots that would attempt to penetrate the ice into the lower layers. These sites would preferably indicate a thin layer of ice.

Using a suite of robotic missions simultaneously has many advantages, but it also poses a greater challenge. This suite may comprise landing rovers with experiments designed to characterize Europa's surface, atmosphere and upper layers, landing robots to penetrate the surface ice to measure chemical evolution as a function of depth and also landing robots capable of operating within Europa's oceans to perform experiments there.

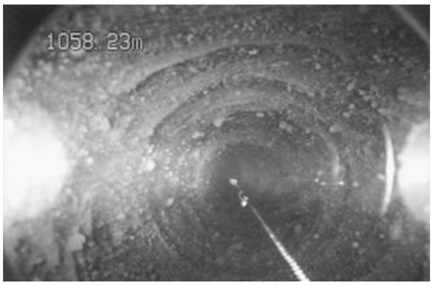

Figure 4.13: Earth ice view 1km deep

Identifying geothermal hot spots may prove very challenging, as they will certainly not be visible using remote sensing orbiters. Methods to find potential geothermal vents may be the use of thermal imaging on submarine robots or the identification of gases trapped under the ice that may have originated from these vents.

Much thought would be needed to address the problem of communication, as robots penetrating deep into the ice or oceans could not use conventional radio transmission. The use of multiple microwave relays, optical, and/or seismic signaling may also be employed. Communications from the lander to the orbiter and from the orbiter to Earth also need to be addressed.

These combined missions might be able to definitively answer the questions:

1. Is there an Ocean beneath the ice layer of Europa surface? What is its physics and chemistry?
2. What is exactly the geological activity in Europa? How much tidal heating is there?
3. Are there forms of life frozen in the ice of Europa?
4. Are there extant life forms in the oceans or in the ice-water interfaces of Europa?

4.4.3.1 Possible New Technologies To Use Within The Next 20 Years

Optical communications Laser optical communications has the potential of providing as much as 10 times higher data-rate with 10 times reduced size and lower mass, relative to the conventional spacecraft communication technology, assuming the same input power.

The technical merit of this key technology relies on the fact that it offers a more concentrated signal than conventional microwave does. This highly collimated beam can result in a terminal design with greatly reduced size, mass, and power requirements. Furthermore, laser communication systems are not susceptible to RF interference. Additionally, the higher data return rates afforded by optical communications reduce the required ground coverage time that is needed by the orbiter to recover the science data. It is worthwhile to say that optical communications are currently not subject to government or international regulations.

Smart lander spacecraft Autonomous navigation/Guidance & Control will be essential for a mission to Europa to avoid hazards during the landing maneuver and to navigate and determine the best places for experimentation. This automation will be supplemented using terrain imaging and mapping.

Radiation and extreme temperature tolerant systems The radiation environment on Europa is extremely harsh (a human would receive a lethal dose in 10 minutes) therefore electronics are required to be very resistant to radiation damage. Although such technology exists it tends to be very dated and so modern radiation tolerant microelectronics need to be designed.

Autonomous technology to operate constellation of spacecraft [302] Commanding a constellation by issuing individual sequences to each spacecraft would be cumbersome, expensive, and unlikely to achieve coordinated action in a dynamic or uncertain environment. New autonomy technologies are needed that can operate a constellation as a coordinated entity by issuing collective mission goals instead of individual command sequences.

Energy production and storage Low-temperature rechargeable batteries capable of operation as low as -60 degrees Celsius would be required, together with high power generators based upon radioisotope thermal generator technology.

4.4.4 Options

One option could be a staggered mission suite with three phases. The first phase would comprise of remote sensing orbiters that will obtain detailed surface chemical and physical analysis and determine potential landing sites. These missions would be primarily designed to address the primary science objective of determining the presence of and then characterizing the possible Europan oceans. These missions will also contain science payloads not necessarily concerning astrobiology.

The second phase would consist of technology demonstrator missions to Europa to develop and refine techniques to land and penetrate the ice layers. New technology can be tested along with in-situ experimentation. These missions will also include important science payloads such as seismometers.

In addition, missions that are designed to land on Europa can be tested in the Arctic. Fully autonomous landers can be dropped on the arctic ice shelf. On landing they would conduct experiments and also send a probe to penetrate through the ice into the water below. This probe needs to be able to communicate to the lander base and be fully autonomous.

Maybe the final phases may include missions to penetrate through the ice into Europa's possible oceans to perform in-situ experimentation. Again communication techniques can be demonstrated. These final phase missions will be highly focused on astrobiology and will be dedicated to studying specific locations.

No sample return missions are envisaged.

4.5 Ganymede

Ganymede is the largest satellite in the Solar System, and if it would orbit the Sun instead of Jupiter, it would be undoubtedly called a planet. It is larger than Mercury, but with only half of Mercury's mass. In the early years of interplanetary exploration of the Jovian system, speculations arose concerning the moon's internal structure. However, in recent years the Galileo spacecraft provided data, which points towards the differentiated structure, with a molten metallic (iron/sulfur) core, a mixed mantle (ice/rocky silicates), and a thick water ice crust. Furthermore, Galileo's magnetometer provided strong evidence for an ocean layer underlying the ice crust[2], raising the count of Jupiter's moons likely to harbor liquid water beneath their surface to three.

Jupiter's magnetic field produces currents in a salty (i.e. conductive) subsurface ocean. These currents in turn produce a magnetic field. Mapping this field gives an insight on the ocean's structure. Europa and Callisto do not have an intrinsic magnetic field (cf. 4.4), and their magnetic field is entirely due to interaction of oceans with Jupiter's magnetic field. Detecting the ocean within Ganymede was more difficult than in the case of Europa and Callisto, because Ganymede has a strong permanent magnetic field. The origin of the magnetic field is probably similar to the origin of Earth's magnetic field, owing its presence to a molten metallic core. The strong magnetic field is also responsible for Auroral light, observed on both of Ganymede's poles.

The giant moon has had a complex geological history. It has mountains, valleys, craters and ancient icy lava flows. Highly cratered, and therefore old ($\sim$3 – 3.5 billion years), dark regions cover forty percent of the surface, and a light, younger (but still ancient) grooved terrain, which forms intricate patterns across Ganymede, covers the remaining sixty percent. The origin of grooves is tectonic – they are probably formed by tensional faulting, or by release of water from beneath the surface. Local crust spreading does appear to have taken place, causing the crust to shear and separate.
'Ganymede has distinct spectral units that mostly correspond to geologic, and albedo derived terrain types. This indicates genetic differences in surface formation processes. Spectra of these units give good indications

[2] Margaret Kivelson, a UCLA planetary scientist and the principal investigator for Galileo's magnetometer, `http://www.space.com/searchforlife/ganymede_ocean_001215.html`

about the number and constitution of different materials, especially for the non-ice material(s) existing on Ganymede.'[3]

Given all stated features – the subsurface ocean, the permanent magnetic field, the complex geological history, non-ice materials on- and within- the crust, and internal heat source – Ganymede is a potentially interesting astrobiological target. Life could have developed in the past, when subsurface ocean was potentially extending closer to the surface, and left fossils, or even dormant (micro-bacterial) life within the ice crust. Major geological processes, or heavy meteor impacts, if occurring in parallel to, or after the hypothetical development of life, could have elevated evidence for life to the surface of the moon.

Therefore Ganymede should remain an actively researched astronomical body.

4.5.1 Science Objectives

Ganymede is a world in essence similar to Europa. Although it is bigger, it lies outside of Jupiter's main radiation belt, and has a permanent magnetic field, it is believed that Ganymede, like Europa, has a liquid ocean, that might have supported life, underneath the water ice crust.
Therefore, the principal science, which will open doors for a more detailed study of possibilities for life, is basically identical to the one described in the chapter dealing with Europa's science objectives (cf. 4.4.1).
However, although similar experiments are used, some differences are expected in obtaining and in the interpretation of data;
Seismic activity should produce a lower response: the tidal crust movement is smaller than on Europa, because Jupiter is further away, and crust variations due to the oceans are expected to be smaller, because the liquid ocean is expected at much greater depths ($\sim$170 km).
As the ocean is situated much deeper than Europa's, radar measurements are not expected to be able to determine presence of liquid water.
Magnetic mapping will offer clues about Ganymede's core, while similar experiments on Europa will tell more about currents in the subsurface ocean. This discrepancy is a consequence of Ganymede's internal magnetic field, which dwarfs the effect of Jupiter's magnetic field lines in a salty (i.e. conductive) ocean.

4.5.2 Hot Targets

4.5.2.1 Energy Sources

As stated in Europa's chapter, cf. 4.4.2, energy flow from the Sun is too modest to expect sustained life on, or near the surface. Geothermal energy could have played a major role in providing appropriate environment for the development of life. Current data (cf. 4.5) suggests that the majority of the ocean is in form of ice crust, with only a thin layer of water buried deep under the ice. However, it is likely that the metallic core was much warmer in the past. The tidal heating effect is substantially weaker than on Europa, because Ganymede's orbit is further away from Jupiter. Geothermal heat sources are not expected to have a significant role today, because even if they are active, their influence is localized by the overlaying ice crust.

4.5.2.2 Life "Hot" Spots

Verifying a remote possibility that life still might be lurking within the Ganymede's ocean is not feasible in next 20 years, simply because the ocean is situated too deep within the ice crust. Localized environments situated around eventual geothermal vents are expected to be even deeper in the crust. However, fossil and/or dormant life could be found throughout the ice crust; a warmer core in the past could have created extended biosphere, and the geologic processes and asteroid or comet impacts could have elevated pre-biotic material or even life forms all the way to the surface.

[3] Katrin Stephan, DLR

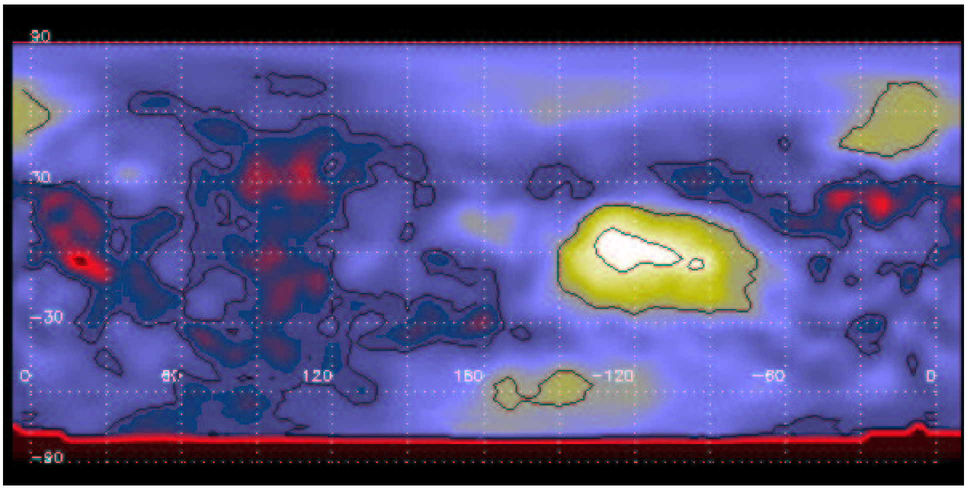

Figure 4.14: Titan seen by the Hubble Space Telescope[284]

4.5.3 Missions & Technology

Again, technology and mission types are quite similar to the ones envisaged for Europa. Radar mapping could reveal the structure of the first few kilometers of the crust. Particularly interesting areas can be studied in detail with a series of (at least three) seismic probes. Hydrobots can not be used in the next 20 years, because of inaccessibility of the ocean (cf. 4.5.1). Radiation on the surface of the giant moon is not extreme, because Ganymede orbits Jupiter outside of the reach of the radiation belts. Therefore, mobile laboratories (smart rovers) could be developed to search for the signs of fossils or potential dormant life. For a suite of relevant experiments, refer to chapter 3.4.3. Melting/drilling cryobots can be used to propagate investigation further down into the crust.

4.5.4 Options

A spacecraft needed to reach and investigate the Jovian neighborhood can currently only fit in a flagship/cornerstone type of the mission. Such status puts high requirements on scientific, technical, and educational return of the mission.

Therefore, any mission to investigate Ganymede, within the next 20 years, will probably have to retrace Galileo's steps (cf. 2.3.1.3). Depending on the mission design, the spacecraft could carry several probes, which could be distributed on the Galilean moons, while the orbiter would investigate entire system from eccentric orbit around Jupiter.

Ganymede should be in a focus of such mission, for it offers very attractive research options for orbiting, surface, and subsurface facilities (cf. 4.5.2 and 4.5.3).

4.6 Titan

Astrobiology is not merely the search for extraterrestrial life but can also "...be considered as the study of the origin, evolution and distribution of life in the Universe,..." [305]. Titan could be seen as "...a natural laboratory in which to study chemical evolution towards complex organic systems in a planetary environment..." [305].

As Titan is the largest of Saturn's moons it has been of astrobiological interest for a long time. Former missions such as Pioneer, Voyager and also more recent pictures from the Hubble Space Telescope, as depicted in figure 4.14, have increased our interest in Titan.

Titan has a thick atmosphere consisting mainly of molecular nitrogen and vast amounts of methane [324].

In addition, it is believed that there are large landmasses, ponds and oceans of liquid nitrogen with hydrocarbons, frozen oxygen and carbon dioxide on Titan's surface [247] [248].

The Cassini/Huygens mission was launched in the autumn of 1997 and will have to fly 6.7 years to get to the Saturn region [266]. After two flybys of Cassini, the Huygens probe will be deployed on Titan more than 7 years after launch. The Huygens probe will then be lowered onto Titan's surface and collect data during descent and on Titan's surface for approximately four hours [290]. For Cassini, approximately four further years of research is planned. The mission will not be finished until 2008.

4.6.1 Science Objectives

The scientific objectives for Titan have to be determined furthermore and readjusted according to the results of Cassini/Huygens. For example, the data about the magnetospheric conditions of the Saturn system that Cassini will collect, during the four years after its arrival at Saturn, could be very valuable information for future missions.

Titan's environment and conditions for an origin of life have to be investigated. As the probability for current life on Titan is very small due to the freezing temperatures, it is more likely to detect fossil or dormant evidence of life from an earlier period with different conditions. The science objectives should also be arranged according to that. It is furthermore believed that Titan has similar conditions to Earth at a very young age[248]. Therefore, it is hoped that by studying Titan, the conditions for an origin of life are better understood.

4.6.2 Hot Targets

In spite of the fact that there is evidence for land and ponds on Titan's surface as shown in figure 4.14, hot targets on and below Titan's surface still have to be determined. Cassini's radar, IR camera and spectrometer [267] in various bands, will provide data that might give a better idea of where hot targets for astrobiology missions on Titan are located.

As there is quite a lot of volcanic and geologic activity on Titan, hot targets could be in certain ponds or oceans or perhaps also in its atmosphere. Perhaps there are also thermal vents or black smokers at the bottom of those ponds or oceans. Nevertheless, we are still "hampered by our lack of knowledge of the surface's nature, as well as by an incomplete understanding of the physical and chemical properties of the atmosphere of the solar system's second largest moon"[268].

4.6.3 Experiments

Remote sensing would have to consider Titan's thick atmosphere. The technology used for the search for life on Titan would be orbiters equipped with radar and IR instruments (optical windows are at 940 nm or 1080 nm [284]) with higher resolution than Cassini.

Furthermore, in-situ measurements to get a better picture of the chemistry and physics of Titan's atmosphere, landmasses and liquids, such as e.g. laser Doppler anemometry in connection with theoretical modeling should be conducted.

4.6.4 Missions, Technologies and Options for Titan

Future missions to Titan will probably be somehow similar to the Cassini/Huygens mission, but continue the research where Cassini/Huygens will end. The trajectory of the spacecraft could use gravity assist or alternatively solar sails to get its payload into the Saturn region.

Options that will be proposed are incremental mission research starting with sending out high resolution remote sensing on orbiters or fly by missions, followed by airborne science in the atmosphere of Titan and eventually robotic missions.

Airborne missions could include balloons, airplanes or helicopters, which could make a closer investigation of a possible hot target. Light Detection and Ranging (LIDAR) and Gas Chromatography-Mass Spectrometry (GC-MS) on airborne vehicles and/or swarms of small weather stations [255] would allow the detection of the vertical distribution of aerosols and gases in the atmosphere.

Finally, robot missions could be sent to identify hot targets to search for possible forms of life and do science that may allow conclusions on the possible origin of life on Titan. Later also robot missions including robots with wheels or insect-type robots that operate by trial and error or even brute force calculators could be the carrier for all kinds of in-situ researching equipment. High Performance Liquid Chromatography (HPLC), cameras in VIS and IR on submarine robots could give information about the chemistry and possible hot targets in oceans and ponds.

As there is quite a lot of frozen water and carbon dioxide on the surface of Titan, missions to these locations would also have to use cryobots, if a closer examination of the ice subsurface and formations, that are hiding beneath, seems to be relevant for the planetary exploration of Titan.

Airborne vehicles like balloons, airplanes, helicopters as well as surface and subsurface robotics would have to be designed in order to withstand the extreme conditions on Titan such as the freezing temperatures as well as the chemistry in ponds and oceans.

As there are strict international rules to avoid the contamination of Solar System bodies with biological material from Earth [296], all the equipment that is entering Titan or Titan's atmosphere has to be sterilized and cleaned sufficiently according to these rules. As total sterilization and cleaning is not possible, the equipment has to be measured for remaining biological material after the sterilization and cleaning processes of the spacecraft and all its components in order to at least know what the planet possibly is going to be contaminated with.

4.7 Comets and Other Small Bodies

4.7.1 Introduction

Scientists have long believed that comets and meteorites have played a role in the origin of life. Comets are now known to hold many of the original ingredients of the life, including a wealth of organic material, probably including amino acids which are building block of proteins and essential for DNA or RNA. [226] They are also rich in carbon-based materials, which provided our planet with many of the ready-to-mix molecules that could give rise to life. A recent discovery by a NASA scientist of sugar and several related organic compounds in two carbonaceous meteorites provides the first evidence that another fundamental building block of life on Earth may have come from outer space [314]. Currently, the study of comets and other small bodies as one of the potential organics sources to Earth is a very active area of research in astrobiology.

Although the composition of comets can be identified using spectroscopy and doing remote analysis and one comet sample return mission called Stardust [312] is on its way, no space probe yet has brought a comet sample back to Earth for study, so no one knows for sure what the chemistry is.

This section will focus on space-based missions and therefore, does not address meteors or meteorites. Missions to asteroids are similar to missions to comets, with comets being the more complex of the two. Asteroid missions can be treated as a subset of comet missions since a majority of the same issues need to be addressed. For this reason only, missions to comets will be addressed and mission approaches for asteroids can be derived from this material. Interstellar dust will be addressed through the study of comets and the debris from left in their orbits. Other sources of interstellar dust have not been addressed here, but are addressed in Chapter 2.3.1.6. The past, present and planed missions for comets and small bodies are addressed in Chapter 2.3.1.6.

4.7.2 Science Objectives

Before we can identify the options for future missions to small bodies, we first need to identify science objectives. By far the most profound scientific objective is seeking the understanding of the role of comets, if any, in the origin of life. The following questions should be answered to satisfy this objective [237] [254]:

- What is the mineralogical, elemental, and chemical composition of comets at the sub-micron scale?
- What is the extent that building materials of comets are found in interplanetary dust particles?
- What the state of water is in comets - is it all in ice or are there hydrated minerals?
- Are isotopic anomalies present?
- What is the nature of the carbonaceous material and its relationship to silicates and other phases?
- Is there evidence for pre-accretional processing either in the interstellar medium or the nebula?
- What is the chemical composition of pristine comet nucleus material?
- What is the story of the primordial solar system?
- What is the evolution process of comets since their formation?
- Variation of the comets' composition with depth and location on the nucleus need to be addressed.
- What is the likely effects and mitigation of cometary impacts on other planetary bodies?

4.7.3 Hot Targets

4.7.3.1 Which Comets?

From previous Earth based observation, each comet has shown different characteristics in its chemical composition ratio, for example comets that formed in the outer solar system include frozen volatile molecules in their icy nuclei, but comets that formed nearer the Sun contain fewer volatiles. Also comets born in the outer solar system contain ices highly rich in heavy water, however comets born in a certain part of the solar system contain water that is more Earth-like [241]. So the choice of a comet for a mission must be carefully considered.

4.7.3.2 What Part of the Comet?

Although a large number of studies have been made on comets, little is known about the geological and mineralogical structure of comets. Recent Deep Space 1 [253] images of cometary nuclei show rugged terrain, smooth rolling plains, deep fractures and very dark material which have told us that comet nuclei are far more complex than we ever imagined [240]. Therefore, we need to know which part of the comet should be studied first in detail.

Cometary dust also affects Earth. Meteor showers sometimes occur as the Earth passes through the orbit of a comet. For example the Perseid meteor shower occurs every year between August 9^{th} and 13^{th} as the Earth passes through the orbit of Comet Swift-Tuttle. Similarly, Comet Halley is the source of the Orionid shower in October. This dust could give rise to life since recent studies are showing that much of the organic matter in comet dust might survive the rapid heating of Earth's atmospheric entry [285].

4.7.3.3 Comet-Asteroid Transition Object [260]?

Although a large number of studies have been done on asteroids and comets, the evolution of these small bodies in the solar system is highly unknown. The investigation of Comet-Asteroid Transition objects (CATs) might show the differences and similarities between comets and asteroids. It will hopefully lead to clearer ideas in explaining the different roles of each body, if any, in the origin of life.

4.7.4 Experiments

4.7.4.1 Looking for the Ingredients of Life [264]

Amino and nucleic acids, from which proteins, RNA, and DNA are built, are relatively simple molecules containing about 20 atoms. Examples are Alanine ($C_3H_7O_2N$), Glycine ($C_2H_5O_2N$) and Lysine ($C_6H_{15}O_2N$). These molecules are synthesized by nature and are found even in carbonaceous meteorites. The evidence of sugars and the closely related compounds that are critical to all known life forms should be looked for. See related information in sec. 3.4.3.4.

4.7.4.2 Looking for Complex Molecules that Enable Life to Function

Complex molecules can be formed from simple molecules by application of energy. Lightning, solar ultraviolet light, impacts and/or volcanism could act as potential energy sources. Comets have energy sources such as solar ultraviolet light and impacts with other small bodies. This can cause those simple molecules described above to react together to form more complex ones. So comets might contain complex molecules that may enable life to function. Typically, these life functioning molecules contain hundreds or thousands of atoms, for example Chlorophyll ($C_{56}H_{66}O_4N_4Mg$). See related information in sec. 3.4.3.4.

4.7.5 Missions and Technologies

4.7.5.1 Mission Architecture

To describe future missions and technologies, we should refer back to past and present missions which are addressed in Chapter 2.3.1.6. Altogether, there have been nine missions to small bodies in the solar system so far. Within the next decade, there are plans for an additional eleven missions. The following section will outline the methods employed by each of these missions, explaining briefly the strengths and weaknesses of each.

Flyby Visual Observation Visual observation is by far the simplest form of science and two satellites, which have been involved in this are Galileo [256] and Ulysses [316]. The level of science return from these satellites is very low indeed, but they can provide some very clear pictures of what asteroids and comets look like, up close.

Flyby Science This section covers most of the missions to small bodies. In general, it covers the study of nearby plasma, gas, energetic particles, magnetic field, interactions with the solar wind and composition. It is relatively safe for the satellite, and can also provide very good scientific results. These missions are: ICE, Vega1 [320], Vega2 [320], Sakigake [307], Suisei [307], Giotto [257], Stardust [312], CONTOUR [245], Deep Space 1 [253], NEAP [294], Rosetta [306].

Passing through Comet Coma This method refers directly to missions involving comets. This method has only been used by two missions so far, Giotto [257] and Deep Space 1 [253]. The main reason for this is the risk involved in sending a fragile satellite into a sea of rocks and ice spewing from the comet surface. These particles can hit the satellite at speeds of kilometers a second, which could lead to loss of a spacecraft. For this purpose, these missions use a protective shield. In terms of science, these missions also provided the greatest return, getting to within a few hundred kilometers of the comet surface; the instruments can give very good scientific data.

Interstellar dust collection Stardust is the only mission in this category. Its complexity is on the same level as flyby science, but its scientific return is extremely good.

Landers and Impactors Deploying in-situ landers presents the same difficulty as passing through the coma, but has a much higher scientific return. It is for that reason that there are three of such mission proposed for the future: Rosetta [306], Deep Impact [252] and NEAP [294].

Sample return The sample return mission is the holy grail of small body missions. This type of mission is by far the most complex, but also has the largest scientific return. A sample return mission has not been completed yet, but one mission is on its way Stardust [312], and the other is scheduled to launch at the end of 2002, MUSES-C [292].

4.7.5.2 Mission technologies

A number of key technologies are vital to the success of any future mission to comets or any small bodies. By analyzing previous missions and their weaknesses, we can summarize the need for technology development as follows [254]:

Power and Propulsion:

- Ion Propulsion
- Advanced Solar Arrays / Solar sails

In situ/Mechanical:

- Drilling/Deep Coring
- Sample Transfer/Containerization
- Anchoring
- Multiple Surface Sampler

Comet Simulation:

- Extraterrestrial Materials Simulation Lab

Thermal:

- Cryogenic Maintenance
- Non-Contamination

Earth Reentry Vehicle Guidance, Navigation, and Control:

- Precision Guidance and Landing
- Autonomous navigation

Avionics:

- Autonomous flight control

4.7.6 Options

4.7.6.1 Flyby Visual Observation and Science

- **The Comet Hunter**
  The multi-comet dust sample collecting vehicle. A spacecraft designed to visit many different comets during its journey through the solar system will be able to provide comparison data between these bodies. Nuclear power systems or a rugged form of solar arrays will enable a craft with a long operational life. As opportunities arise, such a spacecraft can be rerouted without the expense associated with multiple crafts, each launched for a limited number of targets.

- **The Comet Nest**
  Flyby and/or return samples from a location, which acts as a reservoir for comets, such as the Kuiper belt and Oort cloud. Inspection of multiple comets will be facilitated by the identification of areas, orbits, or trajectories that contain a proportionally higher number of comet visits.

4.7.6.2 Planetary Dust Collection

- **Seeding the Earth**
  Collect the cometary dust, which are causing the Perseid and Orionid meteor showers. 4.7.3.2 Through the analysis of dust and debris in these orbital wakes, much can be learned about the nature of the material that annually enters the Earth's atmosphere.

4.7.6.3 Landers and Impactors

- **Iron Head**
  Land on the comet surface and take in-situ measurements. Spacecraft hardening and shielding improvements will lessen the risk associated with entry into a comet's coma and debris field. Once this is achieved, instrumentation can be reliably delivered to the surface and gather sample data. The minimal gravity environment will also permit sampling from multiple locations with minimum propulsion requirements.

- **Comet Surfer**
  Land scientific instruments on a commentary nucleus and take continuous measurements sending the data back to Earth during an entire period of orbit. This approach will take advantage of a comet's natural trajectory and provide a means of accessing deep areas of space with minimal human intervention required by unexpected trajectory perturbations. Since, the orbits of comets are mature, hitchhiking on the comet will reduce the complexity of reaching regions such as the Kuiper belt and Oort cloud, should these regions be included in the comet's orbit. Power would be allocated for data collection and communications and minimal power would be required for propulsion and trajectory corrections since they are not needed.

- **Space Tourism for the "Little Guys"**
  Deliver small biosphere of organisms to a comet and monitor life in the extreme environment of space. Short period comets would provide a low cost space vehicle to transport the vessel with minimal propulsion requirements. Extended analysis of the organisms can be performed near real-time using on-board instrumentation. The biosphere could even be retrieved for additional analysis on Earth.

  Understandably, there are many planetary protection issues that must be considered with this approach; however, such a mission should not be dismissed without careful consideration of the potential benefits of such a study.

4.7.6.4 Sample Return

- **Rings of the Tree**
  Collect samples of comet dust and ice from different depths under the surface and return the sample to Earth. A mission is currently planned to sample a small terrestrial body surface [292]; however, solar radiation may have destroyed the markers and indicators of comet's roles in the origin of life. Samples taken from varying levels under the surface will provide a window into a comet's history and possibly our own.

- **The Older Brother**
  Return samples of the deep core and surface of Comet-Asteroid Transition objects (CATs) to Earth 4.7.3.3. These missions will serve multiple scientific purposes and further understanding about the life cycle of comets and asteroids.

4.8 New Space Technology

4.8.1 Introduction

This section gives an overview of some space technologies and future space technologies that are relevant to astrobiology missions. Propulsion systems like solar sails and magnetic sails and ion propulsion, because of their suitability for interplanetary missions, will be described. Astrobiology missions, that aim for in-situ measurements on planets and other bodies, will require precise and safe landing capabilities on unknown and hazardous terrain. Therefore, the current development of technologies that will enable landings at identified hot targets are important. As optimization of existing systems is not sufficient to reach certain scientific goals, Micro Electro-Mechanical-Systems (MEMS) must be used to a high degree to make missions feasible. A step of several orders of magnitude further down to nanotechnologies (collectively referred to as Micro/Nano-Technologies(MNT)) will furthermore give advantages. The latter will not be looked at in this report. The development of new space technologies is especially important for astrobiology missions. Considering the policy and strategies of the leading space nations, astrobiology missions do not have first priority. Therefore they would not receive as much financial resources as other space programs, e.g. the International Space Station (ISS).

4.8.2 Propulsion

A solar sail is a light-weight structure that is capable of stretching out a huge light-weight fabric.

The principle of a solar sail is to use the momentum of the photons emitted by the Sun which are reflected and leave some momentum at the sail and thereby produce the thrust. The great advantage of a solar sail is that it does not need to carry its own propellant. The solar sail can be adjusted to an angle of the direction of the Sun in order for the spacecraft to go into the desired direction. The development of this exotic kind of propulsion could lead to spin-off effects in other fields of technology such as e.g. material sciences. A successful deployment of a solar sail was conducted for the first time during a MIR space walk by a Russian cosmonaut in 1993 [249]. The photograph in figure 4.15 shows a prototype of a solar sail.

Figure 4.15: Model of a possible solar sail [295]

Magnetic sails , or also called magnetic bubbles, reach out farther into the future and are beyond the time scale of approximately 20 years that are set for this work. Nevertheless, they shall at least be mentioned here. A magnetic sail or a magnetic bubble is created around a spacecraft in order to interact with the solar wind that means the charged particles that are expelled from the sun. A physicist of the Marshall Space Flight Center states the possible performance of a magnetic sail as follows:

"A 15 km-wide miniature magnetosphere one astronomical unit from the Sun would feel 1 to 3 Newton of force from the solar wind. That's enough to accelerate a 200 kg spacecraft from a dead stop to 80 km/s (180,000 mph) in only 3 months." [301]

Ion engines are currently used on interplanetary flights and for communication satellites. In an ion engine, particles are ionized, accelerated by electric and magnetic fields and finally expelled through the nozzle at very high speed. Focusing electrodes are used to force the ionized particles into the right direction. The advantage of an ion engine is the very high speed of the expelled particles, which is in the range of 20 to 48 km/sec, leading to very high specific impulses in the region of 2000 to 5000 seconds. The drawback of an ion engine is that it has to be supplied with a lot of electric power. The electric system can take up to 90 % of the mass of an ion engine [250]. The picture in figure 4.16 shows a Xenon Ion Engine at the Jet Propulsion Laboratory.

The Radiofrequency Ion Thruster Assembly (RITA) in figure 4.17 uses xenon as a propellant. Assuming an acceleration voltage of 1.5 kV it would have a power consumption of 500-600 W, a thrust of 15 mN, a specific impulse of 3000 seconds and achieve an exhaust velocity of 48 km/sec [261].

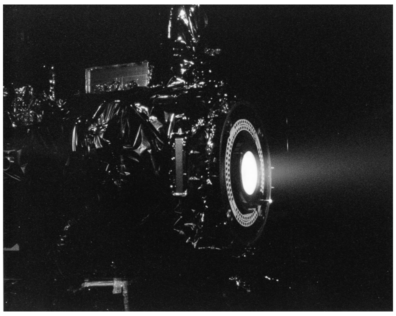

Figure 4.16: A Xenon Ion Engine at JPL[325]

4.8.3 Communication

In recent years the problem of communication bottlenecks emerges more clearly. One option is to use filtering of the data on board, which some spacecraft already use [280]. Only the data of interest will be sent to Earth. This requires well functioning filters and there is always the danger that surprising data of high scientific value is going to be erased. In the near future, missions are expected to collect data that exceed the possible data rates of conventional radio frequency transmitters.

Laser have a much greater frequency and therefore a wider bandwidth than radio frequency transmitters. Laser beams have also a very small divergence and could therefore direct the energy much more efficiently. Laser communication in space, though, is a

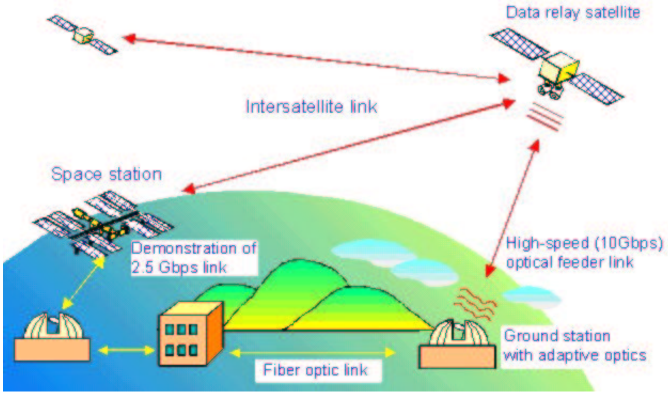

Figure 4.18: Overview of a Earth near space laser communication system [282]

very complex and difficult task, due to the laser properties, like e.g. jitter and small divergence, the distances in space and vibrations caused by internal spacecraft subsystems. Other drawbacks are that laser equipment has very delicate and sensitive optics and the pointing mechanism due to the small divergence would have to be much more accurate.

Laser links from space to Earth would have to go through the atmosphere. Clouds would disturb the continuous communication. Therefore a worldwide laser communication system with many receiving stations would be required .

The overview of an Earth near space laser communication system in figure 4.18 gives an idea about the various components of such a system.

In the end of the 1990s, a project of the US military had the aim to develop an inter-satellite laser communication system [283]. ESA has already demonstrated the ability to use laser technology for communication between ARTEMIS and SPOT-4 [283] [278]. An entire space to ground system would take approximately 10 to 15 years to build, if ESA and NASA combine their resources [278].

Figure 4.17: Radiofrequency Ion Thruster Assembly (RITA) [265]

4.8.4 Power Systems

At greater distances from the Sun, solar cells do not produce enough energy to power the spacecraft. A radioisotope thermoelectric generator uses the decay of radioactive material, such as plutonium as the energy source, which is encased in small metal spheres embedded in graphite. The hot graphite heats a gas which drives an electric generator to produce electric power.

Cassini, for example, uses 33 kg of mainly plutonium-238, which is stored in bricks of plutonium dioxide. The radioactive plutonium dioxide is emitting alpha particles which can easily be shielded [308].

Radioisotope thermoelectric generators (RTG) have been in use since the 1970s especially for spacecraft that are heading out of the solar system.

It has to be mentioned, though, that the use of RTGs is not without controversy. At the launch of the Cassini spacecraft, there were many anti nuclear activists, who were protesting against the use of RTGs. Even institutions in favor of space activities, such as the National Space Society, oppose the use of RTGs [311].

4.8.5 Precise Landing

The process of descending and landing on a planet is not an easy one. Communication delay due to the distance of the spacecraft to the control station on Earth complicates the procedure furthermore. Because of the latter, landing technologies also need a certain amount of autonomy.

Safe and precise landing includes hazard and avoidance algorithms, laser altimeters, stereoscopic cameras (or surface reconstruction from a pair of images acquired from one single camera), Light Detection and Ranging (LIDAR) and inertial measurement sensors, such as accelerometers and gyroscopes[269].

4.8.6 MEMS-Based Space Technologies

A significant miniaturization of space systems, space subsystems and space components becomes absolutely necessary [313]. A mass reduction for space systems, for bus systems as well as for the payload, is highly desirable in order to save costs, to reduce power consumption and to make certain missions at all possible [262]. One endeavor in this respect is the development of MEMS-based space technologies. There are quite a lot of research institutes that are active in this fairly new interdisciplinary field of research.

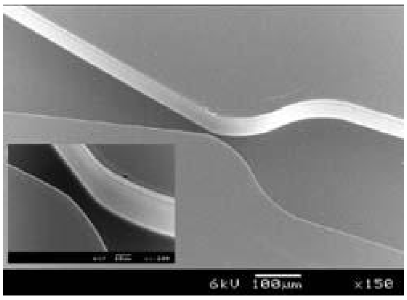

Figure 4.19: Michromachined nozzle (courtesy to The Ångström Space Technology Centre)[227, 274]

The microthruster depicted in figure 4.21 is a so called cold gas microthruster. The gas that will be expelled through a micro-machined nozzle - an image generated by an electron microscope is shown in figure 4.19 - is lead into a sphere of approximately 40 mm. The gas is passed through micro-machined filters, goes through a micro-machined valve and is finally heated before it is expelled with supersonic speed out of the nozzle. The valve that regulates the flow of the gas, and thereby the thrust, is actuated by piezoelectric ceramics, soldered on silicon wafers as shown in figure 4.20. The control electronics, gas filters, channels, valves, heaters and nozzles are all integrated in a silicon wafer stack circled in figure 4.21.

A problem of small spacecraft is the thermal control of all elements, due to the increased area to mass ratio. One approach is to use so called variable emittance panels (VEP) , electro chromic multilayers that change their radiation properties if a voltage is applied between the two electrodes on either side.

A great reduction of mass and size is also achieved by packaging electronics with MST. An example for this are Multi-Chip-Modules (MCM or even called 3D-MCM). Multi-Chip-Modules house interconnected chips with integrated circuits on silicon wafers and may contain integrated thermal control.

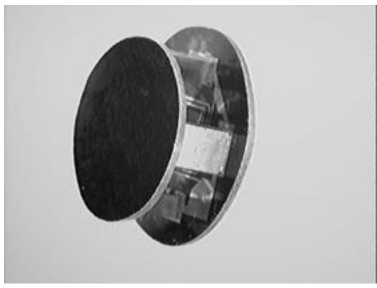

Figure 4.20: Michromachined valve (courtesy to The Ångström Space Technology Centre)[227, 274]

Micro strip antennae [276] that could be used for communication between the lander and the orbiter of the observed planet and miniaturized equipment for in-situ measurements are also currently under development [262].

Miniaturized equipment include, for example, micro weather stations, radiation densitometers or micro laser Doppler anemometers. A micro hygrometer is depicted in figure 4.22 which could be included in an eventually walnut sized micro weather station.

Miniaturization of space components have of course to include sensors such as accelerometers, gyroscopes and laser gyroscopes, sun sensors [227], startrackers and a lot more. An electron microscope image of a miniaturized gyroscope is shown figure 4.23.

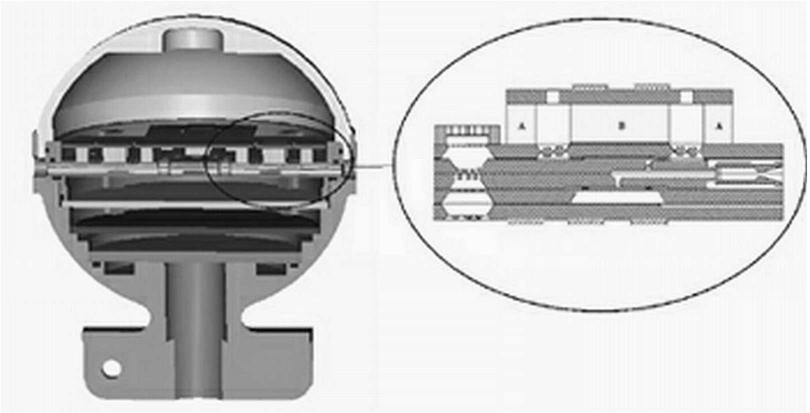

Figure 4.21: Thrusterpod (Courtesy to The Ångström Space Technology Centre)[227, 274]

Figure 4.22: Micro Hygrometer [262]

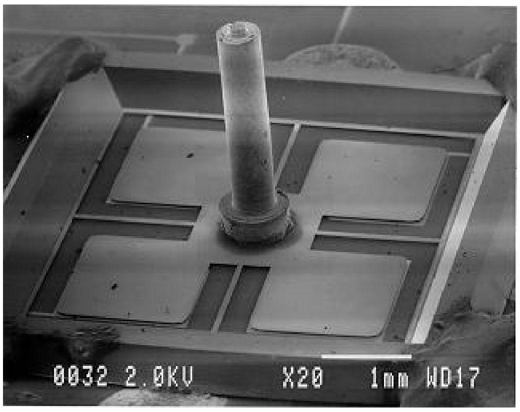

Figure 4.23: Electron microscope image of a gyroscope [321]

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Chapter 5

Planetary Protection

5.1 Introduction to Planetary Protection

Planetary Protection is the protection of humanity, Earth's biosphere, and all celestial bodies that Earth-based spacecraft may encounter. Humanity must not be reckless and insensitive in its incessant quest to explore the Universe and in bringing the Universe back to Earth.

5.1.1 Overview

The idea of modern planetary protection had its origins as early as the 1950's. In 1957, Joshua Lederberg wrote to the US National Academy of Sciences in anticipation of the real possibility of space travel and exploration. His concern was that contamination of the Moon with terrestrial organic matter transported on spacecraft would interfere with the scientific testing of the origins of Earth life. [344]

Lederberg's concerns on contaminating the Moon have continued to be a significant issue for space exploration missions in general - protecting extraterrestrial environments, and also Earth, from harmful contamination. Demonstrating the importance of these early planetary protection principles, international and national agencies subsequently incorporated them into their policy and doctrine which continue to evolve over time. Ethical issues are intertwined with those of law.

Strategies for implementing planetary protection have resulted in bio burden (contamination) reduction methods, including cleaning, sterilization and biological containment. Methods have improved as Society's constraints dictate.

While preparing this chapter we identified key planetary protection issues to consider in designing future Astrobiology missions:

1. Only send or receive what you can control
2. Do what you can to increase public understanding
3. Allow for unexpected events
4. Take into account diverse opinions

5.1.2 Mission of Planetary Protection

To increase understanding of key issues related to planetary protection. Where appropriate, we also want to present unique and original ideas relating planetary protection to the future of Astrobiology.

5.1.3 Chapter Summary

In this chapter we outline and define contamination issues. We then discuss the ethics of planetary protection and space exploration in general. We evaluate the legal framework regarding planetary protection, and identify issues to consider. An evaluation of past and present bio burden reduction methods follows, and the chapter concludes with some key issues and suggestions for future Astrobiology mission designers.

5.2 Definitions

This section explains the detailed definitions adopted by the ISU SSP 02 Astrobiology Design Project team that support the recommended planetary protection guidelines presented. These definitions are consistent with current NASA Planetary Protection Policy as documented in directive NPD 8020.7E. [336]

5.2.1 Contamination Defined

Contamination is defined as ***the uncontrolled or un-cataloged transfer of biological material, potential life forms, or other potentially hazardous substances on board a spacecraft.*** This definition recognizes the impossibility of completely sterilizing a spacecraft and places the emphasis for planetary protection on the ability to understand and anticipate the resultant consequences.

Contamination issues specifically related to astrobiology missions include both forward and backward contamination. In general, forward contamination is the transport from Earth to a celestial body and backward is the transport from the celestial body back to Earth.

5.2.2 Forward Contamination

Forward contamination (FC) is defined as ***the unintentional release of biological materials or pathogens into an extraterrestrial environment from an Earth-based spacecraft***.

FC policy is motivated by two different imperatives. [344] The first is preservation of the scientific integrity of the mission. Terrestrial materials or organisms must be accounted for to avoid the inadvertent contamination of test samples that would produce false results in life detection experiments. The second imperative is to protect any indigenous organisms from harm. This imperative is derived from an ethical perspective as well as from scientific interest to maintain a pristine extraterrestrial environment for future study.

A third imperative that may develop, as successive missions discover and accumulate knowledge, is to protect the natural extraterrestrial resources for future exploitation by humans. For example, frozen water reservoirs on Mars should be protected from terrestrial organisms, which could survive and potentially contaminate the resource. Uncontrolled contamination would increase the technical complexity and cost of extracting and processing the water for use by future human colonists.

Methods to prevent FC are discussed in Section 5.5.1.

5.2.3 Backward Contamination

Backward contamination (BC) is of fundamental concern to the astrobiology field, and is defined as ***the unintentional release of possible alien life or pathogens into Earth's biosphere***. The primary goal in handling BC is to protect humanity and Earth's biosphere, and only then to preserve the integrity of alien life forms for science.

NASA and the Space Studies Board (SSB) of the US National Research Council (NRC) have evaluated BC from a general perspective, providing recommendations and guidelines for mission designers and scientists.[342] In 1997, the NRC also published, "Mars Sample Return: Issues and Recommendations," which takes a more focused look at BC.

So how do we handle BC? There are basically two current thoughts in handling the potential risks from returned samples and spacecraft. With high enough risk, we should employ strict containment and handling measures for the spacecraft. With little to no risk, precautions are not necessary beyond what is needed for scientific purposes. As recommended by the NRC, samples en route to and on Earth should be *"... contained and treated as though they were potentially hazardous until proven otherwise."*[340] There should also be strict methods for verification of spacecraft containment en route to and on Earth, finally ending at a sample receiving facility. The NRC recommended that a multidisciplinary team staff the sample receiving facility, concerned with being able to appropriately handle and analyze the unknown.

Methods to prevent BC are discussed in Section 5.5.2.

5.3 Ethical Considerations

"The Problem of the search for forms of life comparable to, or different from, those existing on Earth must be considered. Appropriate measures must be taken to administer the return on Earth of samples taken from other planets (especially Mars)." [348]

"Some of you know what I have brought back. That's what all this is about. There is life on Mars."
"That's where we should leave it", someone shouts." [334]

These quotes, the first from a recent United Nations Educational Scientific and Cultural Organization (UNESCO) Ethics in Space Conference; the other from a novel, show the extreme breadth of views which could, in this case, surface in future sample return missions. The Conference takes the view that sample return should happen; with the manner in which it happens being considered. The speaker in the novel however, takes quite the opposite view, a view heard in the real world too.

As humanity moves into space, the ethical debate takes these views and others and creates a forum for them to be heard. The UNESCO recently hosted the World Commission on the Ethics of Scientific Knowledge and Technology in Paris. [337] Known by its French acronym COMEST, the commission's work followed on from Alain Pompidou's 1999 report, The Ethics of Space Policy [348], with a mandate to advise decision-makers in the public or private sectors who have to make choices founded on ethical reflection. Looking at space from different viewpoints, as a dimension, as an instrument and as a perception, the Commission's report covers many areas. It points out that ethical reflection should both precede and guide the definition of national space policies to safeguard the long term vision for the sustainable development of space activities.

A recent International Academy of Astronautics (IAA) paper [326] discusses the various evolving ethical dimensions of space exploration policy. This is particularly relevant to the subject of planetary protection. The three dimensions given were:

- The **Anthropocentric Dimension** with its central moral principle of Nature as a utility for human ends, no matter what the cost. A policy based on this dimension would alter the extraterrestrial environment.
- The **Biocentric Dimension** which concentrates on the intrinsic value of life and humans' responsibility to respect *and support* the interests, and even rights of, life whether animal, biota or microbes. Two views apply here, the one which would allow terraforming of Mars to allow Martian life to proliferate and then be quarantined for environmental protection; the other questioning if humans have a moral right at all to alter an inhabited world. Policy may be divided under this dimension.
- The **Cosmocentric Dimension** which treats the Cosmos as a priority and would involve non-violation of the extraterrestrial environment and the preservation of its existing state. A policy based on this dimension would promote peaceful co-existence but may not encourage further colonization. [326]

We could argue that current planetary protection policies are tending towards the latter Cosmocentric view. This is a luxury we have while our ability to travel to other celestial bodies is limited. We can look from afar but not really touch. The planned avoidance of Europa by Galileo's crashing into Jupiter is one extreme example of this view. What will happen as we venture more into the solar system and beyond? Will a need for a home away from Earth trample on those principles we have managed to build up?

In the coming years, mission planners will need to keep abreast of the developments in ethics and test the prevailing winds of opinion and practice. Given practice to date, ethical concerns will figure largely in future mission planning.

Guideline: Incorporate ethical concerns into mission planning. Public education should be a high priority and the public should be engaged in public debates about the reasons for the mission with a broad cross-section of society.
(Note: Section 7.3 in its Gap Analysis provides an insight into possible activities to educate children.)

5.4 Legal Aspects of Planetary Protection

Legal aspects tell us about the constraints and requirements of our proposed actions. Even though the concept of planetary protection was conceived long ago, a single law for planetary protection does not yet exist. We will try to highlight the key issues.

5.4.1 International Law

The Planetary Protection Regime has a basis in International Space Law. “International Space law can be described as the body of law applicable to and governing space-related activities. The term "space law" is most often associated with the rules, principles and standards of international law appearing in the five international treaties and five sets of principles governing outer space elaborated under the auspices of the United Nations Organization.” [352]

Even before these treaties however, planetary protection as a specific subject had been considered by the International Council of Scientific Unions (ICSU) and the US National Academy of Sciences as far back as 1958, and it was their recommendations that resulted in the eventual incorporation of Article IX into the 1967 Outer Space Treaty (OST).

5.4.1.1 Outer Space Treaty 1967 Article IX [349]

> *State parties to the Treaty shall pursue studies of outer space, including **the moon and other celestial bodies**, and conduct exploration of them so as to **avoid** their **harmful contamination** and also **adverse changes** in the environment of the **Earth** resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt **appropriate measures** for this purpose.*

The later Moon Treaty in 1979 also makes provision for this principle.

5.4.1.2 Moon Treaty 1979 Article 7 (1) [351]

> *In exploring and using **the moon**, [and other celestial bodies] State Parties shall take measures to **prevent the disruption** of the existing balance **of its environment**, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise. . . .[and] shall also take measures **to avoid harmfully affecting** the environment of the **earth through the introduction of extraterrestrial matter or otherwise.***

Guideline: Be aware of the treaties governing outer space. Check if they are applicable to the mission.

5.4.2 Current Policies and Guidelines

The ICSU’s committee on Space Research (COSPAR) is the most important body providing policies and protocols for planetary protection. COSPAR is a non-governmental organization, which serves as a reference and international standard for planetary protection requirements in various projects. It has solid policies and detailed guidelines to avoid biological contamination in space exploration. It interacts with and provides advice to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), other international organizations, and world space agencies.

COSPAR's general policy says:

> *Although the existence of life elsewhere in the solar system may be unlikely, the conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants should not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by spacecraft returning from another planet. Therefore, for certain space mission/target planet combinations controls on contamination shall be imposed in accordance with issuances implementing this policy.* [331]

Based on this policy, COSPAR has issued guidelines for minimizing biological contamination in space missions that are currently categorized to five levels. Appendix D provides a detailed description of the five categories of missions defined by COSPAR. Depending on the mission, requirements vary dramatically. Table 5.1 shows these requirements, consisting of documentation needed and implementing procedures for each of the categories (see Appendix D for details). Through the UN, the world space agencies interact with COSPAR and so its final recommendations are used by the space industry as a whole. For example, COSPAR's policy is the model for NASA's policy that has been adopted as a Directive (see Appendix D).

Guideline: When designing a mission, look at the *current* COSPAR, NASA, and relevant space agency's policies and guidelines.

5.4.3 National Laws

The planetary protection principles from the Outer Space Treaty are not enshrined in national laws. However, they become important when dealing with sample return issues. Existing laws of the different countries need to be consulted. Both the launching state's laws and the receiving state's laws must be taken into consideration.

To take a recent example, a paper written by Centre National d'Etudes Spatiales (CNES) and presented at the 2001 International Astronautical Congress (IAC) discussed the existing French laws on environment, transportation, occupational health and labor. [333] It concluded that with the present state of knowledge, the French regulations would appear to allow the possibility of transporting, storing, analyzing and studying, for example, a Mars sample in France. The reasoning comes from the basis that if it is not forbidden, it is authorized.

It is possible that this basis would not be acceptable when dealing with living samples and national laws will need to look at this area in greater detail.

Guideline: Care must be taken in selecting the launching and return states. Be aware of the laws relating to mission activities and any developing trends and new agreements or laws that will have an impact on those activities. Employ a legal representative who has specific knowledge in this area.

5.4.4 Quarantine Facilities

While sample return missions are planned by the science community in the near future, there are those who argue it should be much later. In the case of Mars, the International Committee against Mars Sample Return (ICAMSR) states that there should be more missions to study the possible impacts of Martian life before samples are brought back.

When a sample return does occur, where should the samples be examined? This will depend on the timescale and which interested groups have managed to have their views heard. In the short term, samples will come to a terrestrial facility; if it is much later, perhaps an Earth-orbiting laboratory such as the ISS may be used. This latter method could also reassure those who are nervous about samples returning to Earth's biosphere. But there would be difficulties using, for example, the ISS. The restricted working environment would place enormous constraints on the type of science that could be carried out, and should infection spread, what

	Category I	**Category II**	**Category III**	**Category IV (A & B)**	**Category V**
Type of Mission	Any but Earth Return	Any but Earth Return	No direct contact (flyby, some orbiters)	Direct contact (lander, probe, some orbiters)	Earth Return
Target Body	Sun, Mercury and Pluto	Venus, Saturn, Uranus, Neptune, comets, Jupiter, outer planets, satellites and asteroids	Mars	Mars	All
Degree of Concern	None	Record of planned impact probability and contamination control measures	Limit on impact probability Passive bio load control	Limit on probability of non-nominal impact Limit on bio load (active control) IV A : level for non-exobiological missions; IV B : level for exobiological missions	If restricted Earth return: - No impact on Earth or Moon - Returned hardware sterile (contamination chain breaking, ie a contact) - Containment of any sample (quarantine)
Representative Range of Requirements	None	Documentation only (all brief): - PP plan - Pre-launch report - Post-launch report - Post encounter report - End-of-mission report	Documentation (Category II plus) - Contamination control - Organics inventory (as necessary) Implementing procedures such as: - Trajectory biasing - Cleanroom - Bio load reduction (as necessary)	Documentation (Category II plus) - Pc analysis plan - Microbial reduction plan - Microbial assay plan - Organics inventory Implementing procedures as: - Trajectory biasing - Cleanroom - Bio load reduction - Partial Sterilization of contacting hardware (as necessary) - Bio shield Monitoring of bio load bioassay	Outbound Same category as target body/outbound mission Inbound If restricted Earth return: - Documentation (Category II plus) - Pc analysis plan - Microbial reduction plan - Microbial Assay plan - Trajectory biasing - Sterile or contained returned hardware - Continual monitoring of project activities: - Project advanced studies/research If unrestricted Earth return: - None

Table 5.1: Summary of Main COSPAR Planetary Protection Guidelines

would become of both the station and its passengers? A future alternative could well be a Moon-based quarantine facility. It is arguable that working in one sixth of Earth's gravity is preferable to working in microgravity and there is less possibility of contamination of the sample by the Moon's environment. Using the Moon as a basis for scientific research should not conflict with the International Treaties and would in effect make it easier for the International Partners of the mission to resolve their differences, as opposed to landing the sample in a particular country.

Guideline: Given the possible debates on this subject and the time needed to prepare, be aware of the current thinking on quarantine facilities for samples.

5.4.5 Environmental Issues

The International Law Commission has recently adopted 'Draft Articles' on the "Prevention of transboundary harm from hazardous activities" [346] which should be considered binding as they codify existing customary environmental law. Two other agreements – the Stockholm Declaration of 1972 [350] and the Rio Declaration of 1992 (Rio Declaration on Environment and Development) formed the basis for these Articles. Articles 9, 12 and 13 are directly relevant to Backward Contamination. They state, respectively, that: An assessment of potential risk is needed; information should be shared with other nations to minimize risk; and the public should be informed about that particular risk.

Guideline: Be aware of the current status of the international provisions and other national environmental laws as they will affect your terrestrial activities.

5.4.6 Liability Issues

More relevant to BC here, normally International Space Law deals with liability via the Liability Convention that provides for State responsibility in the event that "damage" is caused by a "space object". This is however limited in its scope in relation to contamination and so, when looking at potential liability issues, you should also refer to the relevant terrestrial liability regime.

If for example, a quarantine facility leaks, the damage is not caused by a "space object" and therefore not covered under the Liability Convention. The International Law Commission has recently adopted 'Draft Articles' on the "Responsibility of States for internationally wrongful acts" [347] and these should be addressed as they codify existing binding customary law. The State hosting the quarantine facility (if terrestrial) will need to make sure it is not held liable under these Articles that will be binding when finally agreed.

Guideline: Be aware of the status of the Draft Articles mentioned and check existing terrestrial law and cases for liability issues that may concern a sample return mission.

5.4.7 Intellectual Property

"Martian extremophile enzymes may be extremely stable at both high and low temperatures. They could have a fantastic future in industry." [343]

While commercialization of mineral resources in space is debated, little work has yet been done on possible biological materials. On Earth, patenting of these materials is now well established, while DNA is regarded as only another chemical compound. Interestingly, no status is given to its information-carrying role. The World Intellectual Property Organization (WIPO) is a United Nations agency administering a number of international agreements or treaties that cover intellectual property. Together with the World Trade Organization (WTO), it negotiated the Trade Related Aspects of Intellectual Property Rights (TRIPS) act which was the final act of the 1986–1994 World Trade Uruguay Round of trade negotiations and deals with all intellectual property rights. At present, the Act says that its signatory states must facilitate the granting of patents in a large number of cases. However, there are exceptions and, in relation to life forms that provide food, its wording is presently being challenged by states, particularly the African ones, who want to keep this category from being patented by business.

Will TRIPS apply to any life forms found in samples? It is certain that a sample return is going to generate enormous interest and rights in both the actual samples as well as anything they generate. Given the sums of money involved, the details of what happens to them on return to Earth should be dealt with.

Guideline:
- Be aware of developments in Intellectual Property laws and agreements when looking at the property rights in samples returned to Earth.
- Keep up to date on gene patenting debates.
- Take advice from people involved in the law of biotechnology.
- Have agreements relating to the samples prepared in advance.

5.4.8 Precautionary Principle

> *Societal and non-scientific factors represent potentially significant impediments for future Mars missions, especially in areas involving planetary protection.... lack of information may lead to uncontrollable impacts on future missions.... Delay or avoidance in dealing with societal issues early in mission planning will increase the likelihood of public opposition, cost increases and missed launch windows.* [338]

The principle generally known as the "Precautionary Principle" has grown over the years in response to perceived high risk ventures which have failed. It urges caution as a pro-active strategy, remembering always that doing nothing can be as risky as doing something; and includes social, ethical and philosophical considerations. It takes in effect a "snapshot" of the risk landscape.

It has been used in negative ways. Even where there has been no proof as to effect, authorities have applied the Principle and decided not to allow a product, or carry out a proposed action. Imagine the effect this could have on a sample return mission.

Guideline:
- Be aware of this Precautionary Principle and show that it has been taken into account when planning the mission.
- Provide public education about specific contamination issues.
(Note: For example, to mitigate adverse reaction, Section 6.3.1 is showing a sample scenario which deals with contamination; this helps to understand the reaction of the public.)

5.5 Methods of Contamination Reduction

Spreading life to other planets has been a concern of NASA for over 30 years. Although this is often uncontrollable with asteroids continually bombarding our planet, bringing materials from their place of origin, it is in terms of missions that we focus this chapter. As astrobiologists look to find life, we need to implement methods to protect our own as well as other possible life that may exist on another planet. In doing so, we protect what we are studying for future astrobiologists. This chapter will introduce both areas of forward (FC) and backward (BC) contamination, as well as giving present examples to illustrate the current methods. When describing such techniques, we will put forward suggestions for missions outside Earth.

5.5.1 Forward Contamination

We need to minimize the organic material that has the potential to replicate on another planet; the spacecraft must be sufficiently clean and sterile. The specific constraints imposed on a spacecraft will vary depending on the nature of the mission and level of knowledge regarding the target celestial body. The following will describe how to reach an acceptable minimum of FC.

NASA uses Table 5.1 (see also Appendix D for details) to determine the cleaning level required for certain types of missions. [341]

Table 5.1 can be the starting point of how to apply protective procedures. It is important to respect FC guidelines in order to improve our knowledge of extraterrestrial environments. But what do those guidelines mean? How can we achieve them? These questions are covered in this section.

5.5.1.1 Cleaning Methods

Cleaning incorporates physically removing particulates such as dust or microorganisms from a surface (e.g. the spacecraft surface). This is the first step in the process to prepare a sterile spacecraft. For example, below is the advice given to a milk factory where their instrumentation must be cleaned and then sanitized:

> *Proper cleaning with alkaline and acid cleaners only removes organic and inorganic matter in the system. Some of the bacteria associated with the organic residues will be removed during cleaning but the system is not clean of bacteria. The total procedure is not complete unless sanitization is practiced.* [345]

Cleaning does not mean sterilizing. The spacecraft could be visibly clean but not sterilized. The next section describes the sterilization process.

5.5.1.2 Sterilization Methods

Sterilization kills the majority of microorganisms remaining on the spacecraft after cleaning. Like cleaning, sterilization methods did not originate in the space industry; rather, this idea started within the medical, pharmaceutical and food industries. After a sufficient sterilization process, there should be minimal viable (living) organisms. For example, the acceptable probability that any “one” bacterium could survive the sterilization process should be less than 10^{-6}. This was the same Sterility Assurance Level (SAL) or D-Value used for the Viking mission. Hence, a few bacteria survived the sterilization; we must allow for an acceptable number of remnants. A typical number of survived spores after sterilization would be 300 spores per square meter. The last statement leads to an operational definition of sterilization: “A carefully designed and monitored process that will assure the probability of an item being contaminated to be equal to or less than one millionth.” [328]

Table 5.2 illustrates a method of sterilizing the Viking Lander proposed by the Committee on Planetary and Lunar Exploration (COMPLEX). This table gives the conditions of operation of each method and also the effects related to the method used.

Table 5.3 gives other examples of sterilizing processes that are planned for a potential mission to Europa. This table gives the conditions of operation and the problems related to each method.

Several methods exist to decontaminate a spacecraft. But, the use of them depends strongly on the scope of the mission or the COSPAR category (I to V) related to the mission (see Table 5.1 and also Appendix D for details). The two last charts (Table 5.2 and Table 5.3) can help when making a decision to choose the type of sterilization process that fits the most with the spacecraft (or the mission). It is important to notice that this text does not provide how and when to apply those methods, it is for the mission designer to decide.

Sterilization Methods Discussion

It is impossible to completely clean and sterilize a spacecraft. A way to verify if it is sterile is to evaluate a maximum number of spores allowable on a certain surface (spores per square meter). However, a spacecraft is a three-dimensional body, a volume that may be full of microorganisms (or bacteria)! For example, one important factor to take into account is the porosity of a material. The higher the porosity is, the higher the chance of having bacteria both on the surface and in the material. This idea contradicts the validation methods used today, which assume only *surface* contamination.

We need to be aware of this, and should re-evaluate methods to validate the sterility of a spacecraft. Instead of evaluating the maximum number of spores per square meter (surface), why not evaluate the maximum number of spores *per cubic meter* (volume)? We cannot validate contamination levels within materials of the actual spacecraft. A solution would be to generate a database of contamination level results within spacecraft material (not the actual spacecraft) before and after different sterilizing processes. Then, better recommendations

	Conditions	Effects
Heat		
Dry (Viking Methods)	135 ^oC, 24h	Alter organics, volatilizes
Wet/Steam	125^oC, 24h	Alter organics, volatilizes
Radiation		
Gamma (60Co)	Plus grand 1 MRAD	Alter organics
Electron Beam	-	Large facility, untested on rock soil microbial mix
Alkylating Chemicals		
Formaldehyde	Liquid, 80 ^oC	Residual organics
Ethylene Oxide	Vapor, 60 ^oC	Residual organics
Oxidizing Chemicals		
Hydrogen Peroxide	Vapor, 50 ^oC	Some residuals, not tested on rock soil microbial mix
Chlorine Dioxide	Gas, 50 ^oC	Some residuals, not tested on rock soil microbial mix
Ozone	Gas, 50 ^oC	Some residuals, not tested on rock soil microbial mix
Peracetic Acid	Liquid, 50 ^oC	Some residuals, not tested on rock soil microbial mix
Hydrogen Peroxide/Plasma	50 ^oC	Some residuals, not tested on rock soil microbial mix
Mixed Chemical/Plasma	50 ^oC	Some residuals, not tested on rock soil microbial mix

Table 5.2: Viking Lander Sterilization Methods. [341]

Procedure - Target	**Technique - Problems**
Dry Heat Exterior/Interior	105-180 ^oC for 1 to 300 hours Problems caused by thermomechanical incompatibility between materials can lead to the failure of electronic components.
Wet Heat Exterior/Interior	120-134 ^oC for 3 to 20 minutes Problems can be caused by steam (e.g., corrosion and water absorption).
Alcohol Wipes Exterior Surfaces	Isopropyl or ethyl alcohol swabbing Problems arise because interior and encased surfaces (e.g., electronic components) are inaccessible.
Ethylene Dioxide Exterior/Internal Exposed Surfaces	Toxic gas, 40 to 70 ^oC Problems arise because the gas can only reach exposed surfaces and because it is absorbed by some types of polymers (e.g., rubbers and polyvinyl chloride).
Gamma Radiation Exterior/Subsurface	Typically, 2.5 Mrad Problems encountered include optical changes in glasses and damage to electronics and solar cells.
Beta Radiation Exterior/Near-Surface	1 to 10 MeV Problems arise because of limited penetration.
Hydrogen Peroxide Plasma Exterior/Internal Exposed Surfaces	6 mg/l H2O2 concentrated at 58% Problems can be encountered because the unexposed surfaces remain untreated.
Ultraviolet Exterior Surfaces	5,000 to 20,000 J/m2 Problems arise because unexposed surfaces remain untreated.
Methyl Bromide Exterior/Internal Exposed Surfaces	Toxic gas Problems can be encountered because unexposed surfaces remain untreated and because the gas catalyzes chemical reactions between metal and other components.

Table 5.3: Represents common sterilization procedures for a possible mission to Europa. [339]

for selecting spacecraft material and appropriate sterilization methods can be made with knowledge from this database.

5.5.1.3 Clean Rooms

To ensure the cleanliness and sterilizing aspects, all the procedures above should be undertaken in a clean room facility. Clean rooms are highly controlled environments accessible only to trained personnel following strict and unambiguous cleanliness protocols. They are the key to a successful cleaning/sterilizing procedure.

The following bullets represent a proposed procedure for the prevention of FC on Europa. [339]Representative standard NASA clean-room protocols include the following:

- During assembly, workers are required to wear full face shield suits.
- No human contact directly with spacecraft is permitted. Latex gloves are worn in the clean room, and spacecraft are *not* seeded with tracer organisms to facilitate monitoring.
- Cameras are used to observe and monitor assembly.
- Clean-room air passes through high efficiency particulate air (HEPA) filters and dehumidifiers to minimize airborne microbial contamination and corrosion, respectively.
- Surface particles are removed by vacuuming.
- Witness plates are regularly collected and stored.
- Contact between hardware and biologically relevant materials is minimized.
- Surface areas of the spacecraft are monitored periodically for their microbiological burden, during and after assembly. Sterile cotton swabs are used to collect contaminating surface microorganisms, which are subsequently cultured and counted.

Unfortunately, clean rooms do not guarantee contamination-free assemblies. Mistakes happen, and clean hardware may not remain clean. Good in-process cleaning procedures are necessary. A federal standard (Fed-Std-209E) [332] exists that regulates all processes that occur in clean rooms (at least in the US).

Guidelines for FC

When designing a planetary mission, use sterilization and cleaning procedures. Two options are considered:

Option 1:

1. **Building and assembling the entire spacecraft (S/C) in clean conditions (clean room)**
2. **Sterilize the entire S/C (e.g. Dry Heat 135 ^{o}C, 44hrs)**
3. **Keep the S/C sterile until the launch (use of bioshield)**

Option 2:

1. **Building parts of S/C in clean conditions (clean room)**
2. **Group parts of S/C into similar components (e.g. electrical devices with electrical devices) and sterilize each group with the proper sterilizing method (the method that would be more appropriate for each group) [Note : usually the sensors are the most sensitive (weakest link)]**
3. **Assembling the S/C in sterile conditions (clean room)**
4. **Keep the S/C sterile until the launch.**

5.5.2 Backward Contamination

Just as there are methods and restrictions to implement FC, the rationales behind BC need to be considered as well. BC regulations revolve around three policies. One of these is to protect our planet from possible bio hazards from extraterrestrial samples. Another is the protection of other balanced ecosystems and a third is the protection of the integrity of samples returned from other planets. In a hypothetical mission to Mars, a rover would be the most likely mechanism in which a sample would be retrieved. Inside the rover there will be a capsule that will be launched and delivered back to Earth. To protect the sample within the capsule from contamination by the Earth's atmosphere and biosphere, certain materials must be developed to effectively contain what we bring back. The sample needs to be sealed and NASA is currently undergoing research so that welding can be conducted remotely. When the sample returns to Earth, it will enter a "Sample Receiving Facility (SRF)" also known as a quarantine facility [328]. This facility must be a combination of a containment facility as well as a clean room (similar to those in pharmaceutical companies) to preserve the condition of the sample. In this scenario the sample is isolated by the container, and not exposed to the Earth's environment.

The rationale for this type of facility was determined in 1997 when the NRC's Space Studies Board concluded that all samples returned from Mars are considered hazardous until found safe and should be quarantined [341]. On October 29, 2001,COMPLEX came up with a procedure manual for sample quarantine which is summarized in the bullets below:

Procedures Required in a Protocol for Handling Samples in the Mars Quarantine Facility [341]
- Sterilize and cleanse of organic contamination the quarantine facility prior to introduction of the Mars samples.
- Place samples in the facility.
- Inventory and carry out preliminary analysis of the samples.
- Search for evidence of biological activity.
- Assess whether the samples contain bio hazardous material.
- Sterilize aliquots of the samples in preparation for their removal from the facility.
- Remove samples from the facility; and store samples within the facility.

COMPLEX recommends sterilization of materials before they are distributed to the scientific community. Such methods include gamma irradiation and dry heat sterilization at temperatures of 105 ^{o}C. Methods disregarded were those involving gases and liquids because these techniques are not able to penetrate centers of samples [328]. The committee also excluded electron beam irradiation because of limits in penetration as well as expense.

An important compromise made in the sterilization process is the viability of the sample. Unfortunately, organic compounds, the materials that scientists are actually looking for, are destroyed with heat and/or radiation. Also of concern is the amount of damage with varying doses of heat and/or radiation that is still to be determined and researched thoroughly. It is our suggestion that organic materials be tested at varying levels of heat and radiation to see how much of the sample is viable after a certain dose level and time. This type of database, if created, could help regulate how we treat the samples once returned from retrieval missions.

Some BC occurs which we have no control over. This phenomenon is called cross-contamination; it originates from debris and asteroid impacts that hit the Earth. In many cases, we do not realize that it has happened and if we do, there are no available quarantine facilities to bring the sample to. Thus, as much as we try to control the contact time between the sample and Earth, it is inevitable that there will be times when we cannot control what comes here.

Guidelines for BC

1. **Bring back the sample to the ISS and perform tests to validate whether or not the sample is harmful before returning it to Earth.**

2. **Bring back the sample to a Moon-based laboratory and perform tests to verify whether or not the sample is harmful before returning it to Earth. Also, the Moon has 1/6 gravity of Earth, which could be easier than conducting experiments in microgravity.**

3. **Bring back the sample in a Soyuz. This capsule has already proved itself over the years, however it would need to be upgraded to comply with the conditions imposed by bio-containment requirements.**

4. **Bring back the sample in a US Shuttle. The Shuttle has also already proved itself over the years, but again, it would need upgrading.**

5. **Bring back the sample by a ballistic entry.**

Guidelines for quarantine facility

1. **Design a new quarantine facility for the proposed mission.**
2. **Reuse the existing Apollo Missions' Lunar Quarantine facility.**

5.6 Planetary Protection Summary

The desire to protect both the interests of humanity and science motivate planetary protection. International law and national policies establish the legal basis of planetary protection and include the Outer Space Treaty, the Moon Treaty, and policies defined by COSPAR. Working within the international legal framework, national space agencies also develop their own policies, guidelines, and protocols on planetary protection.

Figure 5.1 gives a pictorial summary of the key aspects of planetary protection discussed in this chapter. It illustrates the interaction between the scientific, legal, political and societal parts of the whole subject and it summarizes the physical methodology presently or proposed to be used to deal with both Forward and Backward Contamination.

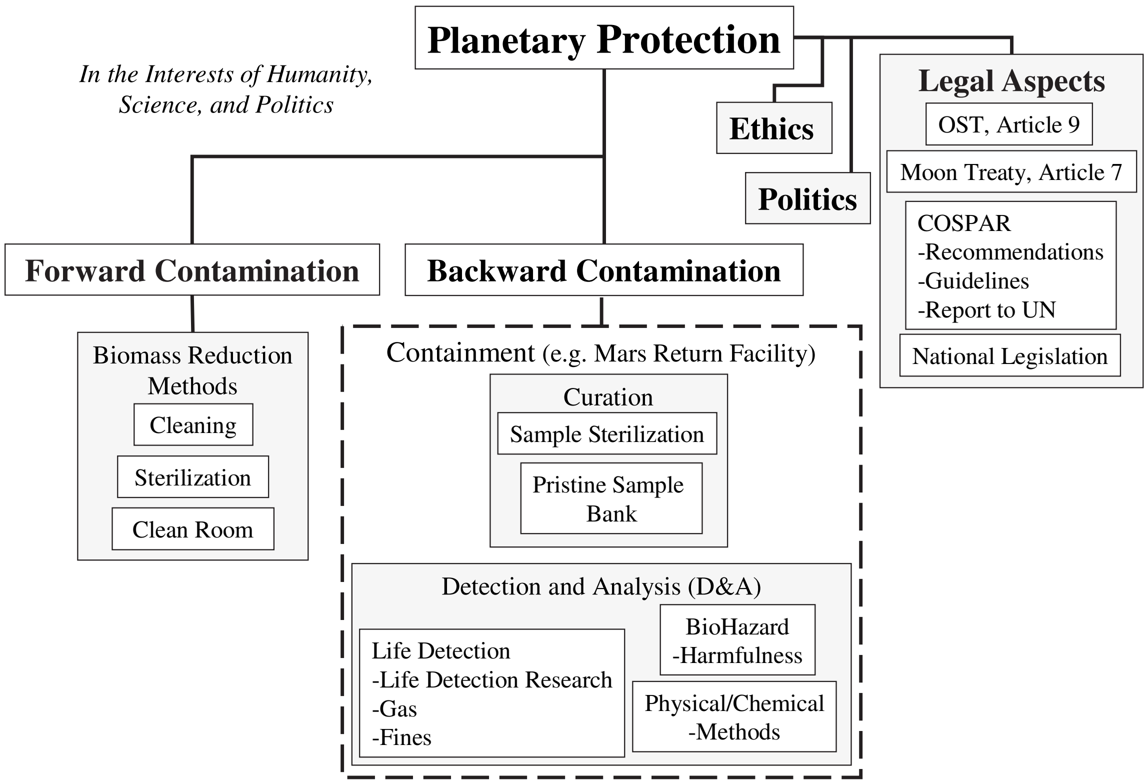

Figure 5.1: Planetary Protection Summary

A well-disciplined protocol for addressing the key aspects of planetary protection is essential to the success of any astrobiology mission. We must address questions and concerns regarding the potential danger to the Earth, the ethical considerations of potential contamination, and the strict adherence to scientific methods. Only then can we look to obtain approval from the public, national, and scientific communities to support humanity's quest to search for life beyond.

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Part III

Human Elements

Chapter 6

Impact on Humanity

6.1 Introduction

"The discovery of life outside the Earth will be the single, most dramatic event in the entire history of humanity, nothing less and nothing more." – European Southern Observatory astronomer Richard M. West. [424]

"Forecasting how contact with an extraterrestrial civilization will impact human society is basically an impossible task." – Ben Finney, anthropologist, University of Hawaii. [377]

In this chapter we discuss both the history of public reactions when it was thought extraterrestrial life had been discovered, and also what the future may hold for humanity if contact is made. In an effort to explore the range of responses that can occur should humanity find evidence of extraterrestrial life we chose to discuss four different scenarios. These have been based on *distance* and the presence of *intelligence*. Distance and intelligence are also two of the variables in the Rio Scale, proposed to quantify the impact of a public announcement regarding evidence of extraterrestrial intelligence [409]. The definitions of these two terms tend to be nebulous, so for the purpose of this report *intelligent life* implies sentience and the ability to communicate, and *near* is within our solar system. This approach allows us to discuss general impacts but also gives us the opportunity to explore the nuances of the scenarios and to develop ideas that may not arise when discussing a generic situation.

The four scenarios discussed are:

- **"Life on Mars" (Near/Simple):** A crewed Mars mission in 2020 has discovered microbial life that is likely to be native to Mars, and is returning a sample to Earth for further investigation
- **"The Wow! Signal" (Distant/Intelligent):** A simple radio signal composed of a count from 1 to 11 has been received from the vicinity of a sun like star 110 light years away
- **"They're here!" (Near/Intelligent):** An extraterrestrial craft is detected during the search for Near Earth Objects. It has entered Earth orbit, but has not responded to efforts to communicate with it
- **"Exoplanet Life" (Distant/Simple):** The Next Generation Space Telescope has observed the atmosphere of a terrestrial planet of a nearby Sun-like star, and determined that the atmospheric chemical abundances indicate the presence of life

The scenarios were defined in such a way to include a wide range of reactions within the 20-year horizon of our design project.

A human sample return mission was chosen in the first scenario, because such a mission would include possibilities that would not exist if only a remote probe was considered. The possibility that the astronauts themselves may be a threat, due to the personal transfer of contagions, is interesting. If it were only a remote probe that was on its way to Earth, there would always be an option to destroy the probe instead of allowing it to return to Earth.

Search for Extra-Terrestrial Intelligence (SETI) and affiliated communities have studied the radio contact scenario for years. The distance in the second scenario was chosen such that two-way communication within a single lifetime is not possible. Also, the aspects of the signal were chosen in a way to suggest non-human intelligence behind the signal.

The detection of an extraterrestrial craft in the third scenario would leave no doubt that it came from an intelligent life form. The craft also displays behavior that is ambiguous and may be interpreted as hostile or benign. Both possibilities will be discussed.

The detection of an exoplanet that shows possible evidence of biological activity is made by inference of spectral features. This scenario is unique among the four, as it does not allow us to conclusively determine that extraterrestrial life has been found within the 20-year timeframe discussed here. In addition, this scenario shares many of the same impacts as those of the Martian sample return mission. This scenario is therefore discussed in less detail than the others.

Finally, a discussion of existing guidelines is presented that may help to counter the adverse effects of contact with extraterrestrials and provide some suggestions for new guidelines.

6.2 Historical Perspective

This section examines some historical examples where humans thought that contact with extraterrestrial life had been established. Although most of them were quickly identified as false alarms, their long-term impact was small. Initial reactions varied from indifference outside of the scientific community to huge mass panic. These examples are therefore helpful for the work on the impact scenarios, which are presented in section 6.3. For three of the four impact scenarios, historical examples exist:

- Near/simple: ALH84001
- Near/intelligent: War of the Worlds, and the Canals on Mars
- Far/intelligent: Discovery of quasars and pulsars

Whilst it was not difficult to find material that explained the history of their discovery and the impact on the scientific community, it was much harder to determine the impact on the public. Newspaper archives proved to be a valuable source, as they represent public consciousness at the time examined.

6.2.1 Canals on Mars (late 19th century)

"*Certainly what we see hints at the existence of beings who are in advance of, not behind us, in the journey of life.*" – Percival Lowell [388]

In the late 19^{th} century many astronomers were turning their telescopes on Mars , among them Giovanni Schiaparelli from Italy. In October 1877, Schiaparelli mentioned for the first time that he saw straight lines on Mars. He called them "canali", which is the Italian word for "channel". In the translation to English however, "canali" turned into "canal", which denotes an artificial waterway. However, Schiaparelli (who was color-blind) was definitely referring to natural channels, which is backed by the fact that he frequently used the synonym "fiume", the Italian word for river. For many years Schiaparelli restricted himself to observations and refrained from speculation about the nature of the channels. Only in 1893 in his paper "The Planet Mars" did he voice his opinion that the channels were natural geological features of Mars.

Schiaparelli was the only astronomer to observe the channels until 1886, when other astronomers finally "discovered" them too. In the 1890's, when the public interest for Mars was rising, the American astronomer Percival Lowell became interested in Mars through reading Camille Flammarion's book "La Planete Mars"[378], in which the author supported the idea of intelligent life on Mars. From 1894 until his death in 1916, Lowell observed Mars and developed a theory that a civilization on Mars created huge waterways in order to collect the scarce water resources to stay alive on a dry desert planet. These theories he published in several books such as "Mars" (1895) (refer to Figure 6.1), "Mars and its Canals" (1906) and "Mars as the

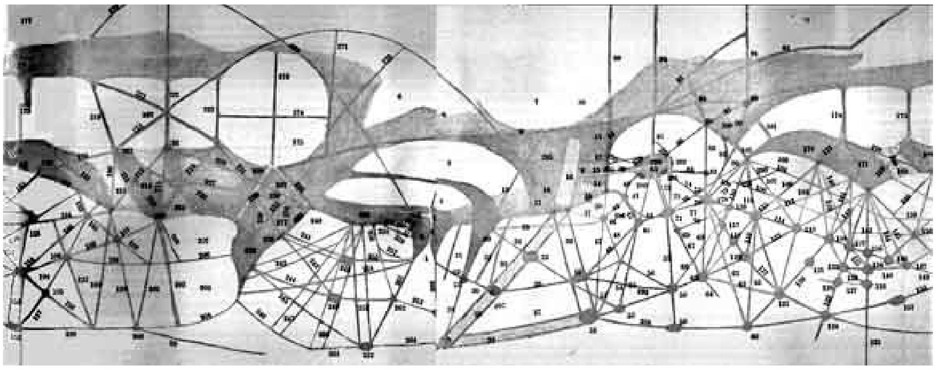

Figure 6.1: Map of Mars Canals by Lowell from his book “Mars”

Abode of Life” (1908). While many of his astronomer colleagues remained skeptical, the idea of life on Mars became widely popular at that time.

6.2.2 War of the Worlds (1938)

“Don’t bother to listen. Probably bore you to death.” – Ben Gross, radio critic [381]

On Halloween Eve 1938, the young actor/director Orson Welles produced a radio play of H.G. Wells’ science-fiction novel “The War of the Worlds” for the Mercury Theater in New York. In this play Martians attack the Earth with superior weaponry after landing in Grover’s Mill, New Jersey. Radio was then seen as a credible source of information and Welles fully exploited the power of the medium. The novel was transformed into an unfolding news story, with field reporters delivering live broadcasts from different locations with short pieces of music in between. As war in Europe was becoming more and more likely, the public was accustomed to frequent news flashes interrupting programs. Also Welles included a speech by a “Secretary of Interior”, which was a clear imitation of President Roosevelt. All this created a realistic atmosphere that fooled a large part of the audience, although several times during the broadcast announcers explained that this was only a radio play. It was estimated that out of 6 million listeners, 1.7 million believed that it was real and 1.2 million were severely frightened. [363] The consequences were amazing, especially in the Northeastern United States. Streets were jammed with cars as people tried to flee from the invaders. People put on their World War I gas masks. Hospitals had to treat people for shock and many volunteered to fight the invaders. This was fully reported by the press, even making it to the front page of the New York Times (see Figure 6.2).

The New York Times

NEW YORK, MONDAY, OCTOBER 31, 1938.

MEAD STANDS PAT AS A NEW DEALER IN BID FOR SENATE

Democratic Candidate Opposes

Radio Listeners in Panic, Taking War Drama as Fact

Many Flee Homes to Escape 'Gas Raid From Mars'—Phone Calls Swamp Police at Broadcast of Wells Fantasy

OUSTED JEWS FIND REFUGE IN POLAND AFTER BORDER STAY

Exiles Go to Relatives' Homes

Figure 6.2: Headline of the New York Times October 31st,1938

While this example is very popular and probably has the best documentation of public reaction [364], one has to be careful to use it as a representative reaction for contact. It can be assumed that if “Martians” had been replaced by “Germans” in the play, similar panic reactions would have occurred. This is supported by the fact that several citizens actually believed that the Germans were attacking. [386] The critical factor for the reaction of the population was that they were being attacked by a superior force. Thus this example serves very well to demonstrate the impact of an invasion, but not necessarily to make general predictions about contact with extraterrestrials.

6.2.3 The Discovery of a Supercivilization (1965)

"A supercivilization has been discovered." – Nikolai Kardashev [415]

In 1965 Soviet astronomer Gennady Sholomitsky discovered that the stellar object CTA-102 emitted huge amounts of energy and that this output was fluctuating rhythmically, with a period of 100 days. This finding was first published in an astronomical journal without creating any major reaction. [411] Although he was careful not to speculate about the origin of the fluctuations, the Soviet News Agency TASS announced on April 12, 1965 that CTA-102 was the beacon of a supercivilization. They went on to quote Russian scientist Nikolai Kardashev with the words "A supercivilization has been discovered." This news made it to page 1 of the New York Times. [415] However, a parallel article that critically reviewed the results and warned about premature conclusions accompanied it. Only one day later the Russian scientists held a press conference and announced, "the news was premature." [414] Obviously TASS was too eager to publish the "sensation" without waiting for confirmation from the scientists. Shortly thereafter, CTA-102 was identified to be a quasar and the artificiality of the signal could finally be ruled out.

6.2.4 Pulsars and Little Green Men (1967)

"Oh that settles it, it must be man-made." – Antony Hewish [413]

Another example from the astronomical world occurred in 1967, when a young Ph.D. student in Cambridge, England discovered a radio signal that was first mistaken as a message from "Little Green Men". Jocelyn Bell Burnell was searching for quasars with a wide antenna field, when she detected a pulsating radio signal with a period of 1.33730113 seconds, which was amazingly stable. The short period excluded all astronomical phenomena known by then as the source and the pulse length of only 0.016 seconds implied that the source must be very small, approximately the size of a small planet. After man-made interference such as radar and satellites was ruled out as the source, the scientists seriously discussed the possibility that these signals were originating from an extraterrestrial civilization. Shortly before Christmas 1967 the scientists gathered, to discuss how these results should be presented to the public. Soon after, more pulsating radio sources were found and they were named LGM-1 through 4, with LGM standing for "Little Green Men".

The results still had not been published when tests showed that the sources failed an important test for artificiality. If the source was a small planet orbiting a star, then a Doppler shift should be visible in the signal. However, no such shift could be detected, which ended the speculation about Little Green Men. When the results were finally published in the journal *Nature* in February 1968, the brief mentioning of the extraterrestrial discussion created some interest by the press, which was further fueled by the fact that a (then rare) female astronomer had made the discovery. However, the coverage was restricted to the newspapers' science sections and "the journalists' interest lasted about two weeks and then died!" [358] Finally, pulsating radio stars (pulsars) were identified as the source of the signals and this discovery earned Antony Hewish (Bell Burnell's supervisor) the Nobel Prize for Physics in 1974.

6.2.5 Fossil Microbial Life in ALH84001 (1996)

"If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered." – Bill Clinton [365]

On August 6, 1996, NASA Administrator Dan Goldin released a statement that "NASA has made a startling discovery." [395] During a next-day press conference NASA scientists explained that they had discovered evidence for fossil microbial life in a Martian meteorite called ALH84001. [396] This 1.9 kg meteorite had been found in 1984 in Antarctica where it had impacted 13,000 years ago. These findings were supposed to be published in *Science* magazine one week later, but rumors about the discovery spread and led to the press conference. This announcement had a large impact and made front-page headlines in major newspapers all over the world. The scientists were very cautious and David McKay, Chief Scientist of Astrobiology at NASA JSC, said " And we're not claiming that we have found (...) absolute proof of past life on Mars". [385] The reaction of religious leaders was mixed. While most of them saw the findings as a manifestation of God, some evangelists refused the claim and insisted that life exists only on Earth. [365]

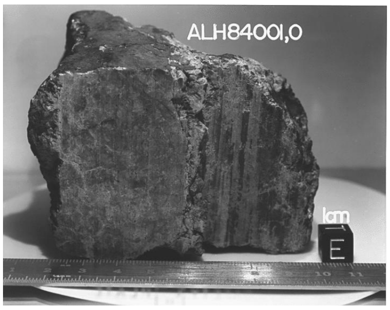

Figure 6.3: Meteorite ALH84001 (Image: NASA)

Shortly after the announcement the scientists were confronted with criticism and doubts. This led to a heated discussion, but due to the highly complex nature of the scientific details and the absence of new developments the interest of the public quickly faded. This is indicated by a steep decline in press coverage approximately two weeks after the discovery. The claim that ALH84001 contains proof of ancient Martian life is still debated today - six years after the initial announcement.

6.2.6 Other Examples

This section contains a short list of other examples of perceived contacts, which had less impact on humanity and are therefore only briefly described.

Bat Men on the Moon: In August 1835 the New York Sun published a series of articles, which claimed the discovery of an intelligent civilization on the Moon. This was however a hoax with the goal to boost the circulation of the paper, that it successfully did as nine out of ten readers believed the story. After a week the secret was revealed and the story ended. [382]

Radio Signals from Mars: In 1899 famous inventor and scientist Nikola Tesla claimed that he had received radio signals from Mars. [410] This was repeated on December 7, 1900 when Lowell's assistant supported this by optical observations. Another famous inventor Gugliemo Marconi claimed in spring 1919 that he received messages from Mars. All this created a large amount of public interest so that in October 1926 radio amateurs were anxiously waiting for messages during a close opposition of Mars.

UFO Sightings, Abductions, Crop Circles: Since the initial flying saucer sighting in 1947 [370] many people believe that they have observed UFOs or have been abducted by aliens. Other phenomena include strange patterns in crops that are considered to be signs made by aliens. These reports are spread all over the world and are not restricted to certain cultures, age groups or social classes. While the general public, as well as the scientific community, do not accept these claims as evidence, it can be assumed that these constant reports have a certain impact on humanity and probably increase the number of people who believe that extraterrestrial life exists.

Roswell: On June 14, 1947 (shortly after the first flying saucer sighting [370]) metallic debris was found on a field 120 km north of Roswell, New Mexico. When the debris was turned in to the US Air Force on July 7, 1947 the base commander released a report to the press that these were parts of an alien spaceship, which was captured at Roswell Army Airfield (RAAF). The news went around the world and created a myth still alive today. The military reacted to the news frenzy a few days later by explaining that a weather balloon had crashed. In July 1994 the US Air Force admitted that the weather balloon story was a cover-up for a crashed balloon used for missile warning [354], and this was confirmed by another report from the General Accounting Office in July 1995. [379]

The Face on Mars: The Viking orbiters (see section 2.3.1.1) took an image of a hill on Mars in 1976, that looked like a human face. When publishing it NASA immediately labeled it an optical illusion, but several people nevertheless claimed to have found proof of an advanced civilization which had constructed the face as a signal. This led to a long lived Mars myth, which was finally dissolved in 1998 when Mars Global Surveyor took high-resolution images of the area showing nothing but an ordinary hill. However, the fact that NASA's observation planning was altered to cover this area is a sign of how strong these myths are and how present they are in our everyday life.

6.2.7 Conclusions

A number of perceived contacts have been analyzed within this section. Almost all of them were false alarms discredited after a few days. Some are long-living myths or still unsolved questions. So what can we learn from these examples?

- Because all contacts were discovered as false alarms quickly, they provide us with some insight only with regard to the initial reaction and not the long-term impacts of discovery.
- The example of Sholomitsky's CTA-102 clearly demonstrates why certain guidelines have to be established for the announcement of the first contact. Independent observers should verify discoveries, and natural or man-made causes should be ruled out before making an announcement.
- Many of the quoted examples (e.g. War of the Worlds, CTA-102, and ALH84001) made it to the first page of major newspapers, which indicates a strong public interest in the subject. The discovery of extraterrestrial life might therefore create strong interest and media hype.
- However, as the ALH84001 example suggests, public interest might quickly disappear when no new developments are broadcast and when the discussion is held on a complex scientific or technical level incomprehensible to the general public.
- Although none of the events mentioned provided final proof, we believe their consequences have already had an impact on humanity, by increasing the awareness for the possibility of extraterrestrial life.

According to a Gallup poll of US citizens, taken in September 1996, 72% of US adults believe that life exists outside of the Earth. [417] Another 45% believe that extraterrestrials have already visited the Earth. These numbers could indicate that humans are already quite well prepared for the first contact.

6.3 Scenarios

6.3.1 "Life on Mars" (Near/Simple)

In the year 2020, an international manned Mars mission is underway. The major partners include the United States, Europe, Canada, Japan and Russia along with other countries. The crew is international, representing the agencies involved in the mission. During the course of the mission, a simple bacterial life-form has been discovered. It seems certain that this life is native to Mars. A sample of this material was collected on the surface of Mars and is now on its way back to Earth aboard the crew return vehicle. The crew return vehicle will splash down in the Pacific Ocean. It will then be transported to a containment facility where the crew will be quarantined for several weeks while they recover and the biological sample is isolated until such time as it can be proven harmless to the Earth's biosphere.

6.3.1.1 Societal/Cultural Impacts

As shown with the suggested discovery of fossil evidence in the Martian meteorite, initial interest in the discovery of simple life may soon fade, as the general populace would go back to coping with their daily lives.

Once the crew return vehicle is on its way back to Earth, elements of the media would start talking about the possibility of Earth being contaminated with a deadly virus, in the worst case leading to the publishing of a possible Armageddon scenario where it could wipe out all of humanity and life on Earth. What would really be important at this point is how well governments and the scientific community are able to allay people's fears and convince them that the quarantine procedures are adequate, and also show that there are no safety risks even if there was to be an accident during re-entry, see section 8.12 for more suggestions on how to educate and prepare people. To calm the populace, the scientists could also use the fact that Earth has already been contaminated by Mars through the natural transfer of material.

If these explanations are not disseminated in an appropriate manner there is a small chance that some citizens would call for the vehicle, and the crew within, to be barred from returning. This would be touted as a sacrifice of the few, to save the many. Nevertheless, as the mission itself would have lasted a number of years, there would have been plenty of time to prepare the populace for the discovery of life, and prove to them that the contamination procedures are adequate.

6.3.1.2 Political/Military Impacts

The most interesting aspect in this scenario is the possibility of backward contamination (see chapter 5.1). There is a chance of the crew being contaminated. There is also a possibility that the crew return vehicle is carrying some Martian bacterial life, posing a threat to the Earth's biosphere if it enters the atmosphere and lands in the ocean.

To date, the main international provisions regarding contamination issues are provided by the Outer Space Treaty (1967) and the Moon Treaty (1979). According to these treaties, countries involved in the mission should take measures to avoid harmful contamination of the Earth's environment (for a detailed discussion of the legal aspects refer to the Planetary Protection section 5.4). Therefore, in the present scenario, the countries would have to find a way to break the contamination chain (perhaps by making a sample transfer between spacecraft). If they are unwilling to do so, the United Nations would need to decide on the actions to take. The nationalities of the astronauts on board may play an important role if the decisions and orders coming from the countries involved in the mission are contradictory.

One way of preventing extreme reactions when dealing with the contamination issues is for governments to take an active role in information control through direct censorship or by undertaking outreach and awareness programs (as suggested in section 7). This stems from the fact that public reaction response might be ambiguous: a feeling of fear of (a possibly dangerous) bacteria and a consequent desire not to return to Mars, or a feeling of joy and accomplishment that can act as a catalyst to further missions. If the countries have state owned communication centers (e.g. television and radio networks), this task will be easier. However, such efforts might be weakened by a prevailing public mistrust of government.

Another important factor at the political level might be that nations try to gain sole access to the sample, so that they have complete control. This could be driven by the possible advantages to be gained in technology, medicine and new biological weapons. This can also influence decisions about where to transport the sample once it arrives on the surface (liability issues would have to be addressed). Use of the International Space Station or the Moon as a quarantine facility might also be a possibility, but the legal issues would still have to be addressed.

6.3.1.3 Scientific/Technological Impacts

Discovering a new form of life would enable us to determine more about the nature of life as we currently understand it. It would be necessary to investigate whether life arose independently, and was not just a transfer between the two planets. This would include showing both the similarities and differences that occur between life on Earth and the newly discovered Martian life.

An increased emphasis would be given to planetary protection, but the discovery of life on Mars may lead to an increase in missions looking for other forms or signs of life. Europa would be a prime candidate for this search, due to the evidence of oceans existing under its icy surface (see sections 2.3.1.3 and 4.4). This would not just be limited to searches within our solar system, but would encourage further development in remote sensing of extrasolar planets looking for biological signatures in their atmospheres.

Further funding may be made available for SETI type signal detection programs as finding life elsewhere, even simple life, may increase the likelihood of intelligent life being discovered. The pharmaceutical and biotechnology industries would be very interested to see how the new organism could be used for research into vaccines or cures. Scientific funding will ultimately only remain at the increased level if it can be shown that significant results are being achieved within a certain amount of time.

6.3.1.4 Religious/Philosophical Impacts

The premise that life might exist on other planets is not a new one. In the 5th century BC, Democritus and his pupil Metrodorus argued that other worlds must be inhabited."To consider the Earth the only populated world in infinite space is as absurd as to assert that in an entire field sown with seed only one grain will grow". [413]

There is a long history of debate between, even within, religions with regards to the presence of other worlds and life on those worlds. Philosopher Giordano Bruno was burned at the stake by the Catholic Inquisition [376] in the year 1600, in part for suggesting that an infinite number of worlds existed. Reverend Timothy Dwight in the late 1700s believed that God created a "countless multitude of worlds with all their various furniture" and in the mid nineteenth century the Jesuit astronomer Father Angelo Secchi insisted that "These worlds are bound to be populated by creatures capable of recognizing, honoring and loving their creator". [413] In fact, many western religious scholars suggest that the presence of other life in the universe does not diminish God's role, but rather amplifies it. These scholars reason that a multitude of living planets adds to the glory of God, since it implies that life was created *everywhere* in the Universe. C.S. Lewis proposed that there is even a reason behind the vast distances between stars, namely to "prevent the spiritual infection of a fallen species from spreading". [413]

The modern picture of the Abrahamic religions (Judaism, Christianity and Islam) is a mosaic. The few sects for whom extraterrestrial life is central to their beliefs will likely see a discovery of this life as validation. Groups without clear views on the subject will likely adapt and revise their views to integrate them with the findings. This group seems to be the majority of the followers of western religions. The Church has shown in the past that it can adapt to revelations of science over time. We can see evidence of this in the past when it evolved to accommodate the Copernican and Darwinian revolutions. Even in light of overwhelming evidence of extraterrestrial life, people who are adamantly opposed to the idea will declare this evidence as fraudulent or that life was transported from Earth. This would support the concept that all life had a common origin.

Eastern faiths like Hinduism and Buddhism will undergo little or no change since the doctrines embrace the concept of multiple inhabited worlds (for details, see Section 6.3.3).

Finding a second, independently originated form of life within the solar system says something about the conditions for life everywhere. The Anthropic Principle states that the universe has the exact characteristics required to enable humans to exist and be capable of observing the universe. If we find another source of life then the implication is that the universe has the characteristics not only for humans to arise but for life in general to arise.

The discovery of extraterrestrial life can also be seen as the latest development heralding the diminishing importance of life on Earth. This is a process that began when it was claimed by Copernicus that the Earth was not the center of the Universe. Subsequent discovery that our Sun was not the center of the Universe and that indeed the location of our solar system and even our galaxy in the cosmos were not special furthered this process of diminishing. However, even acknowledging that our physical place in the universe was unimportant, there existed a mentality that humanity itself was special due to its uniqueness. The discovery of extraterrestrial life would, at least to some extent depending on what kind of life was found, invalidate this reasoning.

The discovery of Martian microbes might spur a movement to expand our environmental ethics beyond our home planet. Chris McKay (planetary scientist at NASA Ames Research Center) noted that the well-being and diversity of non-human life forms on Earth are considered to have inherent value regardless of their usefulness to humans. Would Mars be valued more if life is discovered on the planet? Would terrestrial environmental ethics be applied to Mars? [376]. See also Chapter 5.3.

6.3.2 "The Wow! Signal" (Distant/Intelligent)

In the year 2008, a radio signal has been received at the Arecibo radio telescope that seems to indicate an artificial source. The signal, a simple pulse count from 1 to 11, is at a frequency of 1420 MHz (the so-called Hydrogen line frequency) and repeats every 3.2 seconds. The signal seems to be coming from a planet around a star 110 light years away. The star is similar to our own - a GII spectral type, luminosity class V main sequence star. Ground based telescopes have been trained on the star to try to determine the composition of the system that the signal came from. It has been determined by Doppler shift data that the system contains at least 4 planets. This stellar system is very different from our solar system. Three of the planets are massive gas giant planets with masses in the range of 2 to 10 Jupiter masses. One of these three giant planets is at a distance of 2 AU from its star. The other two giants are much farther away from their star at distances of 12 and 23 AU. The fourth planet is a very heavy terrestrial planet with a mass of 3 Earth masses. This planet orbits its star at a distance of 0.7 AU.

6.3.2.1 Societal/Cultural Impacts

In all of these scenarios the impact of popular science and science fiction must be considered. Since 1984 the SETI Institute (refer to section 2.4.1.3 has been searching for radio signals, and so society may be prepared to discover proof of extraterrestrial intelligence in this way.

The level of fear produced in this scenario should not be too significant, as there would appear to be no immediate threat, unless the message itself could be deemed threatening. Much of the reaction of the general populace would depend on whether scientists could decode the transmission received. There would be initial euphoria about the discovery of intelligent life outside of our planet. However, as the months go by without any unraveling of the message, interest would begin to wane as people realized that their lives were not going to change.

There is a chance that it would not be possible to decipher such a message, in the absence of detailed decoding instructions. The translation of ancient Egyptian hieroglyphs can serve as an analogy. In this case the hieroglyphs remained indecipherable until the Rosetta stone was discovered. This stone provided a translation of hieroglyphs into Greek, a language that could be read. So unless the extraterrestrial intelligence provides its own Rosetta Stone it is highly unlikely that the message could be decoded.

Is the signal simply a beacon that tells us that they are there? If the message is decoded then the content of the message becomes of utmost importance. If it were a simple greeting of no practical use, the societal impact would most likely be minimal, once the initial excitement subsides. However, if the message contained understandable encyclopedic information that could be put to immediate use, the societal impact would be immense. For example, if a method to solve Earth's energy requirements in an everlasting, extremely cost effective method was supplied. This would be even more so if repeated in all fields of human endeavor. Vast numbers of the populace would suddenly not be required to work and this could lead to a complete change in lifestyle. This could lead to the human race becoming stagnant and not contributing to the newly found galactic community. Instead, whenever anything was required we could refer back to this galactic encyclopedia for solutions. Our values, attitude and behaviors could also change, in a similar way to the history of Hernando Cortez and the Spanish conquest of Mexico in the early sixteenth century. The Aztec empire ceased to exist at this point and became a Spanish colony, gradually adopting their values and way of life. However, it must be remembered that any analogies made are just possibly useful guides rather than behavioral predictors.

A great deal of discussion would take part as to whether we should respond. The speed of the conversation, using radio waves, would be of the order of a couple of hundred years. This would allow generations of humans to grow up thinking of this scenario as being "normal", and so the impact of further communications would be considerably lessened. The shorter the turn-around time of communication, the closer this case resembles the near/intelligent scenario to be discussed in section 6.3.3.

6.3.2.2 Political/Military Impacts

Individual countries might consider how urgent it is to address the situation where a signal has been discovered. The fact that it is 110 light years away implies that there is no immediate threat. In addition there are so many more immediate concerns in the individual countries, for example hunger, regional conflicts, diseases, malnutrition and environmental concerns.

The measures taken by the different countries depend on the different initial public perceptions regarding the existence of an extraterrestrial civilization. The political and military climate in individual countries has a large influence on what these perceptions are. In this context, the role of the individual governments and possibly the military hierarchy will be critical in avoiding extreme reactions at the social and economical level. If the public thinks the extraterrestrial intelligences (ETIs) are a threat, it may lead to public disorder. Strong and effective government actions might be expected, including military enforcement, if necessary. If the signal is perceived as suggesting a friendly extraterrestrial civilization, a much more moderate reaction is expected. Governments and special interest groups, both publicly and privately funded, are expected to continue investigating the signal.

The political reaction will also oscillate between two very different scenarios. The first one is a "united humanity" reaction where an international organization (e.g. the United Nations) would try to address the problem from a global perspective and try to find a consensual solution suitable for all countries. That organization would also have a major role in preventing any country from feeling displaced, frightened or angry, as a way of avoiding violent reactions. The second scenario is an "each country for itself" reaction, where individual countries attempt to deal with the situation independently. Distrust, national prestige and the necessity to feel in control could be some of the reasons why individual nations would want to follow this strategy.

One of the factors that could have a strong influence on how political decisions are made is the problem of deciphering the message. Some countries have more developed decoding methods than others. If a world response were prompted, the international organizations involved (governmental or not) would have the task of guaranteeing all nations free access to the decoded signal information. This task may be unattainable if the deciphering program were to fall under the command of a military or intelligence organization. This effort may have to be an intense and continual one.

For the possible developments of the scenario under consideration, the control of information flow is always a critical factor. Despite the existing SETI protocols, that are considered later, united governments can exert control to minimize negative public reaction. The countries involved in the decoding process, can also exert control in order to have a stronger position in eventual negotiations (along with the possible military/economic advantages of being the first to decode the signal information). Aldrin suggests that "the military institutions would not deal with the issue because the extraterrestrial civilization is too far away to be initially considered a threat". [355] Despite this, a limited amount of resources might be devoted to try to determine if there is actually a threat and if there exist any tactical advantage to be gained.

International organizations involved might have to address the following questions: who decides what to do and how to do it? Should we reply? The IAA position [404] was presented at COPUOS [423]. An official response to the transmission would probably have to be made to try to negate the effect of any unofficial "rogue" transmissions. Who is going to reply on behalf of all societies, countries and cultures?[1] How should relations be conducted in the distant future? The ones that may receive an answer will not be the same that sent the question (because of the delay of transferring the signal). In fact an effort encompassing several generations may have to be made, and the way that countries deal with this area of communication is likely to create the area of greatest tension.

"It is important for SETI scientists to face the chilling reality of government power. If a national government becomes strongly displeased with a small group of SETI scientists, then in actual practice there is almost no limit to what that government could do." [420] Governments may choose to regulate information to slow down the spread of possibly false or misleading news (internet, television, newspapers, etc), or even decide to bring certain communication relays to a complete stop. An extreme reaction would be to shoot down the communication satellites if necessary. Other extreme reactions could include hijacking/jamming communication signals, military takeover of communication centers and control of communication between colleagues in the SETI environment, or they could "... arrest anyone who tries to help them... even jail them or make them disappear. It is foolish and dangerous to underestimate the covert and overt capacities of major national governments..." [420] However, SETI scientists have attempted to come up with a mechanism to properly spread the information, to prevent some of these events from occurring (SETI protocol as described in [404]).

From the economic viewpoint, technology companies involved in the reception and deciphering of the message, remote sensing and supporting space infrastructure may see benefits as funding is increased in these areas.

[1]During the World Space Congress, in October 2002, one of the sessions organized by the recently formed SETI Permanent Study Group will address these issues.

6.3.2.3 Scientific/Technological Impacts

The first reaction of the scientific community to the news of this signal would be that the astronomical community would allocate every appropriate resource to observation of the stellar system from which the signal originated. Social scientists including cryptographers and linguists, mathematicians and other experts would scrutinize the signal to verify that it is artificial and to attempt to decode it.

If the signal cannot be decoded or turns out to be a simple beacon, public interest and funding will soon be reduced if no results are obtained. It is possible that the decoding of the message will not be possible immediately, but will have to wait for our technology to mature somewhat. In any case, the receipt of a message that is confirmed to be artificial, is likely to result in a return of SETI to public favor and subsequent allocation of funds.

There must be a distinction between decoding and interpretation. It may be possible to decode the message and still obtain no understanding of its contents due to fundamental differences in our basic knowledge and experience, compared to that of the extraterrestrials.

The long-term effects could include the construction of more ground and space based telescopes to continue the search for life (refer to section 2.2.3). This is likely to occur years after the initial discovery is made, when some of the excitement subsides. It is also possible that there will be a long-term investment in supporting enabling technologies required for sustained presence in space. Areas that may be focused upon include advanced propulsion systems, communication systems, power systems and life sciences.

6.3.2.4 Religious/Philosophical Impacts

The receipt of this signal in itself may not be any more significant than the near/simple scenario. Some groups would likely contend that this signal is naturally occurring and the resulting doubt would diminish any paradigm shift.

If however there were information coded into this signal, what could we learn from it? What does the signal say about the aliens? For instance, can we learn about the appearance of the alien race? What are the implications of their appearance? Arthur C. Clarke , author of the novel Childhood's End, which concerns mankind's first encounter with an alien species, suggests "The assertion that God created man in his own image is ticking like a time bomb in the foundations of Christianity" implying that the alien race is likely to look radically different from humans and that Christianity, as well as many other current religions, may not survive this kind of discovery intact. However, Bahaullah, the founder of the Baha'i faith, indicated in his writings that there are likely to be creatures on other planets that may, or may not, resemble humans. "Know thou that every fixed star hath its own planets, and every planet its own creatures, whose number no man can compute." The Baha'i community even has its own SETI workgroup. [356]

If we come into contact with extraterrestrial intelligence, humans may no longer be considered the sole focus of a deity. This can potentially pose a threat to Abrahamic faiths, which are based on the assumption of a special human bond with God. However, in eastern religions, like Hinduism and Buddhism, the lines between humanity, divinity and the animal kingdom are often blurred. All beings in the Universe, regardless of their state or form, are subject to the laws of karma (the laws of cause and effect). According to the doctrines of the Indic faiths, the aliens are also subject to karmic laws. Moreover, we could have been an ETI in a prior existence, or could be one in a future life. [366]

Another important question is: are these beings sentient and more importantly, do they have a soul? Western religions tend to make a connection between sentience and the presence of souls whereas some eastern religions do not necessarily do this. Implicit in the discussion of souls are the matters of sin and salvation[2]. Is it possible that the alien society is still in a state of grace[3]? If they did fall from grace, were they redeemed[4] or were they beyond redemption? The imagery of Christ suffering on innumerable worlds was such an appalling vision to one of Martin Luther's supporters, Philip Melanchthon, that he objected to the idea of many inhabited worlds on this basis "It must not be imagined that there are many worlds, because it must not be imagined that Christ

[2] deliverance from the power and effects of sin
[3] a state of sanctification or pureness, as man was before Adam's original sin
[4] to be atoned for sins committed

died and was resurrected more often, nor must it be thought that in any other world without the knowledge of the son of God, that men would be restored to eternal life." [375] However, Father Daniel Raible, supposed in 1960 that "we may learn in heaven that there has not been one incarnation of God's son but many." [413]

According to philosopher Ronald Puccetti, the particularisms of world religions will make it difficult for them to adapt to the new reality of a world inhabited by intelligent beings.

"For example, Confucianism and Taoism are deeply immersed in Chinese culture; Hinduism has its caste system and regard for cows; Shintoism holds that the first divine creation was the islands of Japan; Judaism is intimately tied to a particular part of the human race, the "chosen people"; Islam has its Mecca and its feasts tied to the moon; and Christianity has the greatest particularism in its emphasis on Jesus Christ and the Incarnation."[374]

The Oriental faiths may be better equipped to make accommodations, in the wake of the discovery of ETI, since they preach salvation through personal enlightenment. [374]

If the message contains any information about the spiritual lives of the alien race, there would be a real temptation to compare our earthly religions to those of the aliens. This would be more important for religions with few followers or ones with radical views who feel the need to establish their faith by validating their views. Mainstream religions would be more hesitant to make this comparison for fear of obsolescence and the consequent loss of influence. If the alien faith was radically different from our own, there would be temptation to learn from them, leading to possible conversion or the creation of new religions on Earth. Any ambiguity in the message may lead to sects forming, but Jill Tarter (Director of the Center for SETI Research) argues that since the alien race is likely to be quite old, and therefore practiced at communicating with different races, that their message would be engineered to remove any ambiguity [376].

The absence of mention of any religion in the message may be convincing to some that there is no God. The existence of a race that has matured well beyond our own, without the need for religion, may imply that religion is not necessary. Others will stand steadfastly by their beliefs, arguing that absence of proof is not proof of absence. In fact, the aliens may be perceived, by the Abrahamic faiths , as the newest.

Lastly, should the alien message contain information for improving our lives through technology and better social constructions, thereby alleviate our constant daily worries, there would be a shift in human perception which might result in a renewed focus on leisure and possibly spirituality.

The receipt of an alien radio signal will suggest that the emergence of intelligent life is an inevitable outcome of the physical and chemical processes in our universe. This will serve to validate the underlying philosophical principles:

1. The Principle of Uniformity of Nature, which states that the laws of nature are universal
2. The Principle of Plentitude – the notion that anything that can happen will happen
3. The Copernican Principle (Principle of Mediocrity) – according to which, Earth is a typical planet going around a typical star and is not special or unique in any way. [372]

Confirmation of the existence of an ETI civilization would mark a shift in the anthropocentric worldview. It is likely to lead to a rise in global consciousness (i.e. greater unity among humans when encountering something alien) and cosmic consciousness (i.e. awareness of fact that humans are part of a bigger whole).

6.3.3 "They're here!" (Near/Intelligent)

In the year 2003, astronomers who are trying to catalog near earth objects have located an object that seems to be moving slowly across the sky but whose photometric intensity is increasing rapidly. The initial assessment is that this is a comet but an orbit solution cannot be made due to the changing nature of the orbital data. It is determined that the object is in fact moving very quickly but in a direction which is aimed toward Earth and that the intensity is increasing due to the object's decreasing distance. The albedo[5] of the object does not

[5] the fraction of solar energy reflected from an object

match any known standards for asteroid or comet bodies. Spectrographic analysis of the light reflected from the object has indicated that it is composed mainly of light structural metals that are known to us as well as some materials that we do not recognize. Within a week after the initial discovery the object has entered a circular Earth orbit at an altitude of 7000 km. All telescopes of significant power have turned to try to observe the object - which by now has been determined to be of extraterrestrial origin. Visual observations show an aerodynamically shaped craft that is approximately 1.2 km along its major axis and has no external markings or features within the limits of our observing power. The craft is silent in emission in all wavelengths and its orbit has remained unchanged for days. All attempts to communicate with the craft have resulted in no reply.

6.3.3.1 Societal/Cultural Impacts

"We are doomed or at least will suffer massive cultural and psychological disruption, should contact with a more advanced galactic neighbor occur." [377]

In this scenario, the method of the announcement plays a large part in the reaction of society. Initially only a small team of people will be aware of what has been discovered and the way that this is delivered to the general populace is of utmost importance. Most likely the public would need to be informed quickly to avoid the information being released via a leak that would be almost inevitable with a story of this magnitude.

However, once the news is in the public domain, most likely given by a governmental or scientific organization, the role of the media will come to the fore. News coverage, whether it is via the television, newspapers or other media, is often tainted by pressure to give opinion, add "spin", or come from a different angle in order to sell their product. Also, many stories are complex and yet need to be delivered in a concise, easily accessible way. Both of these media requirements will lead to misinformation at least, and outright lies in the worst cases. Stories of possible human – alien contact (exploitation or subversion) could cause society to panic.

For most people, life would momentarily stop. People would stay with their families and wait for information, trying to assess the actual threat level. Fear of the unknown would drive some to unrest and possibly looting or hoarding supplies in urban centers. According to Jill Tarter, "Removing the enemy to celestial distance might defuse terrestrial conflict." [376, 148], but it could also splinter as individuals fall into a survival instinct and just look after their own immediate interests.

The response in developed and underdeveloped countries might be different however. This will relate to how it would affect the daily life of the populace. For example a person who lives in an impoverished country and has no access to media of any kind, will not be largely affected by the mere presence of an alien craft.

If we were to communicate with the extraterrestrials, we would likely project our morality and value system upon them because we have no other experience to base our assumptions on. This could lead to potentially dangerous miscommunication. Our morals and values may not be relevant to all galactic species. The perceptions of right or wrong are largely subjective, as even on Earth there are differences in values between cultures.

If communication with the alien craft is not achieved promptly, a return to near-normal conditions would occur. This can be seen historically during the Cold War when many faced fear and uncertainty every day but life continued. Humanity would simply accept this new information in their lives and go on living.

Any talk of generalities in regard to the reaction of society must be thought about with respect to how individual types of people will react. An emotionally stable person, for example, is less likely to break down on news of contact. This is because the effects of stress are known to be cumulative and so someone with less stress already in their lives will cope better.

6.3.3.2 Political/Military Impacts

Contrary to the previous far/intelligent scenario, the situation presented above is urgent since the origin and intent of the object is not clear.

At an individual level, each country may have to deal with negative reactions to the situation if the presence of an extraterrestrial craft is perceived as a threat. The intensity of the reaction will depend on that perception. Such reactions might include public disorder or, in a more extreme case, societal breakdown. Conspiracy theories are likely to proliferate. The military would enter into a state of maximum alert if governments prepare for a worst-case scenario situation. Interestingly, these defensive procedures might be interpreted as hostile by the spacecraft.

Michael Michaud (Deputy Director of the US Office of International Security Policy) in the Foreign Service Journal ‘Interstellar Negotiation’ postulates that “distance is not a guarantee of our security and neither is an advanced civilization a guarantee of peaceful negotiation” [393]. It may be possible that the alien species have had hostile encounters in their past and that they may take a very defensive position with humans.

Confronted with this scenario, governments face two options with the international community: to cooperate with other countries or to deal with the situation independently. If countries decide to act unilaterally, international political friction might arise and insecurity will increase. A critical incentive for a country to react independently to this ‘contact’ might be a perception of military advantage if one country is the first to achieve communication with the alien craft. However, one could also expect the formation of special interest groups, “blocs” of countries, or even a global coalition in order to deal with the situation co-operatively. They would be responsible, for example, for establishing a hierarchy and a communication protocol. One of the reasons countries might band together is to prevent extreme reactions from any one country and provide a unified front to the alien race.

Some form of information control is likely to be employed. This control would not only be limited to the dissemination of information, but also encompass information content. Governments’ control over public and private communication centers would enable the governments to minimize the concern of the public while maximizing their defensive position, in a clear contravention of such social compacts as the U.S. constitution.

Either way, governments might begin consultation with experts in order to choose the appropriate course of action and to decide what to tell the public. The actions taken should be firm and authoritative and the message to the public should be coherent in order to avoid the spread of rumors.

Special interest groups may form to lobby governments, a situation similar to the one during the development of the atomic bomb, where scientists lobbied the American government not to use the bomb. One particular reason lobbies would arise is due to differences in opinion regarding communications with the aliens, especially when there is a possibility of exposing human weaknesses that could be used against us.

6.3.3.3 Scientific/Technological Impacts

Author and physicist Philip Morison, one of the original conceivers of the SETI program, postulates that aliens could bring us a richer store of information than that inherited from medieval Europe and from ancient Greece. [413] Cures for warfare, poverty, common diseases or even a way to counteract aging may be among the many technologies that the alien race takes for granted.

The science and technical community may be united in an effort to solve the puzzles of the alien technology and even to be able to communicate with the aliens. It can be argued that this community may have to face the most radical changes, as much of our current technology could become obsolete and many of our current scientific theories may become invalid overnight.

If little or no technology is transferred from the aliens to humanity, scientists and technologists would feel a desire to rise to the challenge of developing technologies which would enable us to become a truly space faring society. Research in propulsion, communication, and life sciences among others would become the focus of attention.

One of the important implications of an advanced alien technological culture is that this can be seen as proof that an intelligent race can survive technological adolescence. However we must consider the differences between the alien race and our own before we can draw any such conclusions about ourselves. In addition, rapid technology transfer between our species may upset the natural balance of technological progress on Earth. This transfer may be beneficial but it may also result in harmful effects due to irresponsible use of technology which we have neither any understanding how to use nor the knowledge of the consequences of use.

6.3.3.4 Religious/Philosophical Impacts

In this scenario, religion will play a vital role. Those of faith would seek guidance and those without faith would seek comfort. Houses of worship could become sanctuaries for the panicking masses.

Some followers of western religions are bound to believe that the arrival of this object is a sign of the Apocalypse of the Bible and would flock to churches to repent or to be saved for fear of impending judgment. Religion in general may become more powerful and influential in our daily lives. Religious leaders would be called upon for their interpretation of events.

The technological capabilities of the aliens may be indistinguishable from magic and they could appear as Gods. [372, 48] Cults would form rapidly and this could lead to dire circumstances such as the suicides of the Heaven's Gate Cult in 1996 during the visit of comet Hale-Bopp. Some may believe that the aliens may be the Gods themselves and that the craft is in fact the chariot of the angels.

Italian physicist Enrico Fermi said that if intelligent life was common in the universe it should have visited us by now. Since there is no conclusive proof of alien encounter Fermi concluded that humans are in fact alone. Confirmed sighting of an alien spaceship would invalidate this line of argument. It would further imply that like humans, alien civilizations are perhaps driven by an urge to explore or colonize.

This scenario also clearly contravenes Ball's "zoo hypothesis" which suggests that we have not been in contact with aliens because we are under some form of quarantine either because we are a brutish race or because we are not ready to become part of a galactic civilization.

6.3.4 "Exoplanet Life" (Distant/Simple)

In 2012, the Next Generation Space Telescope has observed the atmosphere of a planet orbiting a sun-like star that is 78 light years from Earth. Spectrographic analysis of the planet's atmosphere indicates an overabundance of oxygen. This, combined with other information gained from the observations, would seem to indicate that some biological process is altering the balance of atmospheric gases of the planet.

Currently the only method to verify the existence of simple life on planets around other stars is by sending an exploratory robotic or manned mission – this is the main constraint when discussing this scenario.

The completion of a mission designed to verify the presence of life in a remote stellar system is not likely to occur in the next 20 years (in part, this is because the travel time is likely to be measured in millennia using current technology). However, the possibility of the existence of simple life in a remote system may result in the allocation of resources or investments in technologies suitable for a future mission that could verify the presence of life.

This scenario would probably have the least impact of the four scenarios discussed in this chapter. The studied impacts are a muted variation of the impacts in the near-simple scenario with some exceptions. The interstellar distances assumed might remove some, if not all, of the concerns regarding the possibility of transmission of potentially harmful microbes to Earth.

The incentive to send a robotic or manned mission might be diminished drastically when compared to the near-simple scenario since the examination of extraterrestrial organisms for medical or biological research is rendered impossible with the technology available within the next 20 years.

Unlike the near-simple scenario, transferal of matter between the exoplanet and the Earth cannot have occurred: there exists almost no possibility that this simple life might have had the same origin as terrestrial life. This suggests that life is fairly abundant in the Universe.

6.4 Guidelines

Based on the research undertaken and on the existing material, this section will look at guidelines to help mitigate any adverse reaction of humanity upon the discovery of extraterrestrial life.

6.4.1 Existing Guidelines

It seems that existing guidelines for dealing with the detection of extraterrestrial life are scarce, the SETI community being the only organization to have established such procedures. Three main documents available from the SETI Committee of the IAA [403] are in different states of completion:

1. Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence (1989) [404]
2. Draft Declaration of Principles Concerning the Sending of Communications to Extraterrestrial Intelligence (1995) [405]
3. A Decision Process for Examining the Possibility of Sending Communications to Extraterrestrial Civilizations - A Proposal (August 1996) [406]

The first document was developed over a number of years and was adopted by the International Academy of Astronautics (IAA) and the International Institute of Space Law (IISL) in 1989. It contains general guidelines for individuals and organizations involved in SETI. In the following years, all major institutions involved in SETI (e.g. SETI League, SETI Institute), the Committee for Space Research (COSPAR), the International Astronomical Union (IAU) , Commission J of the Union Radio Scientifique Internationale, and the International Astronautical Federation (IAF) endorsed this document. However it has not been recognized yet by the United Nations and it is not binding [382]. The key points of this document are:

1. Verify the extraterrestrial origin of the signal.
2. Inform other SETI researchers to seek independent confirmation of the signal.
3. Notify the IAU and UN and other interested organizations e.g. COSPAR, IAF, ITU.
4. Ensure open and prompt dissemination of the news. Discoverer has the right of making announcement.
5. Make all data available to the scientific community.
6. Ensure proper recording and storage of all data.
7. Protect the frequencies where the signal was received in cooperation with ITU.
8. No response before international consultations.

The other two documents are still in their draft and proposal phases and are therefore not further discussed here. Another set of more technical guidelines is available from Project Argus of the SETI League. [418]

Recommendations for scientific research aimed at preparing humanity for initial contact can be found in a long-range study performed by the Brookings Institution for NASA in 1960. There it is stated: "…two research areas can be recommended:

- Continuing studies to determine emotional and intellectual understanding and attitudes – and successive alterations of them if any – regarding the possibility and consequences of discovering intelligent extraterrestrial life.
- Historical and empirical studies of the behavior of peoples and their leaders when confronted with dramatic and unfamiliar events or social pressures. Such studies might help to provide programs for meeting and adjusting to the implications of such a discovery. Questions one might wish to answer by such studies would include: How, and under what circumstances, might such information be presented to or withheld from the public? What might be the role of the discovering scientists and other decision makers regarding release of the fact of discovery?" [392]

These form the main body of existing guidelines pertaining to the discovery of extraterrestrial life.

6.4.2 Suggested Guidelines

The guidelines presented below are intended to serve as a possible supplement to the existing guidelines in section 6.4.1.

- In the event of the discovery of extraterrestrial life it is important for governments, scientific institutions, media representatives and any interested organization to verify the facts before disseminating the information. However, **transparency and timely distribution of information** is also essential to avoid fueling public suspicion and distrust. Under certain circumstances, and only as a last resort in order to prevent mass frenzy, governments might attempt to control information flow, but policy should recognize that information control would be temporary at best.
- **Public education and awareness** regarding ET life should be given high priority and should begin during the mission planning process (refer to section 8.12). To reach a broad audience, various modes of communication should be used simultaneously for broadcasting information (for example newspaper, television, internet, radio, discussion forums etc).
- Media as well as religious and social groups should embrace **responsible reporting**. The news, messages and suggestions they communicate should be carefully considered. In some instances, working closely with government may be desirable.
- An individual's response to the discovery of ET life will depend to a great extent on their **political/military, social, cultural and religious environment**. These factors have to be **taken into account when formulating strategies**. Detailed studies should be conducted to examine the effect of these factors on public response.
- An **international panel of experts** from a wide range of fields should be assembled to correctly assess the situation at hand[6] . The information received from such a panel is likely to appear more credible in public perception. The experts should also establish networks within their own countries so that the panel can reach a broad audience.
- Giving guidelines on religion is a difficult task, not just due to the diversity of religions, but also because religions tend to draw their guidelines from divine inspiration. Nevertheless, **religion should provide counsel and comfort** in the same way it has done through history during times of stress, ranging from simple worry to social upheaval.
- An **international agreement with treaty status should be established** to deal with issues pertaining to the discovery of extraterrestrial life including but not limited to the information dissemination process, forward and backward contamination (refer to section 5.1), liability and intellectual property rights regarding ET life and ET communication protocols. SETI guidelines can be used as a starting point and be extended to all possible discovery scenarios[7].
- And, last but not least, **DON'T PANIC!** [353]

[6] The creation of the "SETI: Post-Detection Science and Technology Study Group" has been proposed to the IAA, with the purpose to "…be available to be called on at any time to advise and consult on questions stemming from the discovery of a putative signal of extraterrestrial (ETI) intelligent origin." [407]

[7] The creation of the "The Subcommittee on Issues of Policy Concerning Communications with Extraterrestrial Intelligence of the IAA SETI Committee" has been proposed to the IAA. [408]

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[419] Allen Tough. *Intelligent Life in the Universe: What Role Will It Play in Our Future?* Online. URL: `http://members.aol.com/AllenTough/bok.html`, Last accessed: Aug 23, 2002.

[420] Allen Tough. *Security During the First 30 Days*. Online. URL: `http://members.aol.com/allentough/post.html`, Last accessed: Aug 23, 2002.

[421] Allen Tough. e-mail, August, 2002.

[422] United Nations. United nations treaties and principles on outer space. *A/AC.105/722, A/CONF.184*, A commemorative edition, 1999.

[423] United Nations. Report of the commitee on the peaceful uses of outer space. *General Assembly Official Records*, Fifty-fifth Session, Supplement No. 20 (A/55/20), ISSN 0255-1144:2, 18, June 2000.

[424] Richard M. West. *Consequences of Discovery of Life*. Online, October 2001. URL: `http://www.lifeinuniverse.org/noflash/Discoveryconsequences-09-05.html`, Last accessed: Aug 12, 2002.

[425] John Noble Wilford. Clues in meteorite seem to show signs of life on mars long ago. *New York Times*, page 1, August 7 1996.

[426] Ray Williamson. personal communication, July and August, 2002.

Chapter 7

Education

7.1 Rationale - Why Teach Astrobiology?

Astrobiology, exobiology, bioastronomy and cosmobiology are all terms that refer to the origin, distribution, change and evolution as well as the future of life on the Earth and beyond. Astrobiology is a link connecting the multiple disciplines of science. Astrobiology encourages one to be familiar with biology, astronomy, geology, physics, technology, chemistry, social science and other disciplines. Therefore, as a tool in the classroom it is a useful mechanism to show how the sciences and humanities[1] are all interconnected. It can be used as an overall theme to tie different disciplines together and to transition from one subject to the next. It facilitates the cross fertilization of various fields of science, technology and the humanities in a manner that is interesting and relevant to all human beings.

"*Education is an investment in the future. The success of space corporations and space agencies depends on the educational system to produce a highly skilled and knowledgeable workforce that is necessary to perform cutting edge research and development work. Likewise, the educational system looks to space exploration activities for inspiration and to exemplify doing things that once were only imaginable - feats that motivate and encourage students to study science, mathematics, technology and engineering. A challenge facing space agencies is to demonstrate the relevance and benefits of space exploration and development to the public. One of the many ways in which space research and development can be made relevant and beneficial is through an effective education program*." Malcolm Phelps[2] Assistant Director NASA Headquarters Education Division.

However, there is a general trend towards a decrease in scientific literacy among the population. Carl Sagan made the sweeping accusation that 95% of North America is scientifically illiterate, whereas this may not be true of the rest of the world [446]. This manifests itself in fewer and fewer students pursuing sciences in high school and beyond. This is a recipe for imminent disaster because the study of science is key for the advancement of technology and the progress of humanity. Astrobiology is an extremely appealing area because of the fascination the general population has for space. Students come into classrooms filled with questions about life on other planets. The public has seen fantastic scenarios presented on television and films. They have read and heard about exploring and colonizing Space using crewed and robotic space missions.

It is important to know the target group before suggesting activities. Age groups have specific characteristics that set them apart from others. Though the following activities have a high degree of universal appeal, we have targeted a specific audience of 10 to 14 years old. Research has shown that this age group is vital for creating a positive attitude towards science. This attitude may persist into the future as significant career choices and interests [429].

[1]The Humanities: Those branches of knowledge, such as philosophy, literature, and art, that are concerned with human thought and culture; the liberal arts [extracted from `www.dictionary.com/search=?q=humanities`

[2]Taken from written notes by Malcolm Phelps for his Education Theme Day presentation at ISU SSP 2002, August 9.

The study of astrobiology is a unique way of inviting all disciplines to participate in the quest for what it actually means to be alive. It promotes the use of not only mathematics and science, but also the contribution of humanities to the study of the meaning of life. The National Aeronautics and Space Administration mission statement, for example, advocates for astrobiology because of its specified purpose of protecting life, searching for life and perpetuating the quest for life. The following sections will attempt to explore present resources and propose new materials and methods for an integrated appreciation of life through the field of Astrobiology.

Space Agencies' Mission Statement

NASA *To understand and protect our home planet, To explore the Universe and search for life, To inspire the next generation of explorers... as only NASA can.*

ESA *To provide for and promote, for exclusively peaceful purposes, co-operation among European states in space science, research and technology and space applications with a view to their being used for scientific purposes and for space application systems.*

7.2 Survey of Existing Resources

The following is a survey of present astrobiology materials. Although it is not a comprehensive list, it facilitates the gap analysis that will follow.

7.2.1 Europe

European Space Agency education outreach and astrobiology

The European Space Agency (ESA) channels its education money through its Education and Outreach Office or directly through specific science programs. At present there are no specific outreach programs focused on astrobiology. Many of the future missions planned have an astrobiology component which may allow ESA to initiate more astrobiology education activities. In the year 2001 there was an astrobiology outreach program conducted in collaboration with other European science associations. Life In The Universe [438] was organized by the ESA Outreach Office with other European science organizations as a competition.

Other activities in Europe

Although ESA has no strong astrobiology education program, it is considered to be an important field of science. Many European nations have their own astrobiology organizations. Actions have been taken to advance the research, co-operation, education and outreach in this field. This is manifested through The European Exo/Astrobiology Network Associations, EANA, a new European organization established to further this cause. This network is an excellent initial attempt to gather astrobiology related activities. For example the first astrobiology course held in Finland at university of Turku in 2001 was such a success that they had to move the lecture to a bigger classroom twice! [435]

7.2.2 USA

NASA has actively been pursuing education in the area of astrobiology. The NASA website contains many references to "astrobiology" and "astrobiology education".

NASA has created the NASA Astrobiology Institute (NAI)[441], which is a virtual institute located concurrently at multiple universities around the United States. NAI has created a website which is designed for teachers' use and for students; the site includes several interactive games, useful links and searches. Along with a nonprofit education research and development organization known as TERC [447], NAI has developed an astrobiology curriculum with a heavy emphasis on science and mathematics. NAI has created an undergraduate level summer program, the NASA Astrobiology Academy. The Academy is a program that helps to develop the astrobiologists of the near future.

NASA developed Astro-Venture[431], which has online, interactive, multimedia modules with off-line classroom lessons. Astro-Venture is aimed at educating students age 10-13 on the requirements of a habitable planet, through the use of astrobiology content, the scientific inquiry process and critical thinking skills. The program is broken into five modules: astronomy, geology, atmospheric science, biology, and designing a planet. Although the program deals with astrobiology, it is concerned with teaching where humans can exist beyond Earth, instead of where exobiology can exist.

More NASA educational resources are found at the Office of Space Sciences. NASA's dedication to science education has manifested itself in a series of Education and Public Outreach (EPO) for specific missions. Therefore, educators can use the Office of Space Sciences directory to find EPO for missions and programs related to astrobiology.

7.2.3 Asia and Pacific

Some national astronomical societies in Asia extend their work in education and outreach to astrobiological subjects. The Astronomical Society of Japan (ASJ) holds a session on astronomical education every six months. A presentation session for high school students is held during each meeting. The ASJ intends to start an electronic newsletter on astronomy education. This will also include information on astrobiology education, and is expected to have wide circulation.

Following the Special Session on "Astronomy in Developing Countries" at the 2000 IAU in Manchester, another Special Session is proposed for the 2003 IAU in Sydney[3]. This will focus on the topic of "Astronomy in the Schools." It has been proposed that the session look for places in the curriculum for astronomy and astrobiology. This is a topic that is crucial to both developed and developing countries. In some countries, there is little or no astronomy in the school curriculum. In others, astronomy is in the curriculum, but astrobiology is overlooked. In addition, teachers receive little or no training and support. The proposed Special Session will highlight:

- Recent research on effective teaching and learning of astronomy and astrobiology
- The rationale for astronomy and astrobiology in the school curriculum
- Programs for teacher training and support
- Exemplary and inexpensive resources
- Practical activities and student research
- The role of new technology
- Interdisciplinary connections
- The role of planetariums and observatories

The Philippines has also been working with the Program Group on Advance Development for the development of their astronomy and astrobiology education outreach.

The following organizations in the Asia-Pacific area are in the process of developing a scheme of public education and outreach for space and astrobiology:

[3] IAU: www.iau.org

Australia	Australian Space Research Institute (ASRI)
Bangladesh	Bangladesh Space Research & Remote Sensing Organisation (SPARRSO)
China	China National Space Administration (CNSA)
India	Indian Space Research Organisation (ISRO)
Indonesia	Lembaga Penerbangan dan Antariksa Nasional (LAPAN)
Japan	National Space Development Agency of Japan (NASDA); Institute for Space & Astronautical Science (ISAS)
Malaysia	Bahagian Kajian Sains Angkasa (BAKSA)
Pakistan	Space & Upper Atmosphere Research Commission (SUPARCO)
South Korea	Korea Advanced Institute of Science & Technology (KAIST)
Taiwan	National Space Program Office (NSPO)
Thailand	National Research Council of Thailand (NRCT)

7.2.4 South America

The Committee on Space Research (COSPAR)[4] - International Astronomical Union (IAU) co-sponsored a workshop at the UN Regional Center in Brazil which took place in December 2001, which including the development of human resources via public outreach and education.

The following South American space agencies are currently looking into space education and outreach. Many plan to include astrobiology in their education and outreach curricula.

Argentina	Comision Nacional de Actividades Espaciales (CONAE)
Brazil	Agência Espacial Brasileira (AEB)
Costa Rica	Fundacion para la Ciencia y la Educacion Espacial (FUCES)
Peru	Comision Nacional de Investigacion y Desarollo Aeroespacial (CONIDA)
Uruguay	Centro de Invetigacion y Difusion Aeronautico Espacial (CIDA)

The 26th International School for Young Astronomers (ISYA) was held at El Leoncito, San Juan, Argentina from August 12 - 30, 2002. Among topics such as Galactic Nuclei, Cosmology, and High Energy Astrophysics, information related to astrobiology was given to the students.

Travel grants were given to delegates from the universities of Nicaragua and Panama to attend the Sixth Central American Course on Astronomy at the University of Costa Rica in March and April 2001. Students were also sent from Honduras and Nicaragua for space science education in Argentina and Mexico.

7.2.5 Africa

Morocco is looking into enhancing its public and private libraries in astrophysics, mathematical physics and astrobiology. Morocco also supported the travel of John Danziger[5] to Casablanca in April 2001 for a short course on the development of education in astronomy, space science and astrobiology. Morocco also supported the travel of Michèle Gerbaldi[6] from Paris to Casablanca in September 2001 for the profession planning of astronomy and space science teaching at several schools in Casablanca.

The following African space organizations are looking into space education and outreach. Many intend to include astrobiology in their outreach: (a) Centre National des Techniques Spatiales (CNTS), in Algeria and (b) National Space Research & Development Agency (NSRDA), in Nigeria.

[4] COSPAR: `http://www.cosparhq.org`
[5] John Danziger, Professor at Astronomical Observatory of Trieste.
[6] Michèle Gerbaldi, French scientist in stellar atmosphere data analysis with MIDAS. Faculty at 2nd industrial school for young astronauts.

7.2.6 Informal Education Venues

Another powerful method of reaching our target age group is "informal education." This would be an avenue to reach interested 10 to 14 year old children in environments outside of the classroom but still conducive to learning as it relates to the disciplines associated with Astrobiology. Children's science museums are a prime location to provide hands-on activities relative to the subject matter [434]. The delivery concept is a central computer station that allows youth to explore the 'cool' subject matters associated with astrobiology with an interactive CD tool combined with multiple hands-on related activities. This concept and methods for designing, developing and implementing will be discussed in later sections. Well-recognized clubs and organizations that are focused on educating and developing young children in the scientific areas covered within astrobiology are also an excellent way to engage our target group. One example in this area would be the Boy and Girl Scouts of America. These youth oriented organizations already challenge kids to learn in the areas of the sciences as evident by the "Badge Process." Each child can obtain a badge for a different focus area (e.g. there is one for astronomy) by performing a set of predetermined tasks that are typically hands-on and engaging.

7.2.7 Curriculum Examples

Curriculum documents are created by governing bodies, in association with educators and educational institutions, to be used by school boards for the delivery of pedagogically sound content and skills in a relevant context. The degree of educator's input can vary depending on the willingness of education ministries to include various components based on the governing body's vision or political agenda. The study of biology and the characteristics of living things appear in all science curricula of many countries. However, the age or stage of learning various biological concepts may vary from country to country.

7.2.7.1 Canada

Astrobiology could easily be used in the delivery of the Ontario Curriculum Grades 1 - 8 Science and Technology document (1998). Because the study of life appears in a number of strands, astrobiology would be an ideal vehicle for the delivery of the prescribed curriculum expectations. In the Grade 7 Life Systems Unit: Interactions with Ecosystems, the first specific expectations that students are required to understand is the identification of living and non living elements of an ecosystem. This is the first priority listed in the understanding of basic concepts. The definition of what is living from an Astrobiology perspective would help the students to see beyond the Earth and really strive to find, "the meaning of life" and what characteristics distinguish abiotic and biotic things [439].

The study of geology includes the rock cycle in the curriculum. Although rocks are considered to be abiotic, a strong astrobiology connection could be made with the unique fact that rocks can support life in the form of cyanobacteria [428]. These types of life-bearing rocks may perhaps be the first "living things" sent to populate other planets because they are extremophiles and tremendously resilient to radiation, dessication, and variations in temperature [439].

7.2.7.2 Europe

In Finland, the education system is divided into three sections. The first section includes grades one to six, followed by "ylä-aste" which is grades seven to nine. High school or "lukio" in Finland covers grades ten to twelve.

"Biologia on yläasteella elämää, sen ilmiöitä ja edellytyksiä tutkiva oppiaine. Sen avulla oppilas saa aineksia muodostaa sellaisen maailmankuvan, jonka olennaisena osana on eliöiden rakenteen, ekologian ja evoluution tunteminen ja ymmärtäminen."[444].

As described in the Finnish Curriculum quoted above, the purpose of teaching biology is to give students a view of biology as part of the world. Astrobiology includes studying and defining extraterrestrial life. Furthermore astrobiology asks basic questions about possibilities and requirements for life itself. Teaching astrobiology as part of biology would give students a broader view of the world as a biological environment and would enable them to see the importance of a global biological system.

7.2.7.3 Asia

The Curriculum Planning and Development Division for the Ministry of Education in Singapore has implemented a new science syllabus as of 2001. Several outcome areas are listed but one in particular relates well to astrobiology. The section on Diversity explains that "Pupils should appreciate that there is a great variety of living and non-living things in the world. Man seeks to organize this great variety to better understand the world in which he lives. There are common threads that connect all living things and unifying factors in the diversity of non-living things that help him to classify them."[432]

Singapore has very clearly delineated learning outcomes that identify the factors affecting the survival of an organism, especially in unfavorable environments. This outcome could be taught with tremendous scope by adding the extraterrestrial environment of another planet and the factors that would be necessary for life in such an extreme location. The astrobiology extension would allow children to think "outside of the box" because they would soon discover that the requirements for life are very different for other planets or extreme environments on Earth. The Science Syllabus for Lower Secondary Special/Express/Normal (Academic) [433] also uses numerous learning outcomes that pertain to the classification of plant and animal life. The use of astrobiology would allow the application of what was learned in these sections because it would necessitate the application of these classification keys to another context with creativity and genuine understanding of the characteristics of living things.

7.2.7.4 Summary of Curriculum Document Use for Astrobiology

Resource materials sited in the section on existing astrobiology resources contain lessons that are aligned with specific curriculum documents. However, there are gaps in the resources that we will try to address in subsequent chapters. The teaching of astrobiology as an extension of the study of life on the Earth is a valuable mechanism for promoting the investigation of biology and environmental issues regarding the respect for life in any form.

7.3 Gap Analysis

Typically, it takes an interested organization two or three years to research and bring to publication any curriculum document. Since astrobiology is a new and evolving field, there has not been enough time to develop many curriculum dealing with it. After the survey of current resources it was found that there are many holes or gaps in the curriculum resources presented. Therefore, the curriculum ideas presented in the following chapter have tried to fill these gaps.

More work needs to be done to include the following topics in Educational Resources for Astrobiology:

- Activities such as the elaboration of scenarios as found in the Impact chapter that promote open mindedness with regard to new things such as the finding of life on other planets.
- Media literacy, critical thinking skills and discernment so that students can distinguish between what Hollywood presents and what the Science community presents. Why pursue astrobiology and what if we find life, what then?
- Preassessment activities that gauge students’ present knowledge of astrobiology and help correct any misconceptions.
- Vocabulary exercises and relevant facts that give students the vocabulary to discuss astrobiology.
- Better cross curricular links for lessons. Resources surveyed so far tend to emphasize traditional sciences and mathematics. More work must be done to include the humanities.

- Activities need to have a self-perpetuating component to them so that students will not lose interest. The section on social impact indicates that once life is found, perhaps in the form of microbial fossils, there will be initial public interest, but it is likely to decline swiftly.

- Lessons that pertain to future missions that use or discuss actual sampling techniques such as gas chromatography, mass spectrometry and pyrolysis are needed because these are actual lab procedures that missions will use in the next twenty years as Space Agencies plan to go to Mars or Europa. Whereas students may not be able to perform these specialized sampling techniques, the principles of proper sampling, the necessity for calibration and repetition could be taught through more traditional classroom lab techniques such as electrophoresis[7] and the use of filter or blotting paper to separate dyes could be adapted.

- Lessons on planetary protection from the less emphasized side of Earth-Mars contamination would help broaden students' views on environmental awareness, where the environment extends beyond our atmosphere making us guardians of the universe with regard to environmental issues.

- Focus more on current Agency missions and scientific developments. Engage students in the near term (next 10 - 20 years) so that when they enter the workforce they feel they can contribute and make a difference in their chosen field of interest.

An attempt will be made to address these gaps. The following sections are outlined in phases which give background information on astrobiology concepts and provide lesson ideas that can be used by educators in both formal and informal education forums.

7.4 Suggested Activities

7.4.1 Introduction

There are many astrobiology web-sites. However there are few actual curriculum documents. Described below is a six-phase curriculum outline. The phases are simply ideas that are to be built upon when the curriculum is created. Phases may become a theme for a semester, chapter in a book, lesson or hands on work station in a museum. In Scouts and other organizations with patches or badges associated with activities then the phases can be shaped to be steps that must be performed to complete the badge process.

7.4.2 Phase 1: Introduction to Astrobiology

Introduction

The appalling gap between what the public perceives as "extra-terrestrial life" and what the scientists hope to find gives much cause for concern. This is especially true since the average "astrobiology" vocabulary consists of "Klingons", "Ewoks" and "Jedi Knights."

Before students can be introduced to the wonders of astrobiology, they should be introduced to the basic terminology that the science of astrobiology is based on. A pre-assessment of what the students already know about astrobiology (together with any misconceptions they may have) is also necessary. This will enable the trainer or teacher to have an adequate grasp of the task that will be necessary to educate the students about astrobiology.

Phase 1 provides the basis for the other phases that are to follow. The emphasis for Phase 1 is to first preassess the students' knowledge and teach the students the vocabulary that will be necessary for them to grasp ideas about astrobiology. Phase 1 also aims to show students the link between the scientific aspects of astrobiology and the humanities.

[7] electrophoresis: the migration of charged colloidal particules or of molecules through a fluid or a gel subjected to an electric field (from Webster Dictionary)

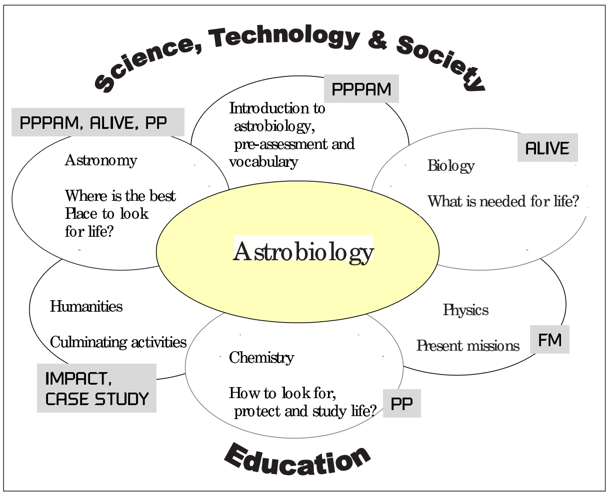


Figure 7.1: This Logo represents the integration of the specific contents of this source book, the traditional areas of study and the six phases of the following proposed curriculum.

Suggested Activities

Pre-Conception Phase A discussion of the concepts students have about astrobiology can be held. Students should be asked what their idea of extraterrestrial life is, and whether the popular media idea of alien life forms is (or should be) accurate. An interesting activity would be to ask students to draw what they think aliens would look like. Besides giving the teacher an idea of what the students expect when the word "astrobiology" comes to mind, this activity allows students to exercise their creative juices and also shows them that there is an artistic component to astrobiology.

Familiarization of Terminology

a. Wordlist & Spelling Bee A wordlist of the various different words that is necessary for a proper study into astrobiology should be developed. Handouts of this wordlist should be passed out to students. Students can be first asked to define or draw the words according to their own understanding, and proper scientific definitions can be provided thereafter. A spelling bee can be conducted to encourage the students' knowledge of the terminology. Students can also be asked to make crossword puzzles based on the definitions and terminology they have been exposed to. An example is given Table 7.1.

b. Poetry Once the students have learned the terminology, a poetry class can be held. This will fulfill two aims. Firstly, it will enable the students to use the terminology they have just learned. Secondly, it will allow the students to see the link between the scientific terminology of astrobiology and the humanities. The link between the humanities and space sciences is often overlooked. This will allow the curriculum to have an interdisciplinary overview instead of a narrow one focusing only on the scientific aspects of astrobiology. Below is an example of a poem about astrobiology:

English	French	German	Spanish	Finnish	Portuguese	Dutch	Italian	Russian	Estonian
Asteroids	Astéroides	Asteroiden	Asteroides	Asteroidit	Asteróides	Asteroiden	Asteroidi	Астероиды	Asteroid
Astronomy	Astronomie	Astronomie	Astronomía	Tähtitiede	Astronomia	Sterrenkunde	Astronomia	Астрономия	Astronoomia
Biogenic			Biogénico	Eloperäinen	Biogenico		Biogenica		Biogeeniline
Biology	Biologie	Biologie	Biología	Biologia	Biologia	Biologie	Biologia	Химия	Bioloogia
Carbon	Carbone	Kohlenstoff	Carbono	Hiili	Carbono	Koolstof	Cabonio	Углерода	Süsinik
Chemistry	Chimie	Chemie	Química	Kemia	Química	Scheikunde	Chimica	Биологии	Keemia
Chromatography	Chromatographie	Chromatographie	Cromatografia		Cromatografia	Chromatografie	Cromatografia	хромотогафчп	Kromatograafia
Comets	Comètes	Kometen	Cometas	Komeetat	Cometas	Kometen	Comete	Комет	Komeet
Contamination	Contamination	Kontamination	Contaminación	Saastuttamine	Contaminação	Besmetting	Contaminazione	Загрязнение	Saaste
DNA	AND	DNS	AND	DNA	AND	DNA	DNA	DHK	DNA
Energy	Energie	Energie	Energía	Energia	Energia	Energie	Energia	Энергия	Energia
Experiment	Expérience	Experiment	Experimento	Koe	Experiência	Experiment	Esperimento	Эксперимент	Eksperiment
Extinct	Eteint	ausgestorben	Extinguido	Kuolla sukupuuttoon	Extinto	Uitgestorven	Estinto	Потухший	Väljasurnud
Extra-terrestrial	Extra-terrestre	Auβerirdisch	Extra-terrestre	Maan ulkopuolinen	Extra-terrestre	Buitenaards	Extra-terrestre	Инопланетянин	Maa-Väline
Fossil	Fossile	Foβil	Fosil	Fossiili	Fóssil	Fossiel	Fossile	Окаменелость	Fossiil
Geology	Géologie	Geologie	Geologta	Geologia	Geologia	Geologie	Geologia	Геология	Geoloogia
Hazard	Danger	Gefahr	Peligro	Vaara	Perigo	Gevaar	Pericolo	Опасность	Oht
Hydrothermal	Hydrothermal	Hydrothermisch	Hidrotermico	Hydrotermine	Hidrotermico	Hydrothermisch	Idrotermico	Тепловой	Hüdrotermiline
Isotopic	Isotopic	Istopisch	Isotopo	Isotooppi	Isotópico	Isotoop	Isotopo	цзотропныч	Isotoopiline
Life	Vie	Leben	Vida	Elämä	Vida	Leven	Vita	Жизнь	Elu
Meteor	Metéorite	Meteor	Meteorito	Meteori	Meteoro	Meteoor	Meteora	Метеор	Meteoor
Methane	Methane	Methan	Metano	Metaani	Metano	Methaan	Metano	Метан	Metaan
Mission	Mission	Mission	Mision	Tehtäuä	Missão	Missie	Missione	Миссия	Missioon
Molecule	Molécule	Molekül	Molecula	Molekyyli	Molécula	Molecuul	Molecola	Молекула	Molekul
Nucleus	Noyau	Kern	Nucleo	Ydin	Núcleo	Kern	Nucleo	Ядро	Tuum
Nutrients	Nutriments	Nährstoffe	Nutrientes	Ravintoaineet	Nutrientes	Nutriënten	Nutriente	Питательное вещество	Toitaine
Organic	Organic	Organisch	Organico	Orgaaninen	Orgânico	Organisch	Organico	Органический	Orgaaniline
Organisms	Organismes	Organismus	Organismo	Organismi	Organismos	Organismen	Organismo	Организм	Organism
Physics	Physique	Physik	Física	Fysiikka	Física	Natuurkunde	Fisica	Физика	Füüsika
Planet	Planète	Planet	Planeta	Planeetta	Planeta	Planeet	Pianeta	Планета	Planeet
Primordial	Primordial	Primordial	Primordial	Alku-	Primordial	Oer-	Primordiale	Исконный	Algne
Protection	Protection	Schutz	Protección	Suojelu	Protecção	Bescherming	Protezione	Защита	Kaitse
Radiation	Radiation	Strahlung	Radiación	Säteily	Radiação	Straling	Radiazione	Радиация	Radiatsioon
Sample	Echantillon	Probe	Muestra	Näyte	Amostra	Monster	Campione	Образец	Näidis
Species	Espèces	Art	Especie	Laji	Espécies	Soort	Specie	Разновидность	Liik
Spectroscopy	Spectroscopie	Speletroskopie	Espectroscopía	Spectroskopia	Espectroscopia	Spectroscopie	Spettroscopio	спектроскопцл	Spektroskoopia

Table 7.1: International word list.

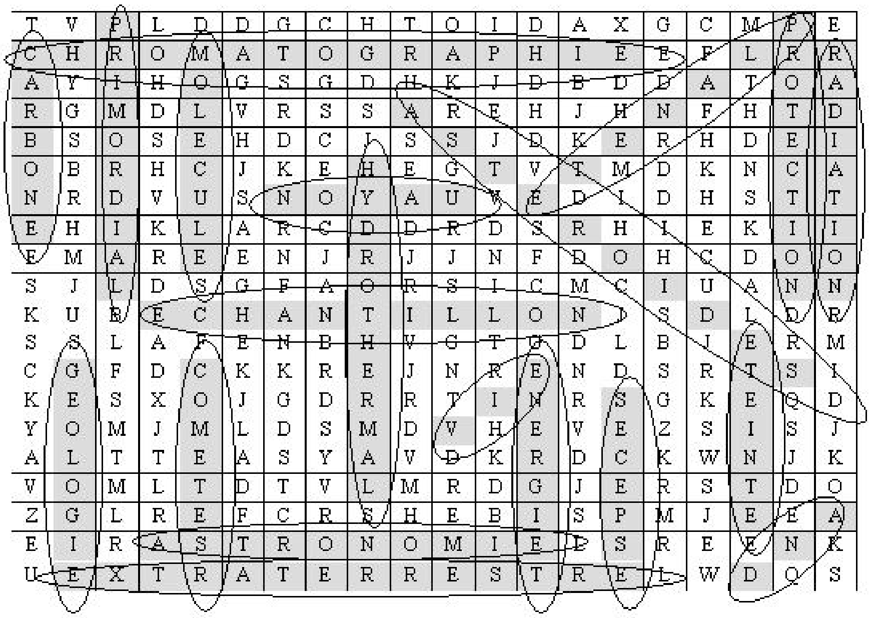


Figure 7.2: French Word Search

Polymers in the ocean get made

When organic compounds are sautéed

By lightning or heat,

Or a UV-light treat,

So that sugars like glucose pervade.

Early life on Earth had to eat,

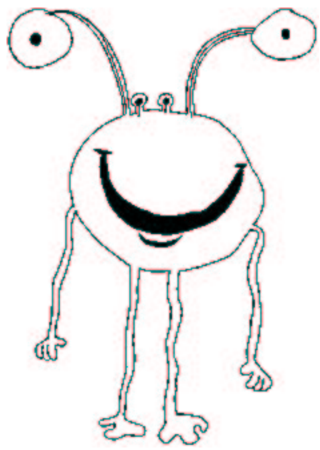
And glucose was a favorite treat.

Fermentation reduced

The glucose and produced

Ethanol,

CO2 and some heat.



Eric Schulman[8]

c. Word searches Another interesting activity for students is to play with Word Searches. This is an easy word game that can be done in various different languages. Figure 7.4.2 is an example of a word searches in French.

Link with Humanities An important aspect of Phase 1 is the link between astrobiology and the humanities. The term "humanities" is a wide term that encompasses perhaps much more than can be taught in one phase in one classroom, but students should be made aware that astrobiology has impacts on society and the humanities as well as the sciences. An interesting activity would be to show students that the Search for Extra-Terrestrial

[8] http://www.science.gmu.edu/~hgeller/astrobiology/ablec12/sld004.htm

Intelligence (SETI)[9] makes use of different ways of communication. Students may be asked to come up with a new "extraterrestrial" language of their own.

Summary

Phase 1 lays the groundwork for the other phases that are to follow in the curriculum for astrobiology. As such, the framework of Phase 1 allows the student to build up a structure for the other phases. Aside from the terminology that will be learned, the most significant aspect of this phase is the fact that students will be challenged to critically assess the misconceptions about alien life forms as popularly perceived. Further, students will be introduced to the idea that space in general, and astrobiology specifically, addresses issues that span beyond science into the humanities.

Armed with this new perspective on extra-terrestrial life, students are more likely to be open to the concept of astrobiology other than that seen through the eyes of the popular media. Teachers will have their own critical thinking skills challenged as they prepare for potential discoveries of confirmed life forms.

7.4.3 Phase 2: What is needed for life?

Traditionally, students are able to identify various characteristics of living things that they can see, measure or experience themselves: take in material, excrete, react to external stimuli, grow, move, cellular composition, die, adapt. However, Astrobiology encourages a student to think beyond the Earth's atmosphere because as scientists have seen, life may have very different characteristics. Some thought needs to be put to generalizing the characteristics of living things to very basic characteristics such as chemical reactions that support life and energy input and output being generated by a life form. This may broaden the definition of life. We can say what life does or what it looks like but it is extremely difficult to give a definition for what life actually is as explained in the Alive Chapter.

Suggested Activities

Preassess students' understanding of what life is. Survey answers to this question. Use analogies such as wind or water for things that you may not be able to see that exist and how do you define and measure these things. Attempt to carefully address misconceptions about theories dealing with the definitions for life.

Generate vocabulary so students can articulate their thoughts on these astrobiology concepts (see previous Phase 1 lesson).

Perform possible experiments that can actually measure the existence of biosignatures. This could pertain to future missions that use or discuss actual sampling techniques such as gas chromatography, mass spectrometry and pyrolysis that are real lab procedures that will be used in the next twenty year as Space Agencies plan to go to Mars or Europa, etc. Students could use simple techniques where the principles of proper sampling, the necessity for calibration and repetition could be taught . The use of electrophoresis, filtering and blotting paper could be used to separate dyes in adapted activities.

Design activities that promote open mindedness with regard to new things such as the impact of finding life on other planets. Self reflection and communication of what individuals and society at large would experience could be done in the form of writing journal articles, debating or open forums with guest speakers from the community.

Summary

Such a phase would entail the use of multiple disciplines: biology, chemistry and laboratory techniques, psychology, sociology, etc. This phase is essential for any curriculum concerning astrobiology because it forms the foundation for future understanding and provides context for subsequent phases. This phase may also be a "stand alone" unit that would address fundamental questions concerning the definition of life.

[9] SETI: `http://www.seti.org`

7.4.4 Phase 3: How to Look For, Protect and Study Life?

Goals

Students develop a general understanding of different ways to find evidence of life and how to protect "them" and us from contamination. After completing phase 2, students should have an understanding of life. Now students will apply their understanding of life to discover for themselves how hard it is to prove that life exists. Students are introduced to the idea of contamination and what it means. They are then presented with thought provoking discussions and activities that allow them to understand what needs to be done to protect Earth from other life, and to protect exobiology from Earth.

The multidimensional aspect of phase 3 is the link between biology, ecology, philosophy and advanced technologies.

Suggested Activities

Some recommended methods for teachers to excite and engage their students include using current programs. EarthKAM is a program that uses a camera mounted on the International Space Station to take pictures of Earth. This can be used to look for signs of life on Earth from space. Students get to choose what they want to image, and then they analyze the image themselves. Students can try to prove there is life on Earth based upon an orbital photograph, discuss what features are man-made in the image, what features are natural, and what features represent life. EarthKAM is run through NASA and the University of California at San Diego (UCSD).The Astro-Venture program could be used to encourage students to use the scientific process and develop critical thinking skills. The Astro-Venture program would help students discuss environmental constraints for life.

Other programs are robotic activities like Red Rover, Student Robotic Challenges, Botball, etc. Students can design and build a robot that will do in-situ investigation for life. What type of instruments will the robot need? Have students conduct standard biological experiments using cultures and dyes to engage thought provoking questions; what is life and how do we test for it? Can these same experiments be used on a rover or lander on Mars/Europa?

Other recommendations for curriculum activities that have not been developed yet, include interactive CD ROMs, simulated sterilization, debates and discussion about contamination. A CD ROM could include animations of possible life on other planets; an example would be to show the past Mars landers, show a Martian playing tag with it, and then explain why no life was detected because of the lack of correct instruments. Create a simulated sterilization of a spacecraft. Have students take a culture of the spacecraft before and after sterilization. Encourage them to think and discuss why sterilization of spacecraft sent to outer space needs to take place, discuss the possibility of backward contamination and what that might mean to Earth.

Summary

At the end of this phase students should have an understanding of how to look for, prove the existence of, and study life. Students should have an understanding of the importance of forward and backward contamination. As students continue onto phase 4, planetology, remind them of the importance of forward contamination to preserve other bodies in the Solar System.

7.4.5 Phase 4: Which planets/bodies in our Solar System are best suited to contain evidence of life?

In phase 4 students gain knowledge of our Solar System, our current knowledge of planets and other bodies. They will also be aware of conditions, composition and activity on those planets. Orbits and distribution of planets/bodies should be included. Based on this information, they will be able to determine which planets/bodies would be most suitable for the existence of life.

Body	Body diameter (km)	Scaled Body Diameter (mm)	Orbit radius (km)	Scaled orbit radius (meters)
Sun	1,391,900	1,000		
Mercury	4,866	3.4	57,950,000	41.633
Venus	12,106	8.6	108,110,000	77.67
Earth	12,742	9.1	149,570,000	107.457
Mars	6,760	4.8	227,840,000	163.689
Jupiter	139,516	100.2	778,140,000	559.048
Saturn	116,438	83.6	1,427,000,000	1025.217
Uranus	46,940	33.7	2,870,300,000	2062.145
Neptune	45,432	32.6	4,499,900,000	3232.919
Pluto	2,274	1.6	5,913,000,000	4248.15

Table 7.2: Size of Solar System's bodies

This phase links geology, planetology, chemistry, physics and planetary missions. A comparison of the similarities and differences between planets would suggest which ones are more habitable than others. Topics such as the distance from the Sun, atmosphere, orbit, inclination, moons, geological activity (past, present, future), chemical composition, and radiation environment should be considered. The design of possible missions that could be made to planets or moons will be discussed in Phase 6.

Educators can obtain information of solar system from Space Agencies and organizations or specific web pages. There is a wide variety of planetary information on the web as well as literature sources.

Activities

Preassess students' knowledge of the Solar System: What planets exist, where they are and what are the main characteristics of those planets.

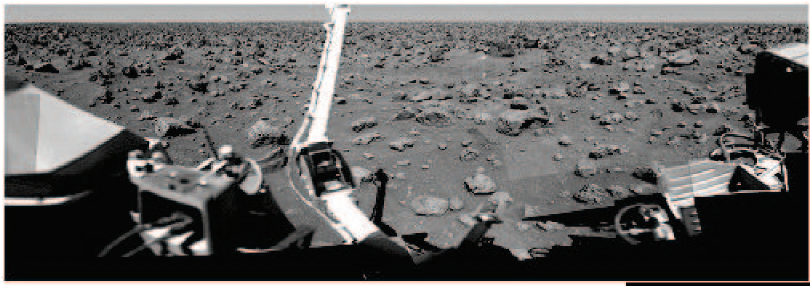
Students can make their own solar system in the classroom. The right scale for planets should be calculated. One planet is given to each team and they have to make it out of cardboard or polystyrene. Then they have to calculate the distances (not in the same scale that the planets are) and make a Solar System model in their classroom. This will give students an idea of the distances and scale of the Solar System.

To calculate the scale of the solar system, a web based program was used [427]. In this example, the Sun's diameter is scaled to one meter. On the Table 7.2 diameters and orbits of Solar System's bodies have been calculated according to the Sun's diameter. This table shows the huge distances and size differences in the solar system. In this model where the Sun's diameter is one meter (about the size of a big beach ball), the Earth's radius is about the size of a glass marble (9.1 millimeters). Jupiter is about the size of an orange (100.2 millimeters). The size of Pluto is as small as a ball bearing (like the ones you could find from your bicycle wheels) (1.6 millimeters). To make a scale model in your classroom, you have to divide the distances, for example, by 100 or even 1000 to fit it in a reasonable space. For example if you divide orbits by 100, Mercury would be 41 centimeters from the Sun, Earth would be a little over one meter away and Pluto would still be 42 meters away!

Generate vocabulary for planetary sciences.

The observation of planets with binoculars through a local astronomy club or association or educational institution would capture students' interest.

"Astrobiology in your classroom, Life on Earth and elsewhere?" is a good Educator resource guide [442]. It provides a suggested game where students look into the features of planets and moons to see which of them would be suitable for life.



Mars Panoramic by Viking 2,
Credit: Edward A. Guinness,
Washington University in St. Louis

Buzz Aldrin exiting Apollo 11 LM,
photo taken by Neil Armstrong,
courteous of NASA (NASA photo ID AS11-40-5868)

Good public outreach exists for "Past, Present and Planned Missions" (see this Chapter 2). Sustained interest for students would be possible through the use of this material and available web sites.

7.4.6 Phase 5: What We are Doing to Learn More About Possible Life Outside our Planet?

Goals

Students understand what current Space Agencies and other institute-sponsored activities are ongoing and planned for the remainder of this decade and the next. Excite students with knowledge of what is being done today and what is being planned. Encourage students to be active in space exploration now and in their future. Persuade them to pursue careers in space by demonstrating what activities are planned for when they are graduating college and starting out in the workforce.

Curriculum Links

Phase 5 links astronomy, geology, physics, biology and engineering. Discuss the stages of current missions. Students can look at a spacecraft and break it down into its primary subsystems.Physics can be used to explain the orbital mechanics of the spacecraft. Does it need to be launched in a specific launch window? How does it reach the planet? What keeps the spacecraft in orbit? Once in orbit does the spacecraft view the planet from orbit or does it land? How does it look for life? How does the method used by the spacecraft compare to the techniques discussed in Phase 3? Discuss other methods of looking for life such as SETI and the Hubble telescope.

Resources

Educators can gain information on current missions by pursuing the sponsoring agency. Almost all NASA sponsored missions have an education and public outreach department. Reference Past, Present, and Planned Astrobiology Missions Chapter for information on current missions. Contact local space agencies for more information about missions and educational outreach programs (a list is found in the Annex).

Suggested Activities

To relate Phase 5 to biology, look at current life experiments being performed on Earth. Relate extremophiles and their habitats to other planets in the solar system. For example, Venus can be related to deep-sea vent life. Study the characteristics of extremophiles and compare how they might differ from other life forms. How have they adapted to their environment? Discuss how geology can leave biomarkers. How can geology prove that life once or still exists there?

A recommendation for a hands-on activity would be to conduct a life search. Life has been known to grow on the underside of rocks in the most barren terrain on Earth. So set up a site where there are lots of rocks that kids can pick up and examine. Place selected rocks that harbor life in the site, approximately 1 in 5 rocks might have life. Let the kids search for the rocks with life. Try to guide them in finding the mostly likely source rocks, but do not discourage any creative behavior.

Have a globe of the chosen target, and label it with locations of missions. Many landers and orbiters have visited Mars; therefore, mark the landing sites on the globe with stickers and attach the orbiters in orbit by use of toothpicks or wire. Determine if astrobiology was taken into consideration during the mission. Discuss how the humanities and knowledge of the target has changed over time. Survey students to find out ideas about future missions and proceed to Phase 6, design of future searches.

Summary

The activities suggested for Phase 5 should give the students a good understanding of astronomy, physics, biology, and history. While this phase could be a stand alone activity, it is best when linked with the past phase dealing with planetology and the next phase that allows them to put to use their knowledge of past missions to design a future mission.

7.4.7 Phase 6: Design Your Own Search

After completing all or selected sections in the previous phases, students will have a greater understanding of astrobiology. They will have developed a personal understanding of the material that will be manifested in an increase of general knowledge that can be subject to assessment and evaluation. Students will have a suite of vocabulary terms that relate to astrobiology. They will have a stronger background with regard to definitions for life, contamination issues, possible habitation zones and actual missions.

The most revealing method of assessing and evaluating what students have learned is to challenge them with the completion of a culminating task that will allow them to relate acquired knowledge and skills to other areas of science, technology, society and the environment. This must take the form of a project, research assignment, science fair presentation or "table top talk" with a student who is now an "expert" in a given astrobiology field. The culminating activities must be hands on in nature. "We learn if we have something in our hands" (Jean Piaget). Astrobiology allows children to be scientists, engineers, sociologists and innovators within the context of its multidisciplinary nature. By designing a search or mission, students will be able to plan; build and problem solve the search for life on other planets.

This type of inquiry and discovery teaching can be used in the formal classroom and informal venues such as museums and children’s centers. The activities must be planned using small groups so that students practice team-building. Problem solving, trying to make things work and sharing information with one another encourages students to think with greater clarity and depth which leads to more profound learning. Astrobiology asks profound questions to children that will grow up to be adults who will have a greater understanding of the "big" questions of life.

Suggested Activities

Conduct research using astrobiology as the theme and have project ideas divided into mission areas such as past, present missions, possible future missions, education and public outreach, spacecraft requirements, health impacts surrounding the mission and science and technology spin offs.

Run a concurrent project design team with real time research that gets incorporated into a group project as the material is created. This models what is done in space agencies today as a mission planning tool.

Prepare a documentary, video or commercial that investigates various aspects of astrobiology and the search for life on other worlds.

Have an "ask the expert" forum where scientists and researchers discuss their work with students doing research in a particular area.

Do cross-curricular projects where multiple subject areas are addressed under the umbrella of Astrobiology. For example, English could be taught using fiction that is scientifically accurate [436].

Find public forums for students' to showcase their research to media, school board officials, parent councils, space agencies, service groups, other schools or grade levels. Investigate the use of competitions for science-based projects such as the Canada Wide Science Fair[10], Science Teachers Association of Ontario[11]and Skills Canada[12].

Summary

The successful use of culminating activities that demonstrate understanding of the astrobiology material covered may have a positive effect on students' attitudes towards questions concerning life, science and technology. This may affect course options when the students pursue careers in astrobiology and other space related fields.

7.4.8 Concluding remarks

Each of the ideas mentioned above requires further development. The goal is not to make each activity strictly astrobiology-related but to encourage the use of science, technology and the humanities under an astrobiology tie or theme. Depending on budget and other constraints the ideas listed above can be implemented in many ways; from small, short lesson plans to be used in the classroom to hands-on stations found at science museums.

The idea is to encourage students to engage in science, technology, and the humanities through a subject that already interests them. Hopefully, if they are excited by the projects, hands-on activities, and thought provoking discussions that they will continue to question and pursue the answers in space fields later in life.

7.5 Suggested Implementation Plan for Activities

7.5.1 Introduction to Strategies

The previous sections have defined what astrobiology educational products are currently available and what types of products should be considered for the further advancement of astrobiology education outreach. This section is focused on a strategy that should be considered:

1. Promoting the proposed outreach concept to a target set of sponsors who are willing to finance the prototype program;
2. Teaming up for the development of the outreach products from concept through to a six phase prototype package;
3. Field testing the prototype products for feedback and improvement;
4. Implementing a building block approach for regional, national, continental and global program adoption.

[10] http://www.usask.ca/cwsf/ & http://www.parentcouncil.com/science/scifairs.htm
[11] http://www.stao.org
[12] http://www.skillscanada.com

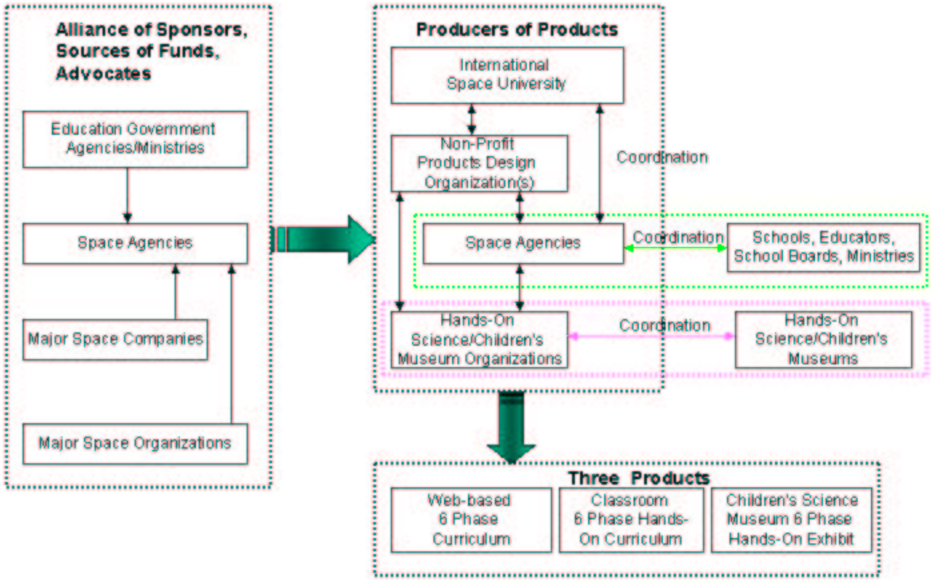


Figure 7.3: Recommended Framework

All proposed strategies are based on the following driving principles:

1. In order to foster the future thinkers who will determine the course of astrobiology, the outreach is focused on 10 - 14 year old students and the course content is aligned with the 20 year plans of major space agencies worldwide;

2. Integrated implementation that minimizes costs, risks and duplication and maximizes use of relevant existing products and the sharing of new products;

3. Targeted sponsors and partners with the proven expertise and resources to produce the highest quality products that energize students;

4. Selected learning environments that are conducive to enhancing scientific hands-on critical thinking skills.

While there are multiple ways to design, develop, finance, implement and sustain an education outreach program, the following paragraphs will outline a recommendation that is compliant with the goals and principles covered above. Figure 7.3 shows the general framework and proposed key contributors for organizing sponsorship, for producing and coordinating products and for the actual outputs. This approach, that will be referred to in the remainder of this report as the Program, relies on the respective space agency within the country or countries. The space agency would establish the alliances associated with sponsorship and coordinate the producers of products to the extent that the goals and objectives of the Program are met. Three output products are to be produced and maintained. The products include a focused and agency aligned six phase web-based curriculum, a six phase hands-on classroom curriculum, and finally a six phase hands-on traveling exhibit.

It is recommended that the International Space University (ISU) play an important role in the early coordination and development of the Program. The ISU alumni, ISU Summer Session Programs (SSP) for years 2003 through 2005, and the ISU Masters of Space Studies (MSS) for years 2002 through 2005, should be used as part of specific focused design projects/assignments for the design and development of the Program's products. There is great synergy between implementation of this Program and the goals and objectives of ISU. This focused support, by those students who choose to participate, will also bring more practical real-world experience and "pride of ownership" into the ISU design projects and individual assignments. ISU and the

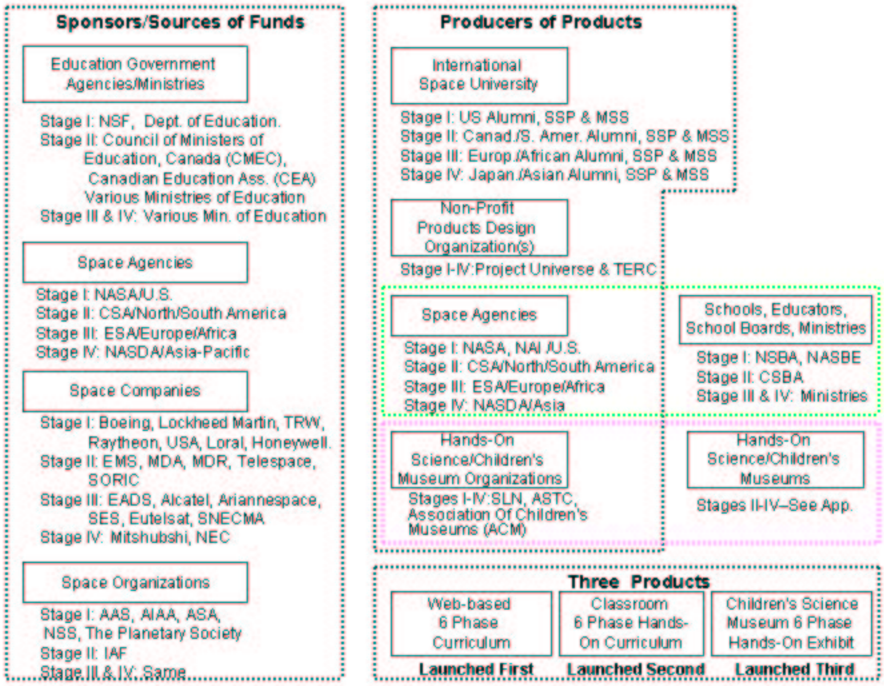


Figure 7.4: Specific International Framework in four-stage implementation strategy.

respective space agency would coordinate with a non-profit product design organization (e.g., such as Project Universe or TERC[447]) to facilitate the design, development and maintenance of the products.

We investigated each of the types of space agencies, sponsors, companies and organizations shown in Figure 7.3. [13] As discussed in further detail later, the strategy recommended for sponsorship includes targeting only those well established and highly funded organizations for this ambitious Program.

Perhaps the most difficult challenge of a program of this magnitude will be maintaining the right pace for product introduction and geographic expansion. This must be done in a controlled and deliberate fashion to ensure any problems can be dealt with efficiency and if necessary early improvements can be incorporated. Four building block stages are recommended for the overall international implementation of the Program. Each stage expands the outreach to another country/continent for targeting funding and sponsorship, for producing and coordinating products and for incremental product deliveries. Stage one is focused within the United States and will take perhaps the longest to complete since all products will be field tested and refined here. The intent is to develop the foundations for the international objective by producing the initial framework & common processes that will be used repeatedly by each subsequent country during follow-on implementations. Figure 7.4 takes the previous framework and shows the staged approach with each block now identifying the specific targets or contributors for the specific stage.

Each stage of the Program, once it has been proven out in the United States, is intended to be very portable or transferable to another user. This will allow for an accelerated implementation as it grows globally. The web-based products for example would simply need to be translated to the appropriate language/culture and tuned to support the specific space agency's direction. The limiting factors in this will be the securing of the proper sponsorship and funding in advance and ensuring that the framework/network for implementation are well defined in advance of product availability in the region. The high level timescale for this strategy relating to the products, the target age group and the agencies direction within the next decade is shown in Figure 7.5.

[13] Lists of the groups researched, can be found at `http://www.nasa.gov/hqpao/other_agencies.html` and `http://directory.google.com/Top/Science/Technology/Space/National_Space_Agencies/`

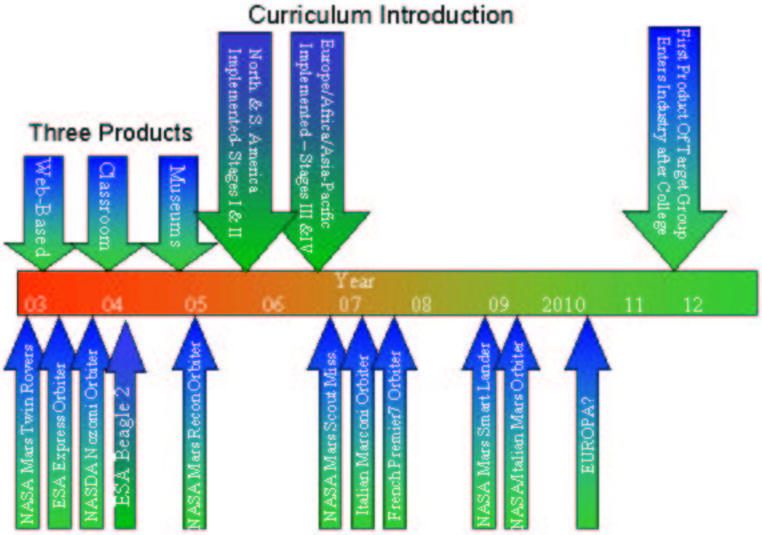


Figure 7.5: General Timescales for Curriculum Introduction and Space Agencies' Astrobiology Missions

7.5.2 Getting the Prototype Program Going - United States Case Study

Figure 7.6 shows the framework chart with the specifics for the United States prototype application. On the left hand side of the chart, NASA Headquarters would play the key pivotal role in supporting this outreach plan. A cost and benefits analysis report would be developed and presented to NASA Headquarters by the National Astrobiology Institute (NAI), the NASA Ames center[14] and the International Space University (ISU). Ames is the leading NASA center for Astrobiology outreach. NASA Headquarters, through the normal channels for education budget allocation and approval, would provide guidance into the five-year plan and eventual support and backing for its implementation by authorization for a new "Cooperative Agreement Notice (CAN)" to be advertised. NASA Ames and the NAI would take the lead on coordinating a coalition of the affiliates listed and others through the CAN process. Note that the NAI was formed using the CAN process and is currently soliciting partners via CAN Cycle 3. Once the alliance or coalition is secured the Program would proceed in line with funding allocations and sponsorship.

Full implementation within the United States would come in the form of three controlled and deliberate sub-stages. The first sub-stage would be the production/field testing and implementation of the web-based products. These products would make maximum use of the existing NASA web-based astrobiology curriculum but focus, align and supplement it as suggested herein. The suggested products that should be screened for transfer to one or more of the six phases of the recommended curriculum are located at the following websites, listed in priority order:

1. `http://astrobio.terc.edu/` - astrobiology curriculum created by NASA and non-profit organization TERC;
2. `http://sse.jpl.nasa.gov/roadmap/pdffiles/Rmap.pdf` - NASA scientific objectives for exploration of the Solar System and how it relates to Astrobiology developed by JPL;
3. `http://nai.arc.nasa.gov/teachers/` - National Astrobiology Institute provides curriculum to teachers;
4. `http://astrobiology.arc.nasa.gov/education/index.html` - NASA Ames astrobiology education resources;
5. `http://quest.arc.nasa.gov/projects/astrobiology/astroventure/teachers/pdf/AVresources.pdf` - annotated bibliography provided by NASA.

[14] `http://www.arc.nasa.gov`

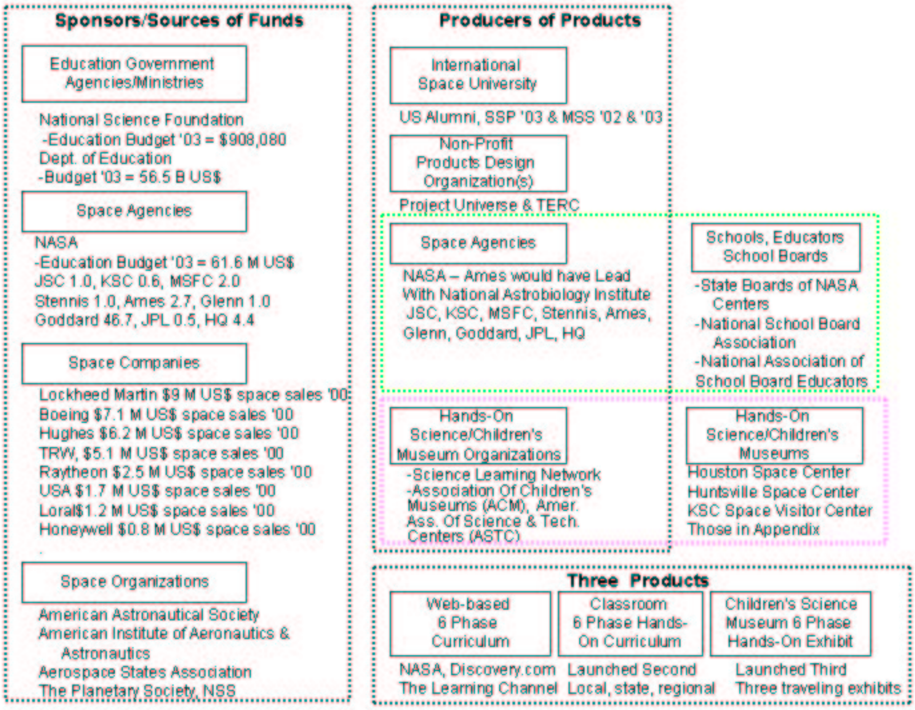


Figure 7.6: Specific United States Framework - Stage 1 of four-stage global implementation.

This product would go nationwide as soon as field-testing results are satisfactory and on-line training to teachers is proven. Nationwide introduction and support would be lead by NASA, but include solicited support and links from leaders in the youth outreach field such as The Discovery Channel and The Learning Channel. The second sub-stage involves the production/field testing and implementation of the classroom curriculum. This sub-stage would include local, state and regional introductions into the classroom with on-site expertise support as needed from sponsoring agencies before being made available nationwide. The concept would be to grow the incorporation of this curriculum outward from the NASA center locations. The final product would be the children's hands-on museum display/exhibits. The American Association of Science and Technology Centers Incorporated (ASTC), the Association of Children's Museums (ACM)[15] and the Science Learning Network (SLN) are three outstanding groups representing children's museums and dedicated to furthering the public understanding of science. These groups in concert with NASA and industry Astrobiology experts and a non-profit design organization such as Project Universe would design and develop this hands-on, interactive exhibit. The exhibit is envisioned to have stations corresponding to the classroom/web-based six phase multi-disciplined curriculum. The product introduction would start with the three NASA Space Visitor Centers at Huntsville Alabama, Johnson Space Center and Kennedy Space Center, respectively. This proving ground will provide a launching point for the traveling hands-on display/exhibits (quantity of at least three exact units) to make it's way regionally in three directions throughout the U.S.

Rough-Order-Magnitude (ROM) cost estimates for the United States Program implementation up through the third and final product introduction (3 traveling hands-on exhibits field tested through JSC, KSC and MSFC visitor museums/centers) and follow-on use (a 5 year plan) are included in Figure 7.3. The basis for the estimates is also included as well as a gauge of the perceived cost risks (low, medium or high) for areas that could warrant closer budgetary monitoring due to the potential for growth.

In summary, this section provides a suggested framework for organizing, funding and implementing an international effort to use the rapidly growing field of astrobiology as the cornerstone to bring our youth closer to space, science and humanities. The framework provides a foundation for each global region to consider when building a program and an approach that is incremental and flexible. The costs estimates indicate that for a country the size of the United States a five-year plan could be carried out at low to moderate risk to produce

[15] List of majority of Hands-On Children's Science Museums extracted from `http://www-2.cs.cmu.edu/~mwm/sci.html`

Program Task	End Product	Basis Of Estimate	Estimated Cost	Cost Risk
Acquiring Approvals to Proceed				
Develop Formal Program 5 Yr Plan	"Business Plan"	1.5 heads x 3 months x 120 hours/month X $50/hour	$27 000	Low
Develop Cost Benefits Analysis	Report to NASA HQ	2 heads x 1.5 months x 120 hours/month X $50/hour	$18 000	Low
Subtotal			**$45 000**	
Forming Alliances and Acquiring Sponsors				
Drafting/Releasing CAN cycle 4 - for NAI focused support	Released CAN	1.5 head x 2 months x 120 hours/month X $50/hour	$18 000	Low
Managing CAN process to completion	CAN announcements of participants	1 head x 6 months x 120 hours/month X $50/hour	$36 000	Low
Acquiring Additional Backing and Sponsoring	Formal Agreements on commitments of sponsors	1 head x 6 months x 120 hours/month X $50/hour	$36 000	Low
Subtotal			**$90 000**	
Design, Develop, Implement and Maintain Product 1				
Research Recommended Web Products for Applicability	Report to AMES on which to Incorportate	2 heads x 1 month x 120 hours/month X $50/hour	$12 000	Low
Review and Supplement Recommended 6 Phase Curriculum	Report to AMES on Final Recommendations	2 heads x 1.5 months x 120 hours/month X $50/hour	$18 000	Low
Design & Develop On-line Training for Educators	Fully Functional Prototype Web Product	1.5 heads x 1 month x 120 hours/month X $100/hour	$18 000	Low
Design & Develop Focused 6 Phase Web Product	Fully Functional Prototype Web Product	2 heads x 1.5 months x 120 hours/month X $100/hour	$36 000	Low
Design, Develop & Incorporate Interactive Animations	Integrated Animations with Web Product	1.5 heads x 3 months x 120 hours/month X $100/hour	$54 000	Medium
Coordinate with Local School System for Field Tests	Formal Agreement on 1 month in class trial	0.5 heads x 1 month x 120 hours/month X $50/hour	$3 000	Low
Field Test Website w/ Local School w/ on-site NASA Support	Comments and Suggestions for Improvements	2 heads x 1 month x 120 hours/month X $50/hour	$12 000	Low
Incorporate Improvements from Field Test	Final Web Product Fully Functional	2 heads x 1 month x 120 hours/month X $100/hour	$24 000	Medium
Full Implementation in all NASA center local areas (11)	Alliance members help engage educators on use	12 heads x 2 months x 120 hours/month X $100/hour	$288 000	Medium
Coordinate w/ School Boards, Discovery Channel,..for use	Alliance members help engage wider use	12 heads x 1 months x 120 hours/month X $50/hour	$72 000	Medium
Maintain/Update Web Product over 5 year plan	Continuous up-to-date operation over 5 years	1 head x 60 months x 120 hours/month X $50/hour	$360 000	Low
Yearly content revisions by subject matter experts	Revised products or different hands-on activities	2 heads x 1 month x 120 hours/month X $100/hour x 4yrs	$96 000	Medium
Sub-Total for Product 1 over 5 years			**$993 000**	
Design, Develop, Implement and Maintain Product 2				
Design & Develop 6 Phase Hands-on Classroom Kits	Protoype Hands-on Kits	2 heads x 1.5 months x 120 hours/month X $100/hour	$36 000	Low
Kit Material Costs	5 kits	Material Costs for Prototype Kits - $750 each	$3 750	Medium
Supplement Web-based Product 1 w/ Formal Curriculum	Protoype Handbook integrated with Hands-on Kits	2 heads x 1.5 months x 120 hours/month X $100/hour	$36 000	Low
Supplement On-line Training for Educators	Fully Functional Prototype Web Product	1 heads x 1 month x 120 hours/month X $100/hour	$12 000	Low
Coordinate with Local School System for Field Tests	Formal Agreement on 1 month in class trial	0.5 heads x 1 month x 120 hours/month X $50/hour	$3 000	Low
Field Test Curriculum/kits w/ Local School w/ NASA Support	Comments and Suggestions for Improvements	2 heads x 1 month x 120 hours/month X $50/hour	$12 000	Low
Incorporate Improvements from Field Test	Final Product Fully Functional	2 heads x 1 month x 120 hours/month X $100/hour	$24 000	Medium
Coordinate w/ School Boards for use	Alliance members help engage wider use	12 heads x 1 months x 120 hours/month X $50/hour	$72 000	Medium
Full Implementation in all NASA center local areas (11)	Alliance members help engage educators on use	12 heads x 2 months x 120 hours/month X $100/hour	$288 000	Medium
Mass Produce Curriculum/Kits for 11 areas x 10 schools each	110 kits	$500 per kit	$55 000	Medium
Maintain/Update Curriculum/Kit Products over 5 year plan	up-to-date operation over 5 years	1 head x 60 months x 120 hours/month X $50/hour	$360 000	Low
Shipping/Maintenance Costs for kits		115 kits x 6 to-from shipping/yr x 5 years + $50refurb/kit	$57 500	Medium
Yearly content revisions by subject matter experts	Revised products or different hands-on activities	1 heads x 1 month x 120 hours/month X $100/hour x 4yrs	$48 000	Low
Sub-Total for Product 2 over 5 years			**$1 007 250**	
Design, Develop, Implement and Maintain Product 3				
Design & Develop 6 Phase Hands-on Museum Stations/Exhibit	Paper Designed Protoype Stations/Exhibit	2 heads x 3.5 months x 120 hours/month X $100/hour	$84 000	Medium
Exhibit Material Costs	1 Prototype Exhibit	Material Costs for Prototype Exhibit - $100000	$100 000	High
Incorporate 6 Phase Curriculum	Integrated Prototype Interactive Display	2 heads x 1.5 months x 120 hours/month X $100/hour	$36 000	Low
Coordinate with 3 Space Center Visitor Centers for Field Tests	Formal Agreement on 1 month trial	1.5 heads x 1 month x 120 hours/month X $50/hour	$9 000	Low
Field Test Exhibits w/ Local w/ NASA Support	Comments and Suggestions for Improvements	6 heads x 1 month x 120 hours/month X $50/hour	$36 000	Low
Incorporate Improvements from Field Test	Final Product Fully Functional	2 heads x 1 month x 120 hours/month X $100/hour	$24 000	Medium
Coordinate w/ Museums/Associations/SLN for use	Formal Agreements on traveling/exhibit dates	3 heads x 1 months x 120 hours/month X $50/hour	$18 000	Medium
Produce 2 more duplicate traveling exhibits	2 more units	$100,000 each	$200 000	Medium
Advertisement Banners/Pamplets on Exhibit	6 banners and 1500 pamplets	6 x 250 + 1500 x 25	$39 000	Low
Maintain/Update Exhibit Products over 5 year plan	Continuous up-to-date operation over 5 years	3 head x 60 months x 120 hours/month X $50/hour	$1 080 000	Low
Shipping/Maintenance/Teardown/Setup Costs for Exhibits		3 exhibits x 10 moves each/year x $2500 + 25,000 Maint.	$400 000	Medium
Yearly content revisions by subject matter experts	Revised products or different hands-on activities	1 heads x 1 month x 120 hours/month X $100/hour x 4yrs	$48 000	Low
Sub-Total for Product 2 over 5 years			**$2 074 000**	
Total ROM Estimate for United States 5 Year Program	Goal is to offset some of this through the Alliance/Sponsors' commitment of Money, Material and Time		**$4 209 250**	

Table 7.3: Detailed ROM Cost Estimates for U.S. 5-year Plan [437][443]

and implement all three products at a total cost of US$4.2M. This cost does not reflect the synergies and savings that could be experienced by utilizing the existing resources within the proposed alliance. It is estimated, based on the implementation schedule outlined in Table 7.3, that during the five-year plan 270 museum-type locations would experience Product 3, 1350 schools would use Product 2 and hundreds of thousands would be exposed to Product 1.

7.6 Summary

"Come mothers and fathers Throughout the land And don't criticize What you don't understand." The Times They are a-changing, 1964, Bob Dylan.

Astrobiology is a new and exciting field that has the potential for increasing the public's interest in space related activities. In a 1998 survey of ESA member states, a professional company surveyed 8 350 weighted respondents and found that 42% had an interest in space exploration [445].

Astrobiology, in dealing with life on Earth and other planets, addresses questions that are fundamental to human existence. Society may criticize the endeavors of space agencies because it does not really understand what all those scientists and researchers are doing. It is the educator's job to bridge the gap between science and the student, who may become "the mothers and fathers throughout the land criticizing what they don't understand". Public opinion will vacillate, but teaching strong, positive principles in the context of space exploration over the long term will ensure that humans continue to look beyond the stars. This chapter and accompanying activities have attempted to address respect for the human element in educational activities. We preassess the knowledge base and provide vocabulary so the audience can think about concepts in astrobiology. This is done in an international fashion with an attempt to adapt lessons for multiple users. The survey of current resources left several gaps that must be filled in future curriculum development. Most of the curriculum that has already been developed focuses on science and mathematics with no emphasis on humanities. Current resources are nebulous, trying to encompass the entire broad field of astrobiology. This curriculum deals closely with missions and developments in a 10 to 20 year time frame that will engage and excite students about events they can take part in. Curriculum must provide for students assessment and mitigation of misconceptions about astrobiology. The promotion of critical thinking skills encourages students to separate science fiction and fantasy from science fact. The use of hands-on activities that are cross-curricular promotes the integration of astrobiology as a vehicle for teaching not only the sciences but technology and humanities. Emphasis is placed on the teacher as the prime resource because we believe that astrobiology as a subject will be "caught not taught" where the motivational abilities of the educator are critical in the implementation of any curricula or activities. This can only be done if excellent international resources, web sites, and multimedia materials are provided. An implementation plan is outlined that sets the stage for serious consideration of education as a driving force in the space industry. It is our desire that educators, ministries of education and informal venues that are well established in our communities see the potential of this resource for promoting astrobiology and science with human resources as its primary strength.

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Part IV

Synthesis

Chapter 8

Case Study: A Conceptual Design of a Europa Mission

8.1 Introduction

The purpose of this case study is to give an example of how the various issues addressed in this design project influence and shape a possible astrobiology mission. This study was performed with emphasis on an interdisciplinary approach by including eight different departments in three subsequent concurrent design sessions. The departments covered the following aspects of an interplanetary mission: Physical Science, Engineering, Space Systems Analysis and Design, Satellite Applications, Life Science, Policy and Law, Business and Management, and Space and Society. Due to limited time and resources we could not elaborate on all technical aspects in detail and this study should be regarded as a conceptual design that can serve as a source of ideas and guidelines for future astrobiology missions.

Several spacecrafts have visited Jovian system. Pioneers 10 and 11, and Voyagers 1 and 2 set the stage for Galileo (cf. 2.3.1.3, pp. 16) mission, which gave important insight on main physical properties of the Jovian system. On its way to Saturn, Cassini flew past Jupiter, and, by working together with Galileo and the ground based telescopes, offered unprecedented data on Jupiter's magnetosphere. Proposed mission should extend science obtained through Galileo S/C, with an emphasis on Europa.

We chose the Jovian satellite Europa to be our mission target as it represents, together with Mars, comets and probably the Saturnian satellite Titan (for prebiotic chemistry), one of the most promising places in our Solar System where we could find at least very basic and primitive forms of life, either in living or fossil form. The various aspects discussed in this study could also apply in a similar form to other potential astrobiology destinations. The choice of our destination was also driven by the fact that potential missions to Europa have not been well studied. Several missions, however, have flown, or are currently planned to head for Mars or comets (cf. 2.3.1.1, 2.3.1.6).

8.2 Mission Statement and Assumptions

Our **mission statement** is to design a mission that

- shall perform a detailed research of the Galilean satellites with emphasis on Europa, to locate favorable places for life as we know it.
- shall look *in situ* for signs of life on the surface, in the ice layer and at the ice/water interface of Europa.
- shall enhance public interest in Europa and space activities and provide educational initiatives that can be used globally by all levels of learning.

Mission Assumptions

- The mission should happen within the following 20 years.
- The mission should be feasible using existing launch and communication facilities.
- The mission should be conducted as a joint NASA/ESA project.
- The budget limitations for the whole mission should fit into the frame of a so called ”flagship/cornerstone” mission.

Environment Assumptions

Jovian system has a very specific environments, which imposes restrictions on the S/C subsystems (cf. 8.4.2, pp. 166) and the choice of the orbit (cf. 8.7.1, pp. 175).

8.3 Science Plan

This section will focus on the scientific objectives and how to achieve those goals. The instruments and equipment needed, and their properties and capabilities, will be briefly described.

8.3.1 Scientific Objective

The scientific objective is to study the Jovian system, following upon the science conducted by the Galileo spacecraft. There will be an emphasis on Jupiter's moon Europa, where the scientific objective is to map at least 80% of the surface of Europa, and to identify possible hot targets. This means to detect locations that are relatively warm and where the ice crust is relatively thin. High-resolution images with an optical camera shall be taken to get more information about the surface structure of the Galilean moons, especially Europa. Chemical abundances on the surface and in the ice of Europa will be investigated. The mission aims to find prebiotic building blocks, or perhaps even signs of dormant or extinct life.

The results of the mission should serve as basis for the design of following missions to Jovian system.

8.3.2 Payload Selection

For this case study the data of the scientific instruments is mostly estimated by analogy and by recent publications.

Details on the scientific requirements for the instrumentation can be found in chapter 4.4.1, page 78. Chapter 3.4 offers background information on the instruments used for life detection.

The first instrument chosen for the orbiter is a radar. It will be used for subsurface mapping. Additionally, it will also scan through the ice to possibly detect thinner spots of the ice, where the cryobot will be able to get all the way through to the water under the ice crust. The radar will have a mass of about 40 kg, a data transfer rate of 300 kbit/s and an average power consumption of 100 W.

The next instrument on the orbiter is an IR camera. It will search for warmer spots on Europa, to assist the radar in the detection of a suitable target for the deployment of the lander.

Furthermore, the orbiter is equipped with a ultraviolet spectrometer (UVS) and an extreme ultraviolet spectrometer (EUVS). These two instruments have a mass of 5 and 12 kg respectively and consume an average of about 13 Watts together. The UVS and the EUVS will provide a better understanding of plasma processes on Jupiter and the Galilean moons.

The last instrument installed on the orbiter is a high resolution optical camera. It will have a mass of 28 kg and consume an average power of 23 W. These images can give further information about the structure of

Diameter (km)	3,138
Mass (kg)	$4.8 \cdot 10^{22}$ kg
Mass (Earth = 1)	0.0083021
Surface Gravity (Earth = 1)	0.135
Mean Distance from Jupiter (km)	670 900
Mean Distance From Jupiter (R_J)	9.5
Mean Distance from Sun (AU)	5.203
Orbital period (days)	3.551181
Rotational period (days)	3.551181
Density (g/cm^3)	3.01
Orbital Eccentricity	0.009
Orbital Inclination (degrees)	0.470
Orbital Speed (km/sec)	13.74
Escape velocity (km/s)	2.02
Visual Albedo	0.64
Surface Composition	Water Ice

Table 8.1: Physical properties of the Jovian satellite Europa

Europa, and have high value for public outreach, for the popularity of the mission, and space activities at a whole (cf. 8.12.1, pp. 190).

Lander will be equipped with a passive seismic sounder to gather information about the tectonic activities on Europa. Seismic waves travel at different speeds in different materials and are reflected, refracted and diffracted at their interfaces. Even if only one seismic sounder is installed, it could give some information about the inner structure of Europa. Future missions should use an array of seismic instruments to obtain a detailed subsurface structure.

The cryobot [459] will have a miniaturized gas chromatograph and a mass spectrometer (approximately 9 kg). As the nuclear heated cryobot melts its way down into the ice, these two instruments will analyze the chemical composition of the molten material. A UV fluorescence camera will scan through the ice for organic material and an optical camera will provide insight of what Europa looks like under the surface, and optical inspection if the other instruments installed on the cryobot detect something of interest.

8.4 Environment

The radiation environment on Europa clearly limits our options regarding surface based science. The very low temperatures prevailing on Europa's surface, and the high heat capacity of water and ice, demand high amounts of energy for the melting process through the ice layer. Contamination issues will be discussed at the end of this section.

8.4.1 Physical Properties of Europa

Europa is about the same size as our Moon, and orbits Jupiter in a tidal lock (the same side faces Jupiter all the time). Due to the very low surface temperature, the satellite is covered by an ice layer of at least 3 to 4 kilometers thickness [471]. Table 8.1 summarizes the main physical properties of Europa [460]. Additional information on Europa can be found in chapters 2.3.1.3, and 4.4.

8.4.2 Mission Design Restrictions

- **Radiation**

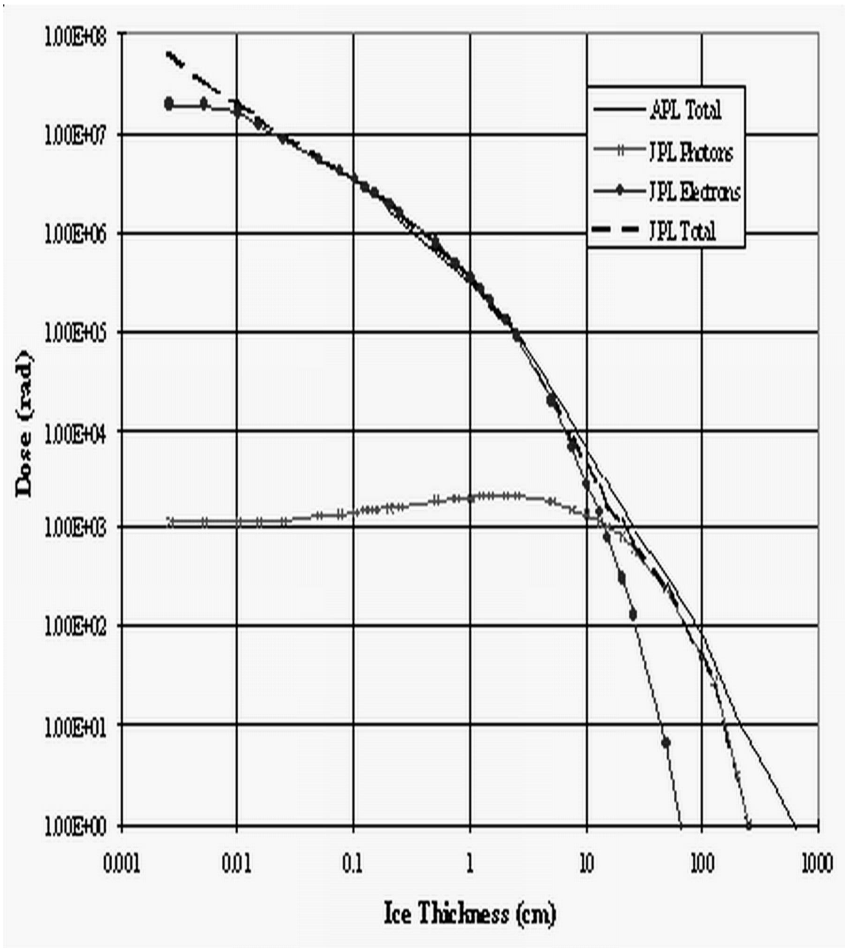

Figure 8.1: Dosage per month over thickness of ice shielding. Courtesy of [470]

Jupiter's strong magnetic field captures huge amounts of solar wind particles and traps them in radiation belts similar to the Van Allen belts around our own planet. Europa's orbit is located in one of these belts, which results in an extreme radiation environment (about 10^7 rad/month). Such a radiation intensity would kill humans in less than an hour and limits spacecraft operations to approximately 30 days. The only way to decrease the radiation dose for the orbiter is to use an elliptical orbit around Jupiter, approaching Europa as often as possible. The lander (including its melting device) could be protected by submerging it into the ice. As seen in Figure 8.1 a 50 cm shield composed of water ice reduces the combined dose rates of electrons and ions by a factor of $\sim 10^5$ from the ambient value [470]. Choosing a landing site on the leading hemisphere of Europa will further reduce the radiation by a factor of 5.

- **Acids**:

  Sulfur and other elements, ejected by Io's volcanoes and geysers, are found at the surface of Europa and could be buried in Europa's ice, making it acidic. This poses a potential threat to any lander and its instruments. Since we do not know how acidic the ice will be, it is important to be prepared for the worst case scenario. Lander, melter and all instruments shall be designed to cope with acidic environments, possibly by covering them in with an acid resistant layer.

- **Pressure**:

  The cryobot is expected to penetrate a relatively warm and thin part of the crust. Ideally it will reach the water/ice interface. Our melting depth will be about 3 km (see chapter 8.6.1.1). Since Europa has about one seventh of Earth's gravity, the weight of 3 km water column produces about 40 bars of pressure which corresponds to a depth of 390 meters in Earth's oceans. The examples of diving to 390 meters and more are very numerous, and finding instruments that work in these conditions should be feasible.

- **Temperature**:

  The surface temperature on Europa ranges from 70K to 100K (which corresponds to $-200°$ C to $-170°$ C). Subsurface crust temperature slowly raises towards water/ice interface, where it reaches approximately 270 K. Instruments will need to be heated, and this will be achieved by the radioisotopic thermal generators (RTGs). As the thickness of the ice is unknown, the temperature on our descent might increase as little as 20K , but it could also be higher, depending on the distance to the ocean.

  The extensive public outreach program deals with the use of RTGs, and is presented in chapter 8.12.

- **Contamination**:

  What has to be done to minimize chances of a forward contamination of Europa by biomass traveling on the spacecraft? We refer to the Planetary Protection Section 5.1 and also the report on the forward contamination of Europa by the Space Studies Board Task Group [452]. The report concluded that because Europa has a possible ocean, we must reduce the amount of biomass that comes from Earth. The probability of contaminating must be less than 10^{-4} (0.01 percent) per mission. Mission Designers can take advantage of the Jovian radiation environment (see sec.8.4.2) which is rather extreme and will do some sterilization of the spacecraft before it submerges into the ice. When we look at the Main COSPAR Table 5.1 we see that Europa should be treated as a IV B mission, which means that we are using a lander that will perform in-situ experiments for life detection. Therefore, physical contact with the Europan surface is foreseen, and accordingly precautions to avoid contamination must be at a high level. Appendix D suggests a Viking-like level of sterilization. These techniques include procedures such as cleaning surfaces with isopropyl alcohol and/or sporicides and sterilization by dry heating, as well as more modern processes such as sterilization by hydrogen peroxide. [472].

  The same applies for the orbiter in case it crashes on Europa's surface at the end of its lifetime, since the orbiter spends much more time in the high radiation environment and will also undergo high level sterilization on Earth. The landing site will therefore be chosen in a way that Europa's ice shield will not be penetrated (see Section 8.6.3). For various legal aspects of contamination issues see Sections 5.4 and 8.10.1.

8.5 Mission Architecture

Here we present mission requirements, identify the various design options to meet these requirements, evaluate an overall Δv budget for the whole mission, and to choose an existing launch vehicle.

8.5.1 Mission Requirements

The mission requirements for the orbiter are to continue investigation of the Galilean moons, choose the landing site on Europa, map at least 80% of the surface of Europa, and estimate the thickness of the ice layer of Europa, Ganymede, and Callisto.

The mission requirements for the lander are to investigate the surface and the subsurface of Europa, to perform chemical analysis of the ice (for better understanding of Europa's past), to detect prebiotic molecules, or possibly organic molecules, on and in the ice layer, and to study the geological aspects of Europa.

8.5.2 Functional Analysis

Figure 8.2 depicts a functional flow diagram of the Europa mission. More detailed description can be found in chapter 8.8. For a general mission schedule, see Figure 8.8.

8.5.3 Mission Elements

The flight segment is composed of 3 different elements: the 800kg orbiter, the lander with a mass of 542kg, and a 60 kg cryobot including a 3 km long tether as a link to the lander.

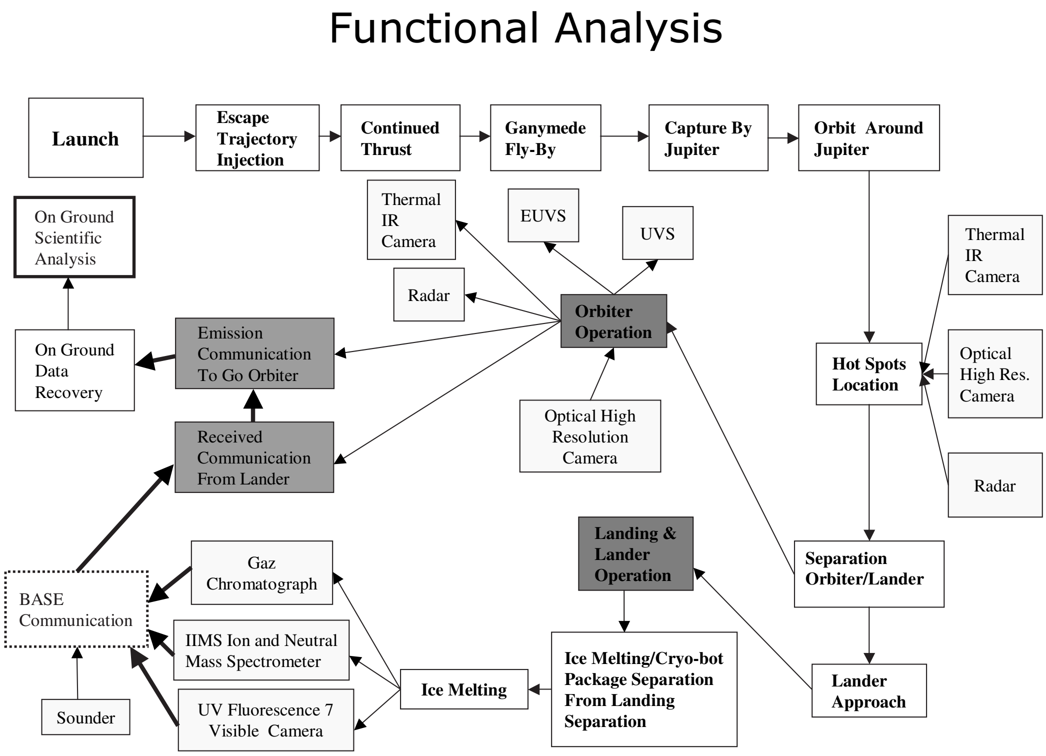

Figure 8.2: Functional Mission Analysis;

The ground segment is composed of four different elements: one geostationary orbiter, the Deep Space Network (DSN), one mission operations center and one Data Analysis Center.

8.5.4 Mission Design Options

Table 8.5.4 shows all the different options taken into account during the case study, and the choices made for our mission. A pre-programmed landing location is needed in case of failure of the remote sensing subsystem, which would provide site locations.

8.5.5 Δv budget

A direct trajectory injection to Jupiter needs enough energy that has to be provided by the launcher. A direct Hohmann transfer trajectory requires a C3 of $\sim$ 77.4 (km/s)^2. Insertion into a circular orbit around Jupiter (R = 12.5 R_J) needs $\Delta v \sim 4$ km/s. This value can be significantly reduced to $\Delta v \sim 3$ km/s using a close Ganymede flyby and additionally choosing a highly elliptic orbit around Jupiter. The semi-major axis of the spacecraft's orbit should be at least 75 Jupiter radii. This implies an orbital period of roughly 80 days. The orbit will be adjusted to allow as many flybys of Europa as possible. The plane of the orbit will match the inclination of the Galilean moons. The high periapse range avoids the high radiation environment and any debris problems associated with ring plane crossings (Europa orbits at about 9.38 R_J having a period of 3.6 days). The lander needs a Δv of $\sim$ 2.4 km/s (with a margin of 10%) for braking.

		1	2	3
(A)	Launcher	Titan 1 Launch	**A5** **1 Launch**	
(B)	TJI Propulsion	Optimal Control programmed	Storable Prop (liquid)	**None**
(C)	TJI Trajectory	Triple Venus Gravity assist	**Direct Trajectory**	Earth & Moon Fly-by
(D)	Capture around Jupiter	Gravity assist & propulsive maneuver	Aerocapture & chemical prop correction	**Electric Prop**
(E)	Propulsion for Europa Landing	**Chemical propulsion**	Electrical propulsion	
(F)	Landing Site	**Mission location by orbiter**	Earth location before flight	
(G)	Terminal approach	Chemical until Landing	Chemical & Airbags	**Chemical & free fall**
(H)	Base	Base on the surface	**Base 1m under ice**	
(I)	Mobility	**No mobility**	5 m	10 m
(J)	Depth of melting	75 m	900 m	**3 km**
	Time duration	1 month	1 years	**3 years**
(K)	End of Orbiter	Jupiter Crash	**Europa Crash**	

Table 8.2: Mission design options

8.5.6 The Choice of the Launcher

The drivers to choose the launcher are the performance, the cost and the latitude of the launching site. Assuming a total S/C mass of 1400 kg and a required C3 of 80 $(km/s)^2$, Figure 8.3 shows that an Ariane 5 ESCA, available in 2002, is able to inject the S/C into a Jupiter transfer ellipse. If some mass increase should appear during the program, a back-up solution is available with the new Ariane 5 ESCB that will be available in 2005 (1700 kg with a C3 = $80(km/s)^2$.

8.6 The Design of the Cryobot, Spacecraft and the Lander

Spacecraft design was constrained by the limited launch capabilities of Ariane V, the desire to fly directly to Jupiter, radiation in the Jovian environment, costs, power availability and the main scientific instruments contained within the Cryobot.

8.6.1 The Cryobot

The radioisotope thermoelectric generators (RTG) in the cryobot must produce roughly 3 kW of thermal energy, to be able to melt down to the desired depth in a lifetime of three years. This implies that electric power will not be an issue for the cryobot. Even an RTG with half the efficiency of standard RTGs [449] will be able to easily produce 100 W of electrical power from 3 kW of thermal power. The length of the RTGs will be 57 cm, based on the Cassini design. The biggest problems are to protect the instruments and the tether from the radiation and the heat (flight only) from the RTG. The tether will only provide data transfer, and the design requires that the overall tether will not be thicker than 0.6 mm, a maximum weight 3.3 g/m, and a minimum curvature radius of 20 mm, which implies that 26 cm of the overall length of the cryobot is used to store the tether itself. This applies to the complete tether, i.e. the optical fiber and protective layers around the fiber. Quite a lot of space, 47 cm length, has been assigned to the instruments, thermal control, radiation shielding, command and data handling, cabling etc. This results in an overall design that is 130 cm long and with a diameter of 20 cm. See table 8.3 and figure 8.4.

8.6.1.1 Melt-Through Calculations

Warming and melting ice requires a lot of energy. Since the temperature is so low on Europa, the process of melting down is very different from what we experience here on Earth. Before melting the ice, it needs to be warmed from about 170K (warm spot) to about 270K. Doing this, energy will dissipate from the main corridor that ought to be melted outwards by thermal conduction. Therefore, a larger cross section of ice needs

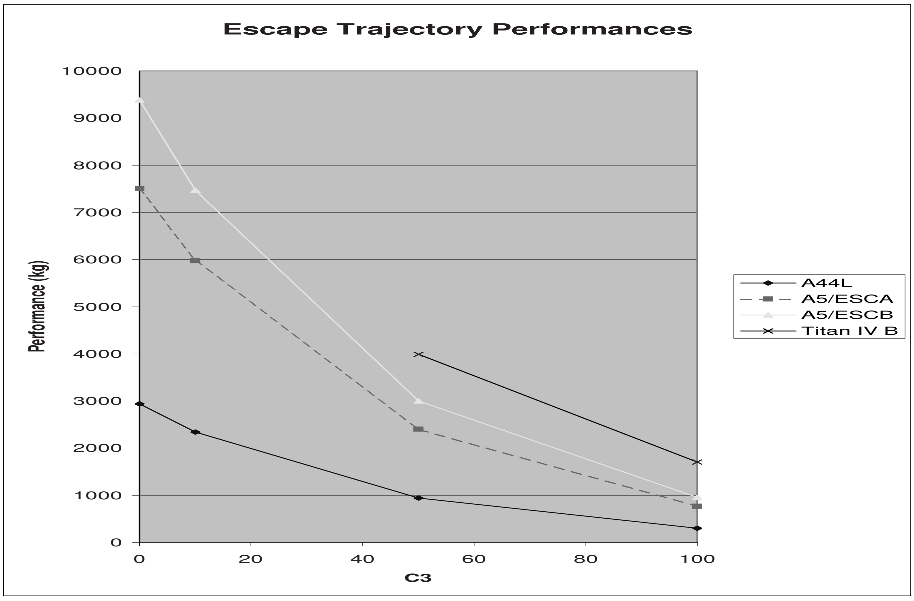

Figure 8.3: Escape Trajectory Performances;

to be warmed, consuming even more energy. Considering this, using melting speeds from tests on Earth could produce large discrepancies from what will happen on Europa. However, this section will show, that sufficient melting speeds can be realized.

- Diameter of the melting probe: 20cm
- Diameter of the melted ice column: 22cm
- Diameter of the heated ice column: 50cm
- Available thermal power from the RTG: 3 kW

As a very rough guess of how the heat will dissipate, we assume to warm a column of 50cm diameter (0.2m^2 cross section) by about 100 K, where warming one metric ton of ice by one K requires about 2 MJ. Heating a column of 1 meter height then requires 40 MJ.

$$0.2\text{m}^2 \times 1\text{m} \times 2\frac{\text{MJ}}{\text{ton}\cdot\text{K}} = 40\text{MJ} \tag{8.1}$$

Having a cylinder of now 0° C, a column of 22cm diameter (0.04 m^2 cross section) has to be actually melted (phase transition). Melting 1 metric ton of ice to water takes 320 kJ. We need therefore 13 MJ for the above mentioned cylinder.

$$0.04\,\text{m}^2 \times 1\text{m} \times 320\frac{\text{MJ}}{\text{ton}} = 13\text{MJ} \tag{8.2}$$

Adding up both values gives 53 MJ to take the probe down one meter into the ice and dividing this number by the power output of the probe's RTG of 3 kW shows that it takes 5 hr to achieve this. This means we can melt through about 2 km of ice per year, the right order of magnitude for our mission.

Probe: Cryobot	Power [kW]	Mass [kg]
Heating elements (RTG):	3.000	12.7
Structure:		**10.0**
Payload, max power:	**0.053**	
UV-camera/flash:		**0.3**
Gas chromatograph (GC):		**0.5**
INMS:		**9.0**
Optical camera:		**0.3**
Fiber optic to comm. unit.	**0.020**	**10.0**
Cabling:		**2.0**
Thermal control:	**0.017**	**4.0**
Command and data	**0.002**	**1.0**
Total el. power available:	0.100	**12.7**
Total:	**0.100**	**61.8**

Table 8.3: The power and mass budget of the cryobot

8.6.2 The Lander

The spacecraft will not orbit Europa because of the radiation hazards of the inner Jovian system, which means that the lander must be able to perform an Europa orbit insertion, and descend to the surface. The S/C will be able to provide some of the Δv required, but the lander must still achieve a Δv of 2.4 km/s. LO2-RP1 is the desired fuel. It has a reasonably high specific impulse (Isp) of 376 s in vacuum, and a density of $1031 kg/m^3$ [454]. Using the S/C high gain antenna as a shield against the sun, it should be reasonably simple to store the liquid oxygen. Two engines, delivering a total thrust 4100 N, are required to perform the necessary maneuvers. The lander must also include dampening features to allow a free fall of 20 m, which is required to protect surface samples against exhaust contamination.

The instruments, command- and data-system will be placed in a container similar in shape and size to the Cryobot. This container will be lowered 1 m into the ice for protection against radiation. Basically the container is a cryobot with the tether replaced with a short cable capable of supporting the weight the container. Its diameter is 20 cm, length 90 cm and mass is 30 kg. To keep the lander as simple as possible, and to avoid the problems of moving parts in cold (140 K) environment, an omni-directional antenna, similar to the one employed on the Huygens probe, will be used, [450]. It is an S-band antenna with 2 Mb/s transfer rate at 10 000 km slant range, see table E.1, [473], therefore most of the data transfer must be done in close proximity of Europa. A rough estimate of the maximum amount of data transferred during a flyby is roughly 20 Gb. Transfer of data at the greater distances is possible, but at the cost of much lower rates. 40 Gb solid state recorder capacity is desired on the lander.

8.6.3 The Spacecraft (S/C)

Attitude control is performed on both the S/C and the lander with nitrogen cold gas thrusters. The NSTAR ion engine will also provide two-axis attitude control on the S/C as it was done on Deep Space 1 to conserve nitrogen.

Since new RTGs are expected to be more than three times as efficient as current RTGs, [465], the overall mass is reduced by roughly 200 kg. Advanced carbon composites are also used to reduce the overall mass of the structure. The spacecraft's total mass at launch is 1394 kg.

An optical link with Earth is desired for the main transfer of data from the spacecraft. A S-band low gain antenna will be used for navigation purposes. The high gain antenna (HGA) communicates only with the lander, but it is also capable of communicating with Earth in the Ka-band at (30 GHz) as a backup for the optical system. As a backup to the optical link with Earth, 40Gb storage capacity is needed as backup also on the S/C. An additional role of HGA is to shield the lander from the sun, during interplanetary flight. This means that the HGA cannot be used as backup until the lander is released. The S/C itself carries instruments to

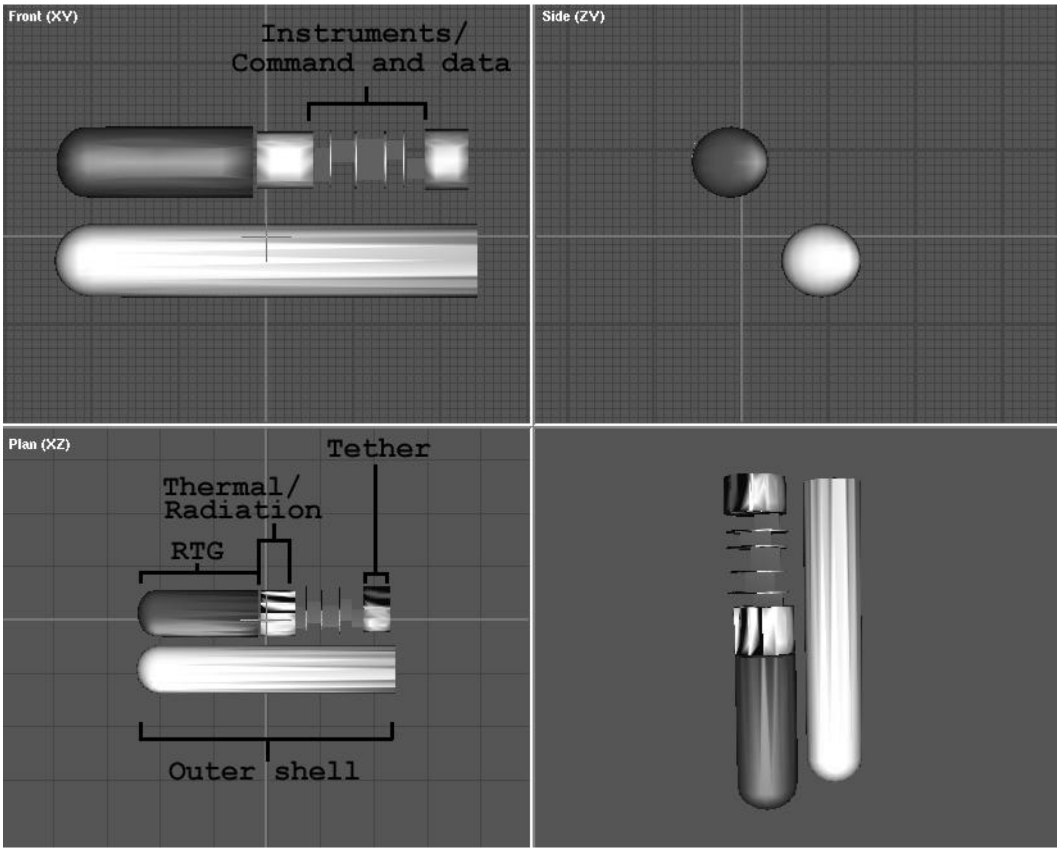

Figure 8.4: Conceptual design of the cryobot. RTG at the bottom, then thermal control, command and data, instruments and tether. The total mass includes a 20% margin.

augment the science data gathered by the Galileo probe.

Impact Calculations

At the end of the orbiter lifetime (cf. Sec. 8.8.5, pp. 179), it will be crashed into Europa to create seismic waves of a known source to be measured by the lander's seismic detectors. We will show in this paragraph that the maximum amount of energy released in the crash is equivalent to an explosion of about 100 tons of TNT.

We assumed the following number for the impact calculation:

- Orbital speed of Europa: 14 km/s
- Relative speed of the orbiter w.r.t. Europa (14 day orbit): 13.06 km/s
- Mass of the orbiter: 1 metric ton

The speed of the orbiter relative to Europa is determined by the angle of approach. In order to find the maximum amount of energy we assume a direct impact realized by an orbit inclination of 180 degrees. The kinetic energy that will be released in the crash is therefore:

$$1000\text{kg} \times (17,000\frac{\text{m}}{\text{s}})^2 \times \frac{1}{2} = 392\text{GJ} \tag{8.3}$$

Note that 320 GJ are the equivalent of 2 tons of TNT.

Lander:	Power [kW]	Mass [kg]
Structure:	**0.000**	**120.0**
Optical camera:	**0.010**	**0.3**
Attitude control	**0.015**	**18.0**
SOUNDER	*0.003*	**5.000**
Command and data	**0.008**	**2.0**
Spacecraft adapter		**5.0**
Cabling		**9.000**
Telecom:	**0.027**	**6.000**
Radiation shielding:		**10**
Thermal control:	**0.017**	**10.0**
Total electrical power (RTG):	0.080	**10.0**
Total (Crybot + dry lander)	**0.180**	**257**
Fuel: L02-RP1:		344
Total(Crybot + wet lander)	**0.180**	**602**

Table 8.4: The power and mass budget of the Lander

S/C	Power [kW]	Mass [kg]
Structure:		**148**
Radar:	0.100	**40**
IR - camera:	0.010	**2**
Opt. High Res. Camera:	0.023	**28**
EUVS:	0.007	**12**
UVS:	0.006	**5**
MAG:	0.003	**3**
Boom:		**5**
Attitude control:	0.015	**38**
Command and data:	0.008	**2**
Telecom:	0.080	**15**
Thermal:	0.100	**35**
Maximum el. power needed:	**0.200**	
Ion propulsion:	**3.000**	
Cabling:		**10**
Radiation shielding:		**30**
Spacecraft adapters:		**20**
Total electrical power (RTG):	3.200	**95**
Total (wet lander + dry S/C)	**3.330**	**1090**
Ion propulsion: xenon	See above	177
Project margins 10%:	**3.663**	**1394**

Table 8.5: S/C mass and power budget

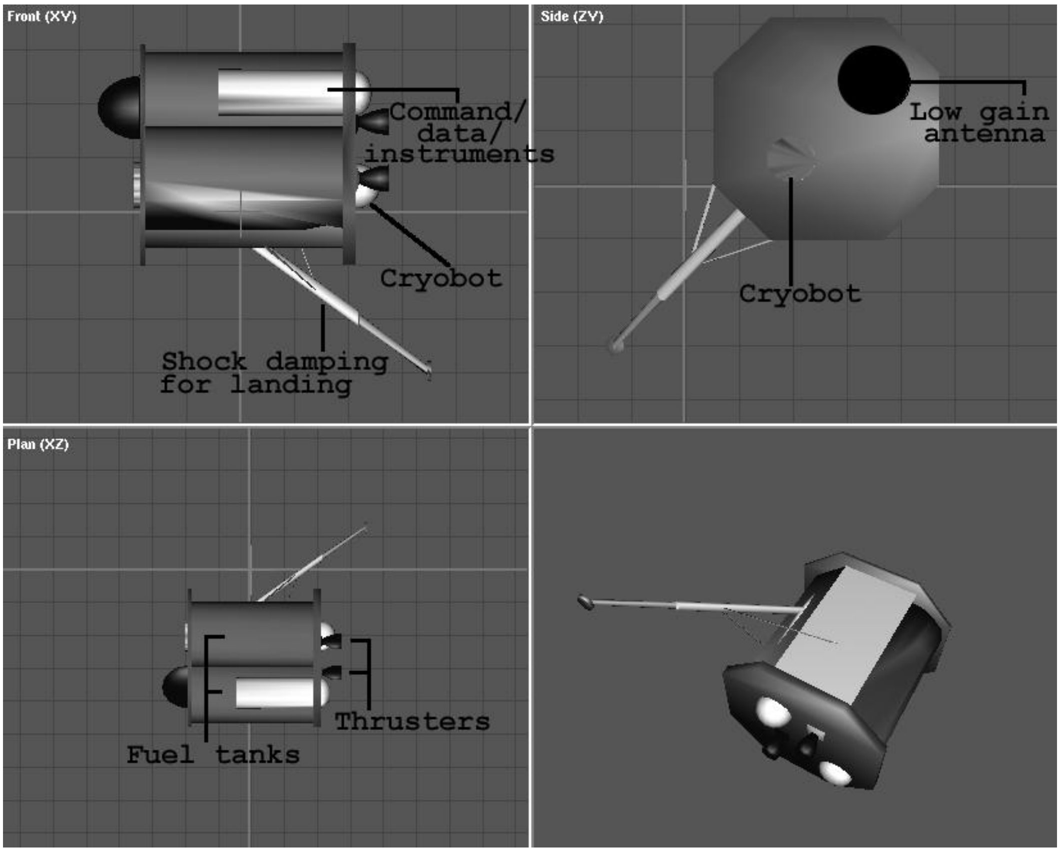

Figure 8.5: Conceptual design of the Lander.

8.7 Orbit, Communications, Propulsion, and Remote Sensing

This chapter discusses the right orbit for the S/C, the establishment of the communication relays between the various assets (i.e., the orbiter, the lander, the cryobot and Earth ground stations), the remote sensing capabilities of the orbiter in order to choose the right landing site for the lander, the choice of the S/C propulsion subsystem, and finally deorbiting of the orbiter at the end of its lifetime.

8.7.1 The S/C Interplanetary Trajectory and Orbit

To reach Jupiter we use a 3-year Type-II Hohmann transfer orbit, using an Ariane 5 launch vehicle. A Ganymede flyby will provide sufficient gravity assist to minimize the Δv required for insertion into Jupiter's orbit

The total orbiter mission duration is three years. The orbiter will not only act as a relay satellite for transmitting data collected from Europa's ground-segment to Earth, but also as a remote sensing satellite of the moons encountered along the orbit.

Fig. 8.7 illustrates Jupiter Orbit Insertion. At this point the S/C will begin a Galileo-like tour encountering several times the four largest Jovian satellites.

Different possibilities were considered for the S/C orbit during the mission:

- A circular orbit around Europa
- A highly elliptical orbit around Europa
- A weak stability boundary orbit among Europa and Ganymede

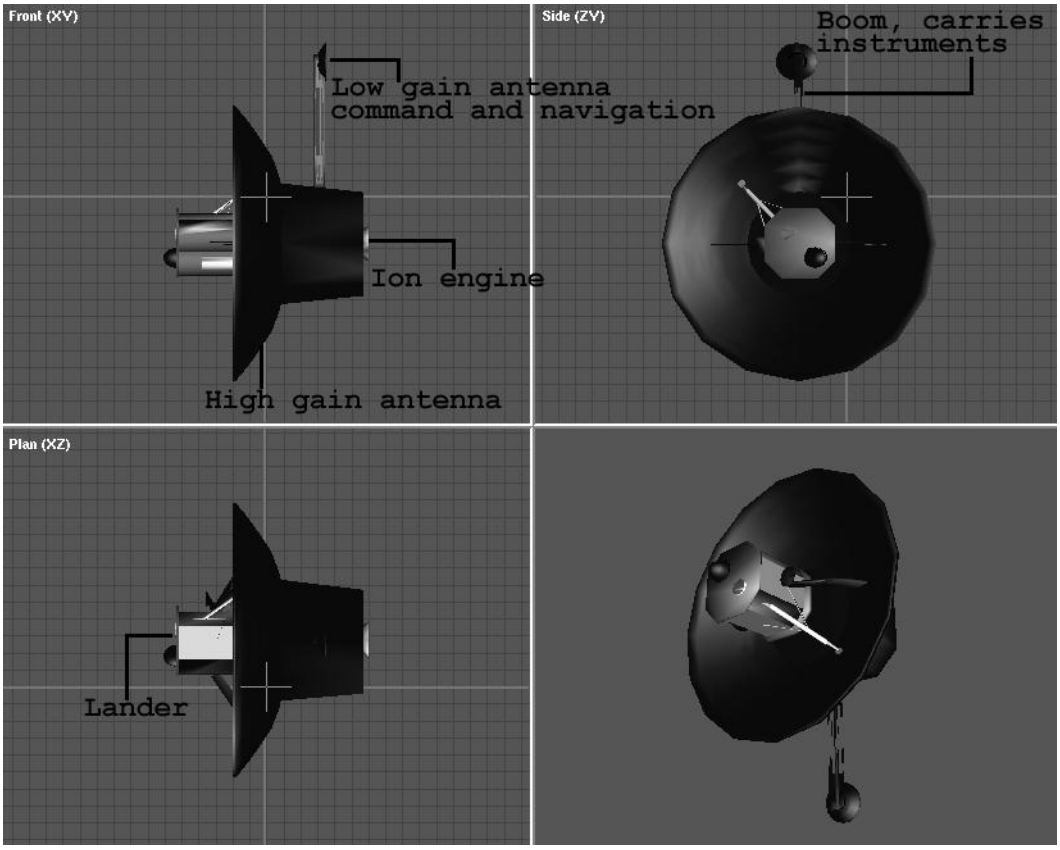

Figure 8.6: Conceptual design of the S/C.

- An elliptic orbit around Jupiter

A circular orbit around Europa implies a higher Δv for the Europa orbit insertion maneuver, and has the additional disadvantage that the S/C is continuously exposed to the high-radiation environment. Even choosing an elliptical orbit around Europa would not lead the S/C outside the Jovian radiation belt. A weak stability orbit was not selected due to the strong gravity field gradient of Jupiter. To fulfill the mission requirement to achieve an orbiter lifetime of three years, the S/C has to spend the major part of its mission outside the harsh radiation environment. This could only be realized by choosing an elliptical orbit around Jupiter.

8.7.2 Communications

The basic relay links between the different parts of the mission will be done via a tether from the cryobot to the lander, via an S-band radio link from the lander to the orbiter and finally via an optical laser or Ka-Band link to an Earth geostationary satellite to retrieve the data. The data uplink from the lander to the Orbiter will be done at the various Europa flybys during the tour. The telemetry and science data will then be stored on the orbiter's solid state recorder (SSR) for later downlink to Earth. In case of a failure of the orbiter optical communication subsystem the data downlink can be done via the Ka-band link of the low-gain antenna and the Deep Space Network. Table E.1 shows the link budget from the orbiter to the lander.

Optical Link

We decided to use laser optical communications to downlink the data to a GEO satellite in Earth orbit. This new technology has the potential to deliver a 10 times higher data-rate, and at the same time to reduce the mass and power by a factor of 10 compared to a conventional spacecraft communication technology.[468]

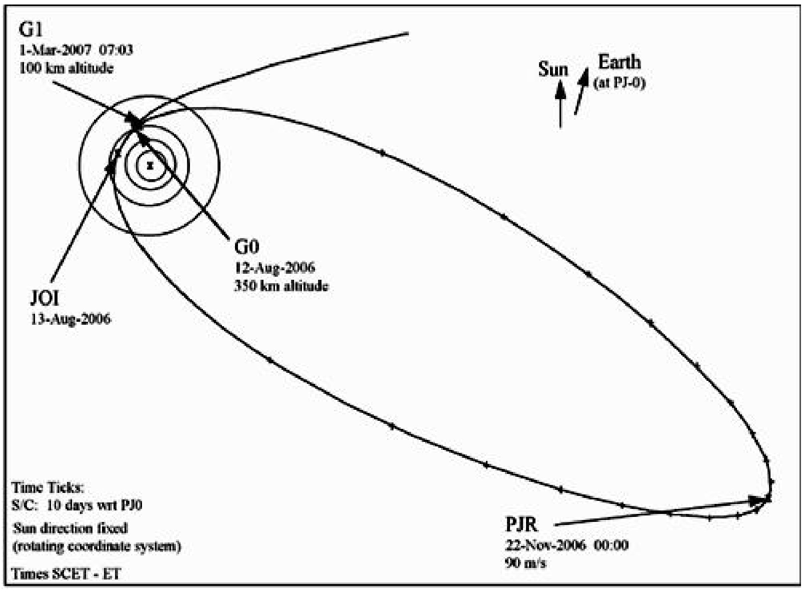

Figure 8.7: Possible Jupiter orbit insertion (JOI) based on NASA's Europa Orbiter mission, assuming a launch in 2006; G0 = first Ganymede encounter, PJR = perijove raise maneuver; (Courtesy of NASA)

The technical merit of optical communications is derived from the fact that it offers a more concentrated signal than conventional microwaves. This super-collimated beam can result in a terminal design with greatly reduced size, mass, and power requirements. Furthermore, laser communication systems are not susceptible to RF interference and are currently not subject to government or international regulations. Additionally, the higher data return rates afforded by optical communications reduce the required ground coverage time that is needed to recover the science data.[462] This also reduces the ground operations cost. This new technology has already been successfully tested in space, though only on a LEO to GEO link [466].

Microwave Link

As an alternative option, we suggested the Ka-band link to provide a 300 kbps data link back to Earth. There are two options. The data can either be sent to a GEO satellite, and then down to an Earth station, or it can be sent directly to the Deep Space Network. The design assumes that a 55 Watt Ka-Band TWTA will be used together with a 3 m antenna. The system allows for a data rate of 300 kbps using Quadrature Phase Shift Keying. Table E.2 shows that a Ka-Band link to the satellite can be achieved with a small margin.

Table E.3 shows the link budget from the orbiter direct to the Deep Space Network. In this case more than 4 dB of margin is shown. Both cases assume that the full CCSDS coding standard will be applied with Reed Solomon and Convolution Coding.

8.7.3 Remote Sensing

Remote Sensing (RS) will be used mainly with two objectives: detection of a suitable landing place to melt into the ice layer, and the study of the surfaces of the Galilean satellites during orbiter flybys. To chose a preferable landing place the RS sensors will look for areas with a higher temperature than the average ambient value, as well as for thinner areas of the crust, which would allow cryobot to reach the water/ice interface.

As pointed out in Section 8.4.2 a preferable landing side would be on the leading side of the moon because of significantly lower radiation levels. The landing itself is accomplished with a simple orbital transfer from the mapping orbit. Europa does not have a dense atmosphere which implies that parachutes cannot be used and a powered landing is therefore the only possibility.

A key technology necessary for such a landing is a hazard detection and avoidance device - most likely implemented by terrain imaging and processing for autonomous redesignation. Spare fuel has been included in mass estimates for the lander, for 100 m of local terrain avoidance during the descent maneuver.

On the other hand, key radar mapping technology relays on using a radar sounder to bounce radio waves through the ice. Thus, the orbiter can detect an ice-water interface down to 5 km below the surface.[467]

8.7.4 Propulsion

The ion propulsion engine will be ignited 10 months prior to Jupiter Orbit Insertion (JOI). It is important to note that ion propulsion and various gravity assist maneuvers will be the only orbit-correcting mechanisms, during the whole tour in the Jovian system. The lander will use chemical propulsion to land.

8.8 Mission Profile

Functional analysis chart 8.2 explains the flow of the mission. The next few paragraphs do the same in a bit more detail. For a general mission schedule, see Figure 8.8.

8.8.1 Cruise Phase

The mission will be launched from Kourou on an ARIANE 5 ESCA rocket. The 1400 kg spacecraft payload will be launched five years after the beginning of the development phase on a direct trajectory injection, and will take three years to reach Jupiter. For the 10 months prior to its arrival at the Jupiter system, the spacecraft will fire its ion engine. This is done in order to reduce the velocity to values required for observations of Ganymede during insertion fly-by, and to lower the Δv required for subsequent insertion into Jupiter orbit.

8.8.2 The Tour

Reaching a high elliptical orbit around Jupiter, the orbiter will begin to do remote sensing during each Europa encounter, to choose a landing site. This remote sensing will be performed with three onboard instruments: a thermal infrared camera, an optical high resolution camera, and a radar. The high perijove helps lower exposure to the high radiation environment around Jupiter, and reduces the probability of collision with debris fields associated with range plane crossing.

8.8.3 The Landing

Once a suitable landing site has been identified, the lander will detach from the orbiter, and perform a direct landing on the surface of Europa. The orbiter will continue its trip through the Jupiter system, and perform extensive remote sensing of the Galilean Satellites. During its descent the lander's velocity will be controlled using thrusters. In order to prevent surface contamination, thruster firings are cut off at a height of 20 m above the surface. The final 20 m is traveled under free fall, and the landing gear equipped with damping devices will protect the lander from the shock of impact.

8.8.4 On the surface

The cryobot, connected by a tether to the base, then begins to melt through the Jupiter ice. It is equipped with four instruments - a UV fluorescence camera, an optical camera (looking up), a gas chromatograph, and a mass spectrometer - and will perform its analysis mission while descending through the ice for 3 years. Upon eventual arrival to water/ice interface, the cryobot will stop its decent.

8.8.5 The End of Orbiter Life

The Lander will survive longer than the three years nominal lifetime of the orbiter, because it will be lowered by about 1 m into the surface, for protection against hazardous radiation (cf. Section 8.6.2). The orbiter will be equipped with radiation protection and radiation hardened hardware. However, it will not be able to survive much more than ~30 days of integrated exposure to the Jovian belt radiation. At the end of the orbiter's lifetime it is therefore planned to crash-land the orbiter into Europa. This will deliver further input for the seismic instrument onboard the lander (see Section 8.3.2). The lander will continue transmitting science data directly to Earth, using its omni-directional antenna and low bandwidth. For the orbiter crash-landing various contamination issues have to be taken into account, and are discussed in Sections 5.4 and 8.10.1.

8.8.6 Epilogue

The presented mission aims to give hints about the possible bio-evolution on Europa. It also investigates Europa and rest of the Jovian system from a more general perspective, searching for clues on how planetary systems such as ours form.

The mission has a great scientific potential, and offers a variety of options for the follow-up missions: from a single orbiter mission, to a orbiter with one or multiple probes, to a constellation of spacecrafts, working together and a offering perspective no single spacecraft could provide.

Probes would be designed with the respect to the knowledge obtained with proposed orbiter/lander/cryobot configuration. More specialized experiments could look for further traces of indigenous life. Alternatively, an array of seismic instruments could be deployed with a lander to a surface of icy Galilean moon. These instruments, combined with gravitational- and magnetic- field data from orbiter(s), could uncover details about inner structure of the inspected moon, giving leads on where to search for environments that could harbor life.

A small fleet of interacting, semi-autonomous orbiters could share the same orbit around Jupiter, offering almost constant coverage of a target in focus. Alternatively, having very different orbits, the orbiters could resolve tantalizing issues regarding the Jupiter's magnetosphere.

8.9 Cost and Risk Assessment

This chapter shows an end-to-end mission cost estimate, proposes a program management structure, and performs a risk analysis of the whole project. An important part of this analysis was to verify whether the costs for proposed mission design would fit in the frame of a flagship/cornerstone mission.

8.9.1 Total Cost ROM Estimation

End-to-end mission cost was approximated using NASA's Advanced Missions Cost Model (AMCM) and by analogy with the predicted costs for a Europa Lander conceptual mission design [456, 461].

The AMCM is a simple model, resulting in rough order of magnitude (ROM) cost predictions for design and development (R&D). Table 8.6 shows the inputs and cost results for the two spacecraft, the Europa Lander and the Orbiter, resulting in a total R&D cost of US$ 1875 million. Cost is a function of dry weight, mission type, launch year, block number, and design difficulty. Notice the "High" difficulty rating for the Lander, and the "Average" difficulty rating for the Orbiter. Dry weight is the best estimate from the systems and engineering case study groups, with a 10 percent mass margin.

Table 8.7 shows in detail the inputs to calculate total end-to-end mission cost, using the above US$ 1875 million as a fixed Orbiter and Lander cost. The cost estimate is divided into two parts, Phases A through D, and Phase E mission operations. Several of the cost estimates were fixed, noted by the superscript 1. All other estimates are cost by analogy, reflecting a percentage of the total end-to-end mission cost.

The end-to-end mission ROM cost is US$ 3.1 billion, which is comparable to the US$ 3.2 billion Cassini mission to Saturn, and the US$ 1.6 billion Galileo mission to Jupiter. [457, 463]. Most of the budget, nearly

Input Data	
Quantity	1
Dry Weight (kg)	537
Mission Type	Planetary Orbiter
Launch Year	2008
Block Number	1
Difficulty	High
Cost (2002 $M)	**1082**

Input Data	
Quantity	1
Dry Weight (kg)	283
Mission Type	Planetary Lander
Launch Year	2008
Block Number	1
Difficulty	Average/High
Cost (2002 $M)	**793**

Total Cost (R& D)	**1875 $M**

Table 8.6: Oribiter/Lander Cost Breakdown NASA Cost Model

60 percent, is in the design and development cost for the Orbiter and Lander. With nearly 15 percent of the total budget, the reserves allocated for Phases A through D are the second largest cost at US$ 458 million. Launch operations sum to US$ 220 million, which is 7 percent of the total mission cost. Because education is an important part of the mission objectives, US$ 5 million is allocated for outreach. Lastly, the mission avoided (by assumption) R&D costs for a LEO communications satellite. However, the mission still needs to develop the optical relay communications, estimated at a cost of US$ 10 million.

8.9.2 Mission Schedule

The preliminary mission schedule is shown in Figure 8.8. In general, there are six years until launch, with three years en route transfer support and three more years for science and mission support. The entire mission will last approximately 12 years, with an extra year for program shutdown.

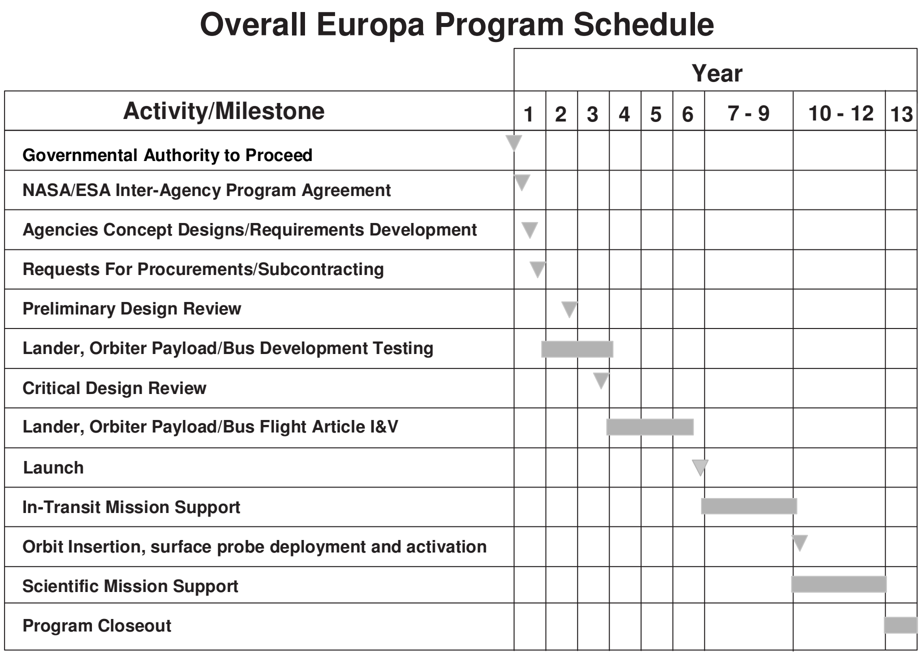

Figure 8.8: Europa Program Schedule

Cost Breakdown: Europa Mission

Phase A, B, C/D Cost Summary in FY '02$M		
	Cost	**% Total**
Project Management	62.4	2.0
Outreach[1]	5.0	0.2
Project and Mission Engineering	140.8	4.5
Bus	156.0	5.0
Instrument Support	31.2	1.0
Orbiter, Lander[1]	1875.0	59.9
Launch Mission Operations[1]	20.0	0.6
A, B, C/D Sub total without LV	2290.4	73.2
Reserves at 20%	458.1	14.6
Launch Vehicle[1]	200.0	6.4
A,B,C/d total with LV and reserves	**2948.5**	**94.2**

Phase E and Overall Mission Cost Summary in FY '02$M		
	Cost	**% Total**
Project Management	31.2	1.0
Science (3 years)	63.0	2.0
Mission Operations (6 years)	63.8	2.0
Phase E Subtotal	158.0	5.0
Reserves at 10%	15.8	0.5
Phase E Total	**173.8**	**5.6**
Phases A, B, C/D Total	2948.5	94.2
Mission Total (Phases A through E)	**3120.0**	99.7
with GSO Optical Communications	**3130.0**	100.0

1 Note: Fixed Costs
Cost analysis based on: Gershman, Robert.
"Conceptual Design of a Europa Lander Mission." publication of US Government.

Table 8.7: Europa mission Total Cost Breakdown

8.9.3 Program Management and Work Breakdown Structure

We chose an international program management structure between the US and European space agencies, NASA and ESA respectively. Figure 8.9 depicts the program management and work breakdown structure, which is color-coded showing approximate agency responsibility. In general, NASA is responsible for the majority of top-level program management positions. Into the third tier, the work breakdown structure (WBS) shows that ESA controls all launch services and the Earth Communication Relay Satellite (ECRS).

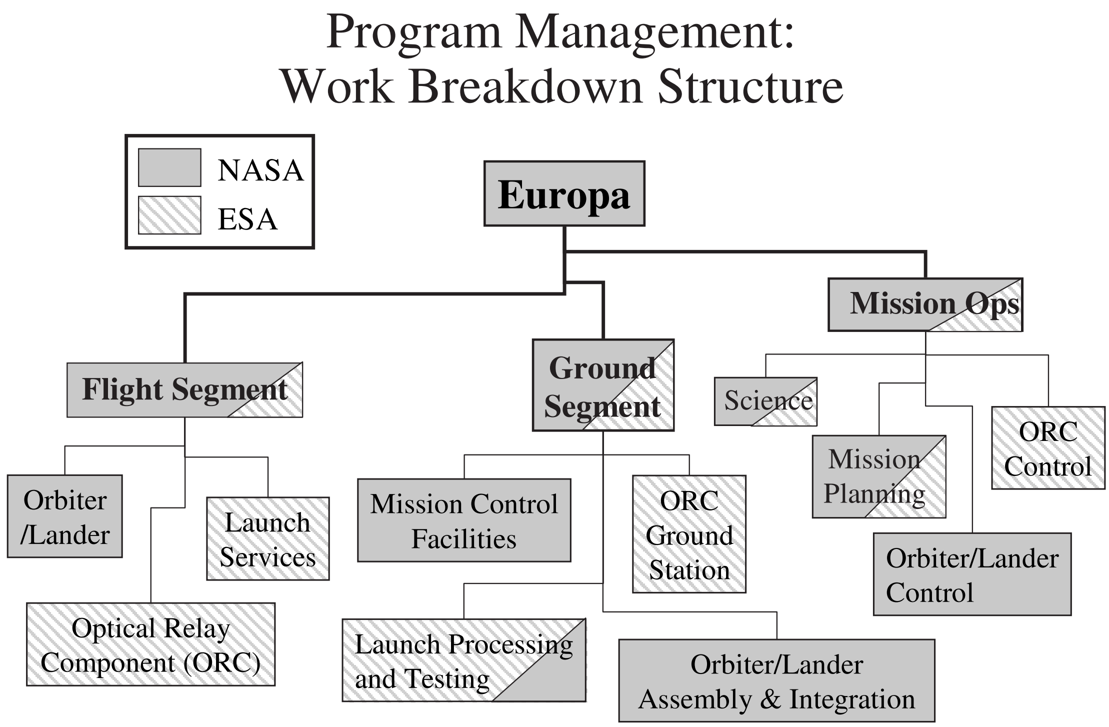

Figure 8.9: Program Management and Work Breakdown Structure

8.9.4 Risk Assessment

To categorize risk, we used the standard NASA risk matrix, Figure 8.10. A risk score between low (L), medium (M), and high (H) is given based on likelihood of event and the consequences of the event. First, the likelihood of the risk event happening is rated, with 5 being the most likely. Then, if the risk event occurs, what and how severe are the consequences, with 5 being the most severe. Appendix E shows the NASA risk matrix, with descriptions of each likelihood level and each category and level of consequences.

Risk

Likelihood \ Consequences	1	2	3	4	5
5	L	M	H	H	H
4	L	M	M	H	H
3	L	M	M	M	H
2	L	L	L	M	M
1	L	L	L	L	M

Figure 8.10: Risk Assessment Matrix (NASA)

Table 8.8 is a list of risks identified for the current Europa mission. The list is broken into technical, cost, schedule, political, and science risk categories. Keep in mind that the identified risk status is a current assessment, and steps should be taken to reduce "high" risk events before established critical design review points. There must be constant monitoring of risk, assuring risk levels become acceptable.

Risk Descriptions

Following is a brief description of each risk listed in Table 8.8, in the same category and order.

Technical

- Radioisotope Thermal Generator (RTG) New Technology Failure: Without backup power, mission is lost without RTG.
- Ion Propulsion Failure: The Europa mission is lost completely with ion propulsion failure; the Lander cannot provide adequate velocity change alone.
- Orbiter Loses Communication in Transit: The entire mission is lost. Communication loss could be from solar storm radiation damaging electronics, a mechanical or electronic failure, or a catastrophic failure.
- Space Debris Collision Damages Lander/Orbiter: Damage is unpredictable.
- Lander Crashes: The Lander transitions from Orbiter to Europa's surface. Without appropriate GN&C, a crash could abort primary science mission. This may come from a GN&C electrical or mechanical failure, from a software failure, or from inaccurate models of Europa's environment.
- Individual Lander Components Fail: Once safely landed, any failure of the Lander's critical systems could impact the science mission in part or in whole - the drill, the tether, the communications, the power.
- Cryobot Tether Fails: Cryobot tether breaks or otherwise loses data transmission capability.
- Catastrophic Failure of Launcher Failure of launch vehicle to deliver spacecraft into orbit results in loss of mission.

Cost

- New Material Applications: Extensive use of Carbon Fiber Reinforced Plastic (CFRP) for previously unproven applications may result in cost growth due to manufacturing complexity.
- Launcher Mass Capability Exceeded: Detailed design solutions cause increased mass.

Schedule

- Earth Relay Satellite (ERS) Program Canceled or Behind Schedule: ERS is outside of Europa program direct influence. The mission may fall behind schedule, with possibility to miss launch window.
- Incompatible Lander/Orbiter to Launcher Interfaces: Incompatible in structural loads, geometric envelopes, system connections.

Political

- Fund Reduction or Program Cancellation by Partner: In an international partnership program, the program fails if one partner cannot follow through financially. Funding to government agencies, like ESA and NASA, may be heavily dependent upon current political agendas, which at times may contradict the space program's desires.
- RTG Environmental Concerns: Public/political concern of nuclear contamination from a launch failure blocks approval for launch.

	Risk	Likelihood, Consequences	Mitigation Strategy
Technical			
RTG New Technology Failure	High	3,5 (mission success)	RTG concept will be proven in early phase of program
Ion Propulsion Failure	Medium	2,5 (mission success)	Extensive reliability testing of ion propulsion, must be demonstrated prior to concept review
Orbiter Loses Communication in Transit	Medium	2,5 (mission success)	Ensure proper radiation protection, and verify spacecraft reliability
Space Debris Collision Damages Lander/Orbiter	Medium	1,4 (mission success)	Appropriate structures design and payload placement, include micro-meteor debris shielding
Lander Crash	Medium	3,4 (mission success)	Implement a test program to assure a 92 percent or better reliability rating. Require redundant software and mechanical systems to prevent single event upsets
Individual Lander Components Fail	Medium	3,3 (mission success)	For critical vehicle bus and science systems (communications), require redundancy
Cryobot Tether Fails	Medium	3,4 (mission success)	Cryobot drilling process will be tested to ensure tension loading on tether does not exceed limits. Tether will have excess optical fiber capacity to allow re-routing of data if a single fiber fails.
Catastrophic Failure of Launcher	Medium	1,5 (mission success, schedule)	Payload will be launched on a proven launch vehicle (Ariane V). Program Management will monitor launch success and reliability ratings for the Ariane V to ensure that there are no unresolved issues with the launch vehicle at the time of mission launch.
Cost			
New Materials Application	Medium	3,4 (cost)	Establish early testing to prove concepts. Trade studies will evaluate criticality of CFRP applications to satisfy mass limits.
Launcher Mass Capability Exceeded	Low	2,3 (cost, schedule)	Allocated mass for orbiter spacecraft and Lander of 1489 kg has 25% growth margin available before exceeding Ariane V payload capability of 2000 Kg. Mass data base will be used to track mass status of all components and identify areas for mass reduction as required.
Schedule			
Earth Relay Satellite (ERS) Program Canceled or Behind Schedule	Medium	2,5 (schedule)	Program management strictly monitoring ERS program, and establish a decision point for ground station backup
Incompatible Lander/Orbiter to Launcher Interfaces	Low	1,4 (schedule)	Interface Control Documents will be used to define and control interfaces between vehicle elements and launcher
Political			
Fund Reduction or Program Cancellation by Partner	Medium	2,5 (cost, schedule)	Necessary to agree on a Memorandum of Understanding (MOU) between both governments
RTG Environmental Concerns	Medium	2,5 (safety, schedule)	RTG will be designed to remain intact if launch failure. Public outreach program for mission will include information to assure the public that this concern has been addressed
Science			
Instrument Contamination	High	4,3 (integrity of science)	Verification methods for assessing acceptable contamination levels on hardware
Jupiter Contamination with Orbiter Intentional Crash	High	5,3 (preservation of Jupiter environment)	Planetary Protection protocols and ethics must be addressed, and the appropriate groups need to be educated on consequences to mitigate them.

Table 8.8: Risk Assessment List

Science

- Instrument Contamination: Both Orbiter and Lander spacecraft will have some level of contamination, 100 percent sterilization is impossible with today's technology and methods. Section 5.5 discusses forward contamination. Science, primarily looking for life on Europa, may be hindered by uncontrolled or un-cataloged biomass material contaminating the testing environment.

- Europa Contamination with Orbiter Intentional Crash: At some level, humanity is contaminating Europa with crashing the Orbiter. The implications and their severity levels are highly debatable. Should we be allowed to put man-made and nuclear material into planets? Many ethical and policy issues exist.

8.10 Legal and Policy Aspects

This case study presents a look at the various steps and considerations involved in the launching of a mission to Europa by a joint NASA/ESA initiative. The *Policy and Law Department* tried to point out and analyze the various legal and political aspects that need to be taken into account in such an endeavor. The mission will be divided into three phases and we will discuss the relevant aspects separately: Pre-launch phase, in-orbit phase and post mission phase.

8.10.1 Relevant Issues - Pre Launch Phase

Ethics

Ethics have been discussed in more detail in Sec. 5.3. the Planetary Protection section but they do not just apply to that area. We need to know about the discussions taking place as they relate to space exploration as a whole. The various reports that have been generated show that ethical concerns are becoming increasingly important. High on the list is the active public debate on the mission itself drawing views from a large cross-section of society. We should speak to the public early on in the planning process, engage them in discussions and provide them with sufficient information about the mission. This helps to educate the general public and can avoid negative reactions in later mission phases.

The Precautionary Principle

The principle generally known as the "Precautionary Principle" is one that has grown over the years in response to perceived high risk ventures which have failed. In essence, we should look at our mission in its entirety and consider all the elements involved, not just the technical ones. Negative public reactions due to a lack of public information can lead the authorities to deem the mission too risky and in the extreme, could lead to cancellation.

International Law

International Space law can be described as the body of law applicable to governing space-related activities. The term "space law" is most often associated with the rules, principles and standards of international law appearing in the five international treaties and five sets of principles governing outer space which have been elaborated under the auspices of the United Nations Organization:

1. The Outer Space Treaty 1967
2. The Rescue Agreement 1968
3. The Liability Convention 1972
4. The Registration Convention 1974

5. The Moon Treaty 1979

The relevant principles are

- The Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space (General Assembly resolution 1962 (XVIII) of 13 December 1963);
- The Principles Relevant to the Use of Nuclear Power Sources in Outer Space (resolution 47/68 of 14 December 1992);
- The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries (resolution 51/122 of 13 December 1996).

International space law also includes international agreements, treaties, conventions, rules and regulations of international organizations (e.g., the International Telecommunications Union), national laws rules and regulations, executive and administrative orders, and judicial decisions. States which have national law and legislation governing space-related activities include inter alia Argentina, Australia, Canada, Finland, France, Germany, Hungary, Indonesia, Japan, New Zealand, Philippines, Republic of Korea, Russian Federation, Slovakia, Sweden, South Africa, Tunisia, Ukraine, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. Mission planners must work in accordance with the relevant national laws of the countries the mission is both launching from and returning to, if different. It is also imperative to employ a local lawyer who will be able to advise, using the benefit of their local knowledge.

A mission based on the co-operation between NASA and ESA will necessarily involve many agreements between the two parties. We will assume for this mission that both NASA and ESA have agreed on bilateral agreements regarding co-operation in all necessary areas. To mention just a few of them:

- Technology transfer: The US International Trafficking in Arms Regulations (ITAR) are very stringent and without prior agreement, the parties will not be able to transfer technology that is covered by these regulations. In the US space industry much of the technology is covered by ITAR due to the industry's history and possibility for dual (i.e., military and civilian) use of the technology.
- Economic policies: European economic protection policies will also apply to the export and use of the same technology.
- Intellectual property (IP): Scientific data from the mission will be shared among the two parties. Copyright issues, as well as other IP areas will apply not only to the data but also to any work that is done on the mission that may create design rights or patents. Database protection will also be an important issue taking into account various existing European Directives as well as a World Intellectual Property Organization (WIPO) Treaty. The ISS partners have dealt with the conflict of all of their national laws by creating the Intergovernmental agreement (IGA) which as well as dealing with liability issues also covers IP matters.

Planetary Protection: Current Policy and Guidelines

From a Planetary Protection point of examine at International and national laws but be aware of current practice in the industry. As this mission is only one-way to Europa, the concern will be with "Forward Contamination" guidelines that deal with the transport from Earth to a celestial body. This is contrasted with backward contamination which is the transport from the celestial body back to Earth. There are two main imperatives of the forward contamination policies which will affect the mission: Preservation of the scientific integrity of the mission and protection of any indigenous organisms from harm.

Should humanity decide to colonize Europa in the future, protection of the natural resources of Europa for the future exploitation by human explorers will be important and should be borne in mind. Uncontrolled contamination by the mission would increase the technical complexity and cost of extracting and processing the water for use by future human colonists.

COSPAR is the International Council of Scientific Union's Committee on Space Research and it is the important body providing policies and protocols for planetary protection. Look at COSPAR's guidelines for missions; these are currently categorized to five levels. These levels are shown in tabular form in the Planetary Protection section Table 5.1. NASA interacts with COSPAR and uses their policies and guidelines as the model for NASA's policy that has been adopted as a NASA Directive.

8.10.1.1 Policy Issues

- Political Will: Due to the large budget involved in this mission firm political support will be needed. For both parties' governments it will take several cycles of the political calendar to complete the funding for the mission. Taxpayers will, as always, have to be persuaded to pay for such a mission and ways to persuade them of the value of an astrobiology mission to Europa should be considered.
- Public Policy: The public will initially be more familiar with Mars as a destination. Will this mission engage the support of those groups advocating a Mars or Lunar mission? Depending on what has happened with Mars questions will need to be asked and answered regarding the possible finding of life on Europa in terms of not only sociological, but political and economic effects. Will the public respond with a demand for further missions?
- Governmental Pressure: An example of governmental pressure is the recent terrestrial Europan analogue of Lake Vostok lying thousands of meters beneath the continental ice sheet under Russia's Vostok Station in Antarctica. Scientists hope that finding microbial life here will prove that life is viable on Europa. Due to governmental pressure and lobbying from the Scientific Committee on Antarctic Research (SCAR), an inter-disciplinary committee of the International Council for Science (ICSU), drilling down through the ice to the lake was stopped above the waters to prevent contamination. Drilling uses kerosene which would not only dirty the waters of the lake but may also introduce bacteria from the fluid. It will be useful to consult bodies such as these as they carry influence with governments. Engage them early on to ensure that the mission is acceptable to them.

8.10.2 Relevant Issues - in Orbit and on Europa

- International Law will apply to all activities in transit to, and on Europa.
- The Forward Contamination regime will also be applicable throughout the stay on Europa.

8.10.3 Relevant Issues - Post Mission

This mission is not a sample return mission so the Backward Contamination aspects of a mission need not be considered here. If it were, bear in mind that it is necessary to be aware of those issues which are, for example, pertinent to a sample return mission and these are contained in the Planetary Protection section of the Report. They include issues of containment of any bio material that is brought back, quarantine of that material on Earth, environmental and intellectual property and other terrestrial issues.

8.11 Societal Impacts

Space missions are often subject to criticism from the public and scrutiny from certain special interest groups. A mission such as this - intending to look for extraterrestrial life and to do so using nuclear power - raises some very complex issues. The potential issues are identified and described in some detail.

8.11.1 Mission Planning

Some groups will be opposed to spending money in the effort to search for life elsewhere. Their reasons may be either that they are convinced that life does not exist elsewhere or that they simply think spending money on space exploration in general is a waste of resources that may be better utilized to improve life on Earth. Even among those who avidly support space science and exploration there are multitudinous views as to where resources should be allocated.

The choice of RTGs as heat/energy sources will be controversial as well. We only have to read the newspaper headlines from October of 1997, to see the reaction of the public to the launch of the Cassini probe to project what may be the consequences of using such technology. The choice to avoid an Earth flyby maneuver in this case study should mitigate the reaction of the public since the mission planner only need to show that the RTGs can survive a failure during launch and the failure statistics are well known for existing launch vehicles. See chapter 8.12 for a public outreach program on this issue. In addition, the fact that no sample will be returned to Earth will eliminate any concerns that a potentially harmful organism may be introduced into the Earth environment.

It is likely that a public campaign will be organized whose goal is to try to prevent this mission from proceeding. This campaign is likely to start shortly after the proposal is delivered to the international community and build in intensity until the day of the launch. As with the Cassini mission, the rally cry will be heard primarily through the internet with public demonstrations serving to draw attention to the issue. NASA responded to this public outcry in 1997, with a special section on its website which was devoted to the nuclear safety issue. Traffic to this section totaled 200 000 hits per day during the week of the launch [464] indicating that many people are interested in the issue and maybe more importantly that the public was willing to read what NASA had to say.

It is critical for this mission to have public support. A planned mission to Europa must survive budgetary reviews over possibly several changes in the international political leadership (cf. 8.10.1), and also within the mission hierarchy. In this regard the public must be educated about the mission (cf. 8.12), especially in terms of what the primary rationales are for the mission, what we expect to find on Europa and most importantly, an honest discourse on the usage of nuclear power sources.

8.11.2 The Discovery of Life

Evidence of life on Europa would have impacts across many areas of life. The possible impacts on humanity of discovering simple life within the solar system are discussed in 6.3.1. However, the scenario described previously was a manned mission to Mars that discovered simple biological matter and returned a sample to Earth. The following is a synopsis of the relevant points of this previous discussion as they apply to a mission to Europa. There would likely be a lot of public interest in the findings initially but this interest would likely fade quickly unless it could be sustained by the usefulness of the study of alien life and the resultant application of new knowledge to improve life on Earth. As a result of these public attitudes, funding for astrobiology missions would see a large short term increase while the success of the mission is fresh in the public perspective.

The scientific return for a mission that discovers extraterrestrial life would be enormous. However, there will likely be a hesitation (conscious or not) on the part of the scientific community to release any definitive information about what was found due to the events surrounding the discovery of the ALH84001 meteorite. Intellectual rights of any research deriving from this investigation and a plan for dissemination of knowledge to the public will have to be clearly established as part of the mission plan (cf. 8.10.1, pp. 185).

The finding of life on Europa would have massive economic effects for companies who create space hardware. This is true regardless of whether we decide to return to Europa to further study the alien life or whether we decide to quarantine this life and go on to look for life elsewhere riding on the success of the previous findings. Pharmaceutical or bio-tech companies who will investigate this life will also gain from a spotlight on their research and public interest in investment.

The religious response to the possibility of detection of extraterrestrial life is widely varied even within one faith however some broad conclusions can be made. For most believers of the Abrahamic religions (Judaism, Christianity and Islam), the interpretation of their respective doctrines would likely be modified to take extraterrestrial life into consideration. We can see evidence of this in the past when these faiths evolved to accommodate the Copernican and Darwinian revolutions. Some eastern religions even take for granted that life exists on many planets. Hinduism, Buddhism and Jainism posit parallel universes containing multiple worlds, which are inhabited by beings both superior and inferior to humans. Thus, the existence of extraterrestrial life is compatible with these eastern faiths.

Philosophically, the discovery of extraterrestrial life can be seen as the next step in the demotion of humanity in the echelon of universal importance. We have gone from being the center of the universe to occupying a mundane location in an unimportant stellar system in the backwaters of a nondescript galaxy. But right now many of us still consider ourselves the center and sole focus of God's attention. If we find life on Europa, even that changes.

It is difficult to argue that the finding of extraterrestrial life would have no impact on religion and other areas of our lives. Author Kendrick Fraser has asserted that "Our religions are not the only of our institutions built upon an unjustifiably self-centered sense of our own importance" [451] and that it is therefore reasonable to assume that many aspects of daily life will be greatly impacted by the discovery of alien life and the subsequent perceived shift of humanity's role in the universe.

8.11.3 The Outlook for Astrobiology

The first and most fundamental question to be asked is: Should we return to Europa? An initial discovery such as this would likely create more questions that we may not be able to answer without returning to Europa many times. On the other hand, there would be great pressure to be sensitive to this life and not jeopardize its existence by interfering with it in any way. Some would suggest that we set up an effective quarantine of Europa. Even orbiting platforms may be banned due to the possibility that they may crash into Europa.

This debate would lead to discussion about contamination. If life is found, we no longer have the option of thinking of planetary protection in the hypothetical sense. Preservation of the alien environs and protection of the Earth would take precedence in the technical pecking order. We would need to reconsider our current protocols and discuss their effectiveness. A positive finding of extraterrestrial life will secure support for many follow-on missions to Europa and other bodies. The number of missions that may follow from this initial discovery is however limited by the dwindling enthusiasm of the public. The overall effect of a mission that does not conclusively detect alien life is an accelerated decline in public and governmental support. Both of these scenarios seem to imply that there are a limited number of opportunities for astrobiology missions unless there is sustained discovery of life in various forms throughout the solar system.

8.12 Europa Education and Public Outreach Program

The Europa Mission Team is committed to education and public outreach, as is evident in the strong educational component in the mission statement (cf. 8.2). The benefits of a significant education commitment will not necessarily be seen immediately because of the nature of the investment being made and the audience being targeted. The teaching of young people of all ages pays future dividends in the form of increased scientific literacy and political literacy, greater quality and quantity of people involved in scientific research and government and the quality of life in general. Public outreach can serve to support the mission objectives, set the climate for educational initiatives and support the use of public funds in science, space technology and policy. The Europa mission has several areas of interest for education and public outreach:

- The promotion of astrobiology which extends the search for life from Earth to the promising subterranean ice fields of Europa and beyond, and professional development addressing the confirmed discovery of life, and the educator's role in this.
- The use of science and technology in design and build scenarios that are directly related to the mission's use of various tools such as cryobots which will melt through the ice in search of a water/ice interface with biogenic material.
- An increased awareness of radiation that sees the use of nuclear power as part of a continuum of beneficial forms of radiation such as that from the sun and x-rays, to nuclear powered machines and RTGs that have dangerous levels.
- The promotion of careers in science and policy so that education initiatives lead to young people eventually working in space and space related fields.

- The global goal of making the resources and outreach materials accessible in a reasonable international framework.

8.12.1 Program Overview and Proposed Activities

Although kindergarten to grade 12 and the general public are the audience for the mission, the target group is generally 10 to 14 year olds in selected activities. The duration of the mission being from five to seven years allows for a target group of this age to grow with the mission and potentially pursue further related science and policy education and careers due to their early exposure to the Europa related activities found in this case study. Four phases would include:

Preassessment Vocabulary Phase

Europa Top Ten Media contest would publish selected questions dealing with Europa trivia. Complete answers would earn a mission patch. This would help to initially assess the general knowledge about Europa that exists then aid in educating the public as they tried to earn the mission patch. This would also generate the vocabulary for the public to use with regard to the mission and astrobiology. If a positive find with regard to life is confirmed as a result of the mission or even future endeavors, educational institutions will be able to help discern what makes this a positive find and why it is important to humanity because the vocabulary to think about such findings will be solidly embedded in future curriculum. Examples of potential vocabulary for Top Ten are: Cryobot, Radiation, Chromatography, Forward Contamination Spectrometer, Astrobiology, Extremeophile, Planetary Protection, Radar, Nanotechnology, Remote Sensing, and Europa.

Build and Design Phase

Students would be challenged by a sponsored contest from a building toy company like Lego or Meccano to enter a design challenge contest. Example: build a Europa autonomous robot out of the provided material that can move in water to a specific target and bring a sample back to the surface of the water. Size, time and material constraints would be given and final tests would be in a local pool of a specific temperature, mimicking Europa conditions and discussing earth analogues of Antarctica.

Curricula covering nuclear based technology would be developed extensively that would be in line with the public outreach regarding the beneficial and harmful effects of radiation. The effects on humans is an appealing topic to school children because of immediate relevance to radiation that comes from electronic equipment such as televisions sets and computer monitors, where children spend hours of their time. Radiation is too dangerous for young people so the use of thought experiments, simulations, or safe analogues to explore radiation should be used in the classroom.

General Public Outreach

Make the public aware of the real risk of an RTG type spacecraft for the environment and effects of radiation in a continuum format (see Fig. 8.11. A continuum format would provide the big picture with regard to radiation such that the public could identify with both positive and negative interactions with the topic. Issues of forward and backward contamination would be addressed in general terms in a positive and informative light.

Nuclear protests that may occur at the launch site can be dealt with so that a positive outcome occurs favoring future funding and research. Radiation at the levels that the mission cryobots and space craft will be experiencing is fatal for humans. However, a greater understanding of the effects of radiation and future research to enhance the beneficial use of radiation could be successfully promoted. The experience gained in dealing with high levels of radiation will benefit other areas of research such as nano-scale biomedical technologies that may see great gains made with how both living and nonliving things can not only survive but thrive in this extreme environment scenario.[469]

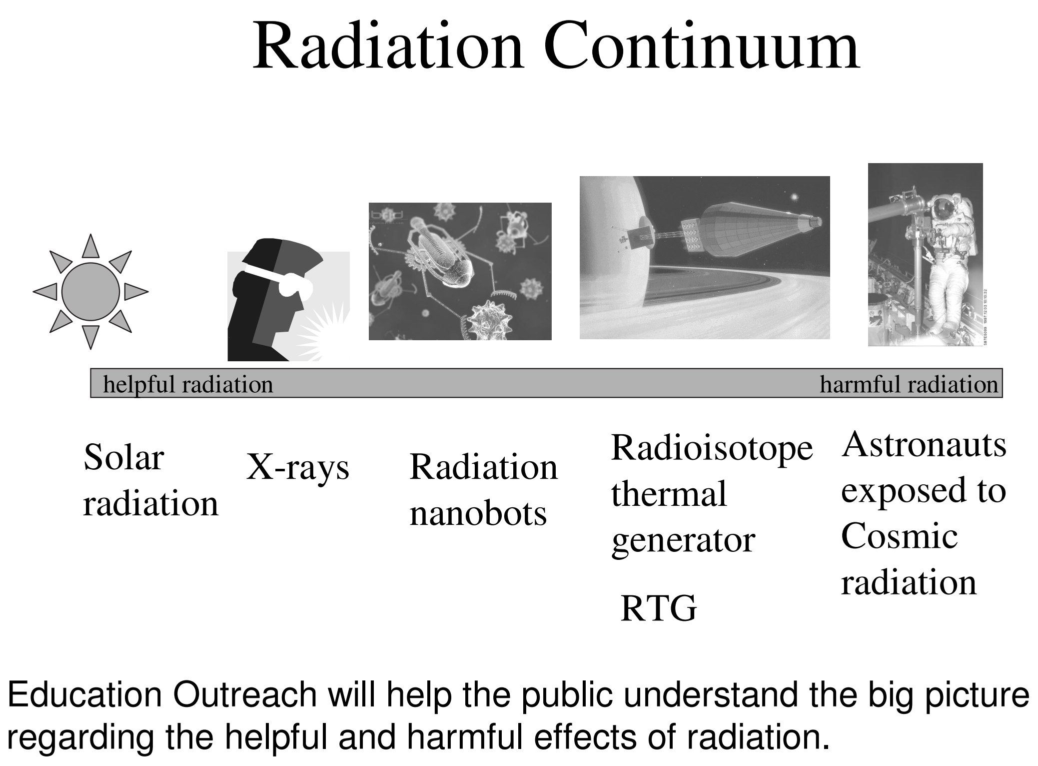

Figure 8.11: The radiation continuum

Career Phase

"Space has a Face". Students conduct real time interviews with scientists, engineers, mission designers and managers to study potential careers in astrobiology and space related careers. Commercials or infomercials would be written promoting space related jobs with the title: 'Space has a Face' could show how many careers are literally "out of this world?"

"Space has a Face" in oceanography: there is a coupling to oceanography where ocean education institutions could be used as a significant resource. Students can interact via interactive websites or CD-Roms to gain an understanding of polar oceans and ice plates on Earth. Students can discover how Europa's cryobot technology is being used to better understand Earth.

All these activities would need to be translated and adapted to partner country languages and significant efforts would be made to assist developing countries to use the educational resources.

The majority of education activities would coincide with the pre-launch activities where culminating tasks would come at the time of launch for maximum use of publicity and exposure. Activities should continue through the life of the mission. Outreach picks up intensity when the spacecraft enters the Jupiter system, when the cryobot is deployed to Europa, and if life is discovered.

8.12.2 Implementation Plan

Implementing the proposed education activities on an international scale is a large endeavor. The activities are broken up three types: formal activities, informal activities, and public outreach. Formal activities are academic institutional based curriculum. Informal activities include after-school activities, museums, and science centers. Public outreach is geared towards the general public, utilizing newspapers, magazines, pamphlets, etc. Table E.4 E.5 and E.6 show the activities, estimated budget per activities, development partners, and intended audience respectively.

8.12.3 Education Summary

As outlined in Sec. 8.11 it is critical for this mission to have public support in order for it to survive budgetary reviews over possibly several changes in the international political leadership and the mission infrastructure. The proposed education and public outreach package promotes specific aspects of the mission especially in terms of what the primary rationales are for the mission and what we expect to find on Europa. The use of translation and the adaptation of educational resources is a significant step towards promoting the global appeal of the mission as a whole. The respect for the overall public consciousness concerning such difficult issues as contamination, radiation, oceanography, astrobiology and space endeavors in general is addressed in an overall theme of giving people knowledge and scope with regard to the broader effects of such a mission.

8.13 Case Study Summary

In our case study we showed that

- Current available technology could meet the major scientific requirements to investigate Europa, and to extend the understanding of the Jovian system.
- Education and public outreach plays an important role, because the mission design requires the use of nuclear power sources. The planned activities could mitigate potentially difficult situations, similar to the one the Cassini project faced during its launch campaign. The use of translation and the adaptation of educational resources is a significant step towards promoting the global appeal of the mission. Topics such as astrobiology, contamination, radiation, and space endeavors in general are addressed.
- Potential discovery of extra-terrestrial life would have profound implications on many levels of Earth's society.
- Various political and legal aspects have to be taken into account, including, but not limited to:
  - technology transfer issues between engaged parties
  - applicable treaties for outer space
  - contamination issues
  - political support throughout entire mission
  - such a mission can be fit in a budgetary frame of a 'flagship', or 'cornerstone' mission, e.g. Viking, Voyager, Galileo, or Cassini.
- The mission to Europa, even if it has to compete with Mars missions, has a scientific and educational return that is significant enough to get the status of a flagship mission.

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Part V

Summary and Concluding Remarks

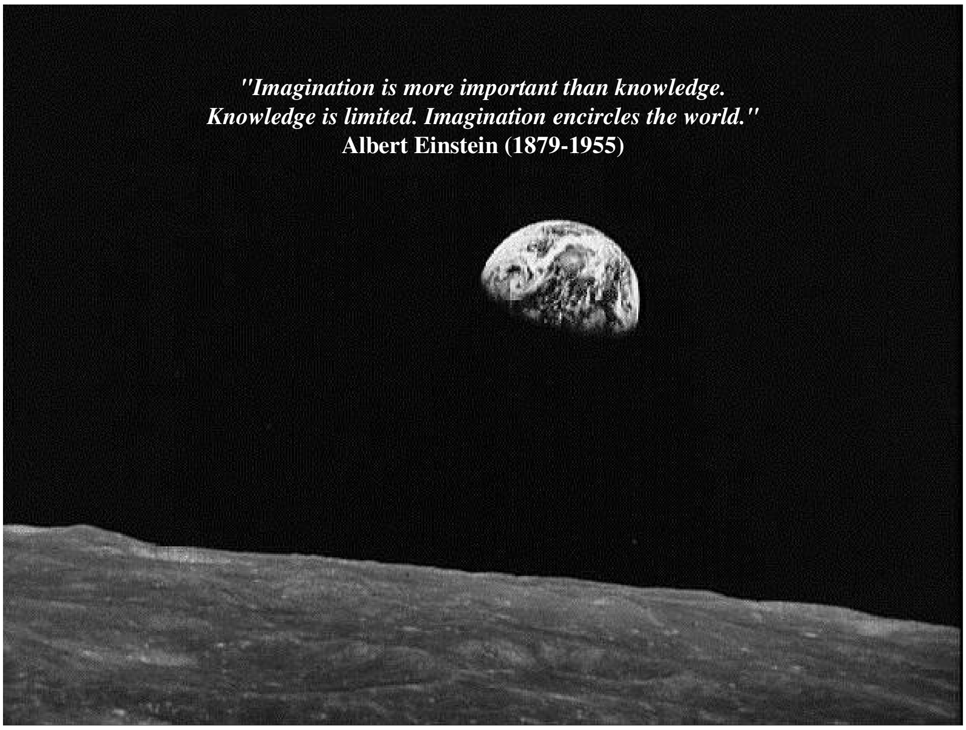
Alone? A Discovery Sourcebook for Astrobiology provided a background of this exciting and emerging field and attempted to look at what potential directions it might take. The report investigated instrumentation for future missions and life detection, suggested guidelines for planetary protection and considered the impact on society. In addition, educational issues were examined and a six-phase curriculum was developed to target 10-14 year old students in order to engender an interest in astrobiology. A case study of a future mission to investigate the Jovian system with an astrobiology focus on Europa was documented illustrating the interplay between the subjects we researched.

Progress in the search for extra-solar planets provides exciting possibilities for finding biomarkers outside the solar system. In parallel, the search within the Solar System is allowing us to identify what biomarkers might be important in determining that life is present.

The possibility for discovery and the consequences of that discovery make astrobiology a very compelling field of study. What is needed now are some samples of astrobiology to study. Here on Earth, the list of extreme locations where life has been found is growing. However, a leap forward is required in the study of regions beyond Earth. Imagine a day when we could have direct physical evidence of simple, near life. And data from an orbiting observatory with resolution of the Terrestrial Planet Finder provides circumstantial evidence of life outside the Solar System! This would advance the quest for discovery, and who knows where it would take us next.

Our report is written within the context of thinking about life in a familiar form. However, perhaps one of the most interesting long term questions is: what about life forms that we currently are not familiar with, life that is not dependent on conditions that exist on our carbon and water rich Earth? This would transform the way we define and understand life. Currently science and the humanities are just beginning to tackle these questions.

Enjoy your quest for discovery!



Part VI

Appendices

Appendix A

Extra Solar Planets: Search & Detection

A planet orbiting around a star with a brightness L_* acquires by reflection a brightness L_P which is given by [485]

$$L_P = \frac{A\,L_*}{8}\left(\frac{R_P}{a}\right)^2 \Phi(t) \tag{A.1}$$

where A is the albedo of the planet and $\Phi(t)$ is a time dependent (t = time) orbital phase factor given by $\Phi(t) = 1 - \sin i \sin(2\,\pi\,t/P)$. i is the inclination of the orbit with respect to the sky plane and $\alpha = a/D$ is the angular distance of the planet from the star (a is the planet's distance from the parent star and D is the distance from the Solar System).

Due to the diffraction peak of the parent star the faint planet is in general going to be immersed in the photon noise of the rings of the diffraction spot. The various methods to counteract this effect where mentioned in Sec. 2.2.2 and are here explained in more detail:

- *Adaptive Optics*: One can modify the surface of the telescope mirror (usually a secondary mirror) in a way such that the star's light coming from different parts of the mirror interfere destructively (but not the light coming from the planet) at the planet location.

- *Dark Speckles*: Instead of deforming the mirror, one can take advantage of the atmospheric turbulence. It makes random changes of the pathlength of the light rays with a random d at a frequency of about 1 kHz. The planet is seen in very short exposures (1 ms) when, by chance, the star light interferes destructively at the planet location [482].

- *Nulling*: One can have two (or more) telescopes separated by a distance l and make the light rays coming from them interfere in the focal plane. Suppose one introduces in one of the interfering branches a device that adds to the light wave phase a quantity π. Then, at the interference point the total wave amplitude for the star is $A_* + A_* \exp(i\,\pi) = 0$. For the planet the amplitude is given by $(A_P)_{total} = A_P + A_P \exp\{i\,[\pi + \epsilon(l/\lambda)]\}$. The distance l (also called ”baseline”) can be arranged such that $\pi + \epsilon(l/\lambda) = 2\,n\,\pi$. Then $(A_P)_{total} = 2\,A_P \neq 0$: the stellar light is suppressed (destructive interference) but not the light of the planet (constructive interference). This set-up is known as ”nulling interferometer” and was first proposed by [475]. By using more telescopes it is possible to create a complex pattern (called transmission pattern) that can be ”tuned” to each individual star that is observed in order to locate the transmission ring (zone of constructive interference) on top of the so called *habitable zone* (see Sec. 3.3.3). The current baseline of the ESA Infra Red Space Interferometer Darwin consists of six 1.5 m telescopes using baselines l between 40 and 250 m (planet finding mode) [479, 480].

- *Occultation*: This technique uses an artificially created occultation (e.g., using a satellite) to improve the resolution of closely spaced objects with comparable brightness (binary stars, microlensing events, etc.) and to facilitate separation of dim objects from nearby bright objects (such as planets around stars) [e.g. 476].

- *IR/choronographic imaging*: Direct imaging in infrared (IR) or visible wavelengths allows to investigate size, structure and characteristics of circumstellar dust disks throughout their evolution. An optical supersmooth coronographic telescope will be able to detect Jupiter size extra solar planets which are typically 10^9 fainter than their parental star [484].

Appendix B

Alive

B.1 Finding signs of life – examples

This Appendix include descriptions of experiments that have been conducted or are planned on missions to Mars, Titan, Europa, Comets and planetary dust.

B.1.1 Mars

Viking (1976)

The Viking missions reached the Martian surface in July 1976, the two landers conducted four experiments intended to detect the presence of microbiological life on the Martian surface [478].

The Gas Exchange Experiment sought to detect alterations in the composition of the gases in the test chamber as a result of biological activity. This experiment detected significant increases in the level of oxygen in the test chamber, which was not inconsistent with biological activity. But the oxygen release was also consistent with the reaction of residual humidity in the test chamber with peroxides and superoxides, produced on the Martian surface by solar ultraviolet radiation. The existence of such oxidants was anticipated, given the predominance of CO_2 in the Martian atmosphere, since, in the absence of such an agent, solar ultraviolet radiation would decompose the CO_2 to CO and free oxygen [481]. The decreasing level of oxygen release reinforced this interpretation over time, which was inconsistent with biological activity.

The Labelled Release Experiment used a liquid nutrient tagged (labelled) with radioactive ^{14}C, to detect the uptake of the liquid nutrient by microorganisms. The Martian soil, when made wet by this nutrient, rapidly released significant volumes of labelled gases over a period of eight days. The initial interpretation of this release was the presence of biological activity. But the high rate of gas release slowly stabilized in a manner that was inconsistent with either chemical or biological activity.

The Pyrolytic Release Experiment was designed to detect the existence of organic materials in Martian soil. After a five-day incubation period under a xenon-lamp, during which it was exposed to radioactive CO_2, surface samples were heated to high temperatures to determine if any of the radioactive CO_2 had been incorporated into molecular compounds. This experiment was repeated nine times, and seven runs appeared to indicate very small concentrations of microorganisms. Nonetheless, in later interpretations of the data acquire, these results were discounted on the basis that indigenous Martian life forms would have been killed by the relatively high temperatures they were exposed to during the initial incubation period.

The Gas Chromatograph is a mass spectrometer that heated a soil sample to determine the chemical composition of the Martian surface. While primarily of interest for geological investigations, this experiment could also be used to detect concentrations of carbon compounds that would be the constituents of Martian microorganisms. Although these tests evolved a surprising amount of water, they failed to detect organic compounds. Two suggestions were derived from these results: (1) that this not only strongly suggested the absence of life on Mars, but (2) it also suggested the presence of some mechanism that was destroying the carbon compounds in meteorites that were reaching the Martian surface. The non-conclusive results of the

Gas Chromatograph - Mass Spectrometer to detect Martian organic matter may have been due to the relative insensitivity of this instrument. Using this instrument on Antarctica rock samples, no biological activity was detected.[474] Also, it did not have large enough sensitivity to analyze some large organic molecules [474].

These results were generally taken to indicate that Mars was not habitable. However, not everyone was convinced. Several lines of argumentation were advanced to suggest that the Viking results were not inconsistent with the presence of life on Mars.

Mars Pathfinder (1997)

This mission landed a single vehicle with a microrover (Sojourner) and several instruments on the surface of Mars in 1997. This mission was not an astrobiologic one, however its reconnaissance data are of great importance for the future planning of such missions. Pathfinder investigated the surface of Mars with three additional science instruments (a stereoscopic imager with spectral filters on an extendable mast [IMP]), an Alpha Proton X-Ray Spectrometer (APXS), and an Atmospheric Structure Instrument/Meteorology package (ASI/MET). These instruments allowed investigations of the geology and surface morphology at sub-meter to a hundred meters scale, the geochemistry and petrology of soils and rocks, the magnetic and mechanical properties of the soil as well as the magnetic properties of the dust, a variety of atmospheric investigations and rotational and orbital dynamics of Mars. Pathfinder landed downstream from the mouth of a giant catastrophic outflow channel, the Ares Vallis. This location offered the potential for identifying and analyzing a wide variety of crustal materials, from the ancient heavily cratered terrains to intermediate-aged ridged plains to reworked channel deposits. Examination of the different surface materials will allow first-order scientific investigations of the early differentiation and evolution of the crust, the development of weathering products and the early environments and conditions that have existed on Mars.

Mars Global Surveyor [MGS] - 1996

The Thermal Emission Spectrometer (TES) conducts infrared scans of the planet. TES works on the concept that different types of compounds will take on different temperatures when exposed to the same amount of sunlight. Scientists are gathering this type of data over many days in order to conduct a planet-wide mineral survey of Mars. TES also scans the Martian atmosphere to provide data for the study of the clouds and weather. It is hoped that TES will yield clues into the location of clays containing carbonate minerals. Although no liquid water exists on Mars surface today, carbonate deposits might indicate areas that could have been shorelines long ago in Martian history. Future missions to Mars might begin their search for fossil remains of life in areas identified by TES data.

2001 Mars Odyssey [MO] - 2001

The Gamma-Ray Spectrometer (GRS) is able to measure the abundance and distribution of about 20 primary elements of the periodic table, including silicon, oxygen, iron, magnesium, potassium, aluminum, calcium, sulfur, and carbon. Knowing what elements are at or near the surface will give detailed information about how Mars has changed over time. To determine the elemental makeup of the Martian surface, the experiment uses a gamma ray spectrometer and two neutron detectors. The GRS measures O, Si, Ti, Al, Fe, Mg, Ca in weight percent, and U, Th and K are measured in ppm.

Mars Express (ME) - 2003

Mars Express will explore the atmosphere and surface of Mars from polar orbit. The mission's main objective is to search for sub-surface water from orbit and deliver a lander to the Martian surface. Seven scientific instruments on board the orbiting spacecraft will study the Martian atmosphere, the planet's structure and geology.

Instruments On The Orbiter

The Planetary Fourier Spectrometer (PFS) - The Martian atmosphere consists mainly of carbon dioxide and nitrogen with a very small proportion of water vapor and ozone. PFS will measure the global atmospheric distribution of water vapor and other minor constituents with greater accuracy than previous missions.

The UV and IR Atmospheric Spectrometer (SPICAM) - SPICAM will measure the composition of the Martian atmosphere over smaller volumes than the PFS instrument. It will measure ozone using a technique similar to that used on the Mariner 9 spacecraft, which first discovered ozone on Mars. SPICAM will also use the technique of stellar occultation, to measure the vertical profiles of carbon dioxide, temperature, ozone, aerosols and clouds.

Beagle 2 - 2003

Beagle 2 includes a series of devices, each composed of one or more analytical instruments. One of them, the PAW, carries the Gas Analysis Package (GAP) that will make isotopic measurements of N_2, H_2, CO_2 (organic burns at 300-400°C+ Ne, Ar, and Xe + CH_4 from the atmosphere and collected samples) to seek trace atmospheric species indicative of extant life. The other instruments in Beagle 2 are a pair of stereo cameras, two types of spectrometer (Mössbauer and X-ray), a microscope, the corer/grinder and mole.

The Gas analysis package (GAP) will be used when a rock looks particularly interesting. A sample will be drilled out with the corer and taken to the (GAP) inside the shell of the lander by means of the robotic arm. GAP is the facility for heating a solid sample (soil or rock) in steps of increasing temperature, each increment being supplied with freshly generated oxygen - any carbon compound present will burn to give carbon dioxide.

The capabilities and functions of this instrument are:

- Handling of the gas generated at each temperature step and delivery to the mass spectrometer.
- The mass spectrometer itself that can detect and measure the amount of carbon dioxide.
- The instrument distinguish and between the two stable isotopes of the carbon and quantify the ratio. Other gases like methane can also be analyzed.
- The design for Beagle 2's mass spectrometer is a 90 degree sector instrument having a magnet of less than 1 kg made from a rare earth metal alloy and an ion pump using the same material. It will embody the principle of the dual inlet whereby light element samples and standards are sequentially compared for high precision isotopic measurements and operate in static vacuum mode for greatest sensitivity.

In GAP, the most relevant experiments to detecting past or present life will be conducted. The instrument has twelve ovens in which rock or soil samples can be heated gradually in the presence of oxygen. The carbon dioxide generated at each temperature will be delivered to a mass spectrometer, which will measure its abundance and the ratio of ^{12}C and ^{13}C. This mass spectrometer has the capability to study other elements and isotopes, and it will look for methane in samples of atmosphere. The stepped combustion experiment, which converts organic carbon to CO_2 can show differences in isotopic composition between biotic and abiotic forms of the element (by the isotopic ratio). Biological processes preferentially use the lighter of the two stable isotopes of carbon ^{12}C and ^{13}C. The ratio of the two stable isotopes (isotope scientists use the term delta ^{13}C to describe differences in the ratio) can give a clue to the type of life processes (e.g. photosynthesis, methanogenesis), which have resulted in the fractionation.

Furthermore, the GAP instrument will also study components in the atmosphere that will reveal the planet's history and monitor climatic effects. Also, when used in conjunction with the X-ray spectrometer, which will provide potassium data, the mass spectrometer will measure ^{40}Ar abundance to enable rocks to be dated based on the extent to which ^{40}K has decayed to ^{40}Ar.

The Environmental Sensors

Several experiments will be conducted by a number of small sensors that will measure different aspects of the Martian environment. The data obtained will help the determination of whether life could have, or could still, exist there. Included is a meteorological sensor package that will measure atmospheric pressure, air temperature, and wind speed and direction. Other sensors will help determine how hospitable the environment is to life by measuring ultra-violet (UV) radiation and oxidizing gases such as ozone and hydrogen peroxide in the atmosphere. Dust fall-out rates will also be measured, as will the density and pressure of the upper atmosphere during the lander's descent.

PAW includes the following miniaturized instruments :

Two stereo cameras whose main task will be to construct a 3D model of the area within reach of the robotic arm, allowing the other instruments on the PAW to be moved accurately into position alongside target rocks and soil.

Microscope will pick out features as small as $4x10^{-6}$ m across in rock surfaces exposed by the grinder. This is small enough to pick out features that could be bacteria. A set of LEDs will illuminate the sample in red, blue, green and UV light. This magnification will reveal the shape and size of dust particles, the roughness and texture of rock surfaces and the microscopic structure of rocks. The UV LED will be used to test whether the rocks fluoresce. Some inorganic rocks fluoresce naturally. However, another common fluorescent material on Earth is chlorophyll and hence, fluorescence could be an indicator of life.

Mössbauer spectrometer will be used to investigate the mineral composition of rocks and soil by irradiating exposed rock and soil surfaces with gamma rays emitted by a radioactive source (^{57}Co). It will then measure the spectrum of the gamma rays reflected back. As the way in which gamma rays are reflected depends on the electronic environment of atoms, this technique can reveal much about how atoms are bound chemically, and hence about the rocks and soil mineral composition. The Mössbauer spectrometer will also look at the weathered surface of rocks and the oxidation state (Fe^{2+} versus Fe^{3+}) of the soil to help determine the oxidizing nature of the present atmosphere.

X-ray spectrometer will measure the amounts of elements in rocks by bombarding exposed rock surfaces with X-rays from four radioactive sources (two ^{55}Fe and ^{109}Cd). The rocks will fluoresce and emit lower energy X-rays characteristic of the elements present. Measurements of potassium will be used together with measurements of argon by the GAP to date rocks using the fact that the isotope ^{40}K decays to ^{40}Ar.

2003 Mars Exploration Rovers

Each rover will carry a sophisticated set of instruments that will allow it to search for evidence of liquid water. Soon after arrival onto the Martian surface, each rover will begin reconnaissance of the landing site by taking a 360° visible color and infrared image panorama.Using images and spectra taken daily from the rovers, scientists will command the vehicle to go to rock and soil targets of interest and evaluate their composition and their texture at microscopic scales. The first targets will be close to the landing sites, followed by targets further away.

Alpha Particle X-Ray Spectrometer (APXS) will measure the concentrations of most of the major rock-forming elements.

Mössbauer Spectrometer will be used to make detailed measurements of the composition of Martian rocks and soils.

B.1.2 Titan and Europa

Voyager 1 (1977)

Ultraviolet Spectrometer (UVS) The UVS is a very specialized type of light meter that is sensitive to ultraviolet light. It determines when certain atoms or ions are present, or when certain physical processes are going on. The science objectives of UVS are:

- To determine the scattering properties of the lower planetary atmospheres.
- To determine the distribution of constituents with height.
- To determine the extent and distribution of hydrogen corona of the planets and satellites.
- To investigate night luminosity and auroral activity.
- To determine the UV scattering properties and optical depths of planetary rings.
- To search for emissions from the rings and from any ring “atmosphere”

Infrared Interferometer Spectrometer and Radiometer (IRIS) The IRIS functions as three separate instruments: thermometer, chemical analysis of the atmosphere and surface, and radiation measurements of reflected sunlight by a body at ultraviolet, visible, and infrared frequencies. The science objectives of IRIS are:

- Determination of atmospheric vertical thermal structure (which in turn aids modeling of atmospheric dynamics).
- Measurement of the abundances of hydrogen and helium (as a check on theories regarding their ratio in the primitive solar nebula).
- Determination of the balance of energy radiated to that absorbed from the sun (to help investigate planetary origin, evolution, and internal processes).

Galileo (1989)

Extreme Ultraviolet Spectrometer (EUV) is an objective grating spectrometer with a mechanical collimator. There is a concave dispersion grating that focuses extreme ultraviolet via a single reflection onto a detector consisting of a photocathode, microchannel plate electron multiplier, and an anode array. The EUV is a modified Voyager spare Ultraviolet Spectrometer with an electrical interface to adapt it to the Galileo command and data bus. The science objectives of EUVS are:

- Study the composition and structure of the upper Jovian atmosphere.
- Determine the loss rates of volatile gases from the Galilean satellites.
- Examine the physical processes occurring in the Io plasma torus.
- Do follow up studies to the Voyager UVS discoveries.

Ultraviolet Spectrometer (UVS) is a Cassegrainian Dall-Kirkham telescope with a 5.03 x 5.28-cm aperture and a 25.0-cm focal length. The telescope is the front end to a standard 12.5 cm focal length Ebert-Fastie scanning spectrometer. The telescope has a sunshade on the front and the telescope/spectrometer has the control logic box mounted on top. Three photo multiplier detectors are situated in the focal plan of the spectrometer. The science objectives of UVS are:

- Study the composition and structure of the upper Jovian atmosphere.
- Determine the loss rates of volatile gases from the Galilean satellites.
- Examine the physical processes occurring in the Io plasma torus.

Near-Infrared Mapping Spectrometer (NIMS) consists of a 22.8-cm diameter (f/3.5), 80-cm focal length, Ritchev- Chretien telescope with a spatial scanning secondary mirror and diffraction grating spectrometer. NIMS will be able to monitor ammonia, water vapor, phosphine, methane, and germane and to look for previously undetected molecules. The science objectives of NIMS are:

- Map the surface minerals on the Galilean satellites at a spatial resolution of 5 to 30 km.
- Identify the phases and mixtures of the surface minerals on the Galilean satellites.
- Correlate mineral distributions with SSI images.
- Determine the Jovian atmosphere cloud structure over a wide range of phase angles.

Cassini-Huygens (1997) ESA/NASA

Relevant Remote Sensing Instruments on board of Cassini:

Composite Infrared Spectrometer (CIRS) consists of dual interferometers that measure infrared emission from atmospheres, rings, and surfaces over wavelengths from 7 to 1000 micrometers to determine their composition and temperatures. The science objectives of CIRS are:

- To map the global temperature structure within Titan's and Saturn's atmospheres.
- To map the global gas composition within Titan's and Saturn's atmospheres.

- To map global information on hazes and clouds within Titan's and Saturn's atmospheres.
- To collect information on energetic processes within Titan's and Saturn's atmospheres.
- To search for new molecular species within Titan's and Saturn's atmospheres.
- To map the global surface temperatures at Titan's surface.
- To map the composition and thermal characteristics of Saturn's rings and icy satellites.

Ultraviolet Imaging Spectrograph (UVIS) is a set of detectors designed to measure ultraviolet light reflected or emitted from atmospheres, rings, and surfaces over wavelengths from 55.8 to 190 nanometers to determine their compositions, distribution, aerosol content, and temperatures. The science objectives of UVIS are:

- To map the vertical/horizontal composition of Titan's and Saturn's upper atmospheres.
- To determine the atmospheric chemistry occurring in Titan's and Saturn's atmospheres.
- To map the distribution and properties of aerosols in Titan's and Saturn's atmospheres.
- To infer the nature and characteristics of circulation in Titan's and Saturn's atmospheres.
- To map the distribution of neutrals and ions within Saturn's magnetosphere.
- To study the radial structure of Saturn's rings by means of stellar occultations.
- To study surface ices and tenuous atmospheres associated with the icy satellites.

Visible and Infrared Mapping Spectrometer (VIMS) is a pair of imaging grating spectrometers designed to measure reflected and emitted radiation from atmospheres, rings, and surfaces over wavelengths from 0.35 to 5.1 micrometers to determine their compositions, temperatures, and structures. The science objectives of VIMS are:

- To map the temporal behavior of winds, eddies, and other features on Saturn/Titan.
- To study the composition and distribution of atmospheric and cloud species on S/T.
- To determine the composition and distribution of the icy satellite surface materials.
- To determine temperatures, internal structure, and rotation of Saturn's deep atmosphere.
- To study the structure and composition of Saturn's rings.
- To search for lightning on Saturn and Titan and for active volcanism on Titan.
- To observe Titan's surface.

Cassini Radar (RADAR) uses the five-beam Ku-band antenna feed assembly associated with the spacecraft high gain antenna to direct radar transmissions toward targets, and to capture blackbody radiation and reflected radar signals from targets. The science objectives of RADAR are:

- To determine whether oceans exist on Titan, and, if so, to determine their distribution.
- To investigate the geologic features and topography of the solid surface of Titan.
- To acquire data on non-Titan targets (rings, icy satellites) as conditions permit.

Relevant Instruments on board of the Huygens-probe:

Surface Science Package (SSP) consists of nine independent sensor subsystems with the primary aim of characterizing Titan's surface at the end of Huygens' descent through Titan's atmosphere. Other useful atmospheric measurements will be performed during the descent phase. Seven sensors are mounted inside or on the lower rim of a cavity in the Probe's fore-dome, and are thus exposed to Titan atmosphere or surface material. There are two additional sensors that do not require direct exposure to the atmosphere or surface. These sensors are mounted on the electronics box inside the descent module. The science objectives of SSP are:

- To determine the physical nature and condition of Titan's surface at the landing site.

- To determine the abundances of the major constituents, placing bounds on atmospheric and ocean evolution
- To measure the thermal, optical, acoustic and electrical properties and density of any ocean, providing data to validate physical and chemical models
- To determine wave properties and ocean/atmosphere interaction
- To provide ground truth for interpreting the large-scale Orbiter Radar Mapper and other experimental data

Aerosol Collector and Pyrolyzer (ACP) will deploy a filter out in front of the probe to sample the aerosols during the descent and prepare the collected matter (by evaporation, pyrolysis and gas product transfer) for analysis by the Gas Chromatograph Mass Chromatograph (GCMS). Two samples will be collected: one from the top of the descent down to the tropopause (160-40 km) and the second sample above the cloud layer (23-17 km). The science objectives of ACP are:

- The chemical composition of the photochemical aerosols (H, C, N, O)
- The relative concentrations of the organic condensates (i.e. C_2 H_2, C_2 H_6, HC_3N, HCN) inside the lower stratosphere
- The relative concentrations of the organic condensates (mainly CH_4, C_2H_6) within the troposphere
- Non condensible constituents eventually trapped in the collected particles (i.e. CO?)

Gas Chromatograph and Mass Spectrometer (GCMS) is a quadrupole mass filter with a secondary electron multiplier detection system and a gas sampling system providing direct atmospheric composition measurements and batch sampling through three Gas Chromatograph (GC) columns. This instrument will measure the chemical composition of Titan's atmosphere from 170 km altitude (approx. 1 mbar) to the surface (approx. 1.5 bar) and determine the isotope ratios of the major gaseous constituents. GCMS will also analyze gas samples from the Aerosol Collector Pyrolyzer (ACP) and will be able to investigate the composition (including isotope ratio) of several candidate surface materials.. The science objectives of GCMS are:

- To analyze the composition of the atmosphere of Titan
- To determine relative abundance of major constituents
- To determine noble gas abundance
- To determine isotopic ratio
- To identify high-molecular weight organic compounds in trace quantities

B.1.3 Comets and Cosmic Dust

Contour (2002) NASA

This mission has two baseline targets, the comets Encke and Schwassmann–Wachmann 3, are part of Jupiter's family of comets.

Neutral Gas and Ion Mass Spectrometer (NGIMS) is a quadrupole mass spectrometer that employs two ion sources each optimized for a specific set of measurements. Using these two sources, NGIMS will rapidly switch between measurements of the cometary neutral gas and ambient ions from the coma as the CONTOUR spacecraft flys by the nucleus. It is able to measure the abundance and isotope ratios for many neutral and ion species in the coma of each comet during the flyby. These measurements together with data from the dust experiment will contribute to the understanding of the chemical composition of the nucleus itself and allow differences between the comets to be studied. The chemical data is expected to provide the best possible record of conditions present in the outer solar nebula early in its history, since the comet nuclei of comets likely contains primitive materials unaltered by the chemical and physical processes that have trans- formed other solar system objects. The science objectives of NGIMS are:

- To measure the relative abundances of simple species such as H_2O, CH_4, CO_2, NH_3, and H_2S and considerably more complex molecules in the early stages of the protosolar nebula.

- To clarify the relationship of the solar nebula to the parent inter- stellar cloud.
- measure the isotope ratios such as D/H and the abundance of "thermometer" gases in comets such as argon and other simple species.

CONTOUR Forward Imager (CFI) was designed for high sensitivity and responsive to ultraviolet wavelengths. CFI will performs its measurements while CONTOUR spacecraft is approaching the nucleus and at a range of >2000 kilometers, so it looks out the front side of the spacecraft through an opening in the protective dust shield. The narrow emission band filters are sensitive to hydroxyl (OH) from dissociated water and to cyanide(CN) and carbon (C_2) from dissociated dust, and will show the locations of jets of gas and dust driven off the nucleus by sublimating ices. The science objectives of CFI are:

- To locate the target comet against the star background days to weeks before an encounter
- To take color images of the nucleus, any gas or dust jets, and other features in the inner coma
- To image the inner coma in wavelengths sensitive to major species of ionized gas.

Appendix C

Future Missions

	’09	’10	’11	’12	’13	’14	’15	’16	’17	’18	’19	’20	’21	’22	’23	’24	’25	’26	’27	’28	Σ
Rovers A	15	50	10																		75
Base A	15	25	10																		50
2 Cruise Stages(Russia)			20																		20
2 Launches(Russia)			70																		70
Insurance(12%)			25.8																		25.8
Drill Package A & Science Packages A				10	20	15															45
2 Cruise Stages(Russia)						10															10
Launch(Russia)						35															35
Insurance(12%)						10.8															10.8
Rovers B						15	30	10													55
Base B						10	20	5													35
2 Cruise Stages(Russia)								20													20
2 Launches(Russia)								70													70
Insurance(12%)								21.6													21.6
Orbiter						15	25	5													45
Launch(Russia)								35													35
Insurance(12%)								9.6													9.6
Drill Package B & Science Packages B								10	20	5											35
Resupplies A										15											15
2 Cruise Stages(Russia)										20											20
2 Launches(Russia)										70											70
Insurance(12%)										16.8											16.8
Operations			5	5	5	6	6	7	7	7	7	6	6	5	5	4	4	3	3	3	94
	30	75	140.8	15	25	116.8	81	193.2	27	133.8	7	6	6	5	5	4	4	3	3	3	883.6

All figures estimated in M$ of 2002

Table C.1: Costs for Scenario1: Continuous search for life on Mars. Estimation in analogy to [483]

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Σ
Orbiter		15	25	5										45
Launch(Russia)				35										35
Insurance(12%)				9.6										9.6
Rover A	40	50	50	40										180
Cruise Stages(Russia)				10										10
Launch(Russia)				35										35
Insurance(12%)				27										27
Rover B+Drill			40	65	65	40								210
Cruise Stages(Russia)						10								10
Launch(Russia)						35								35
Insurance(12%)						30.6								30.6
Rover C+Drill					37.5	60	60	37.5						195
Cruise Stages(Russia)								10						10
Launch(Russia)								35						35
Insurance(12%)								28.8						28.8
Operations				7	10	6	6	7	7	7	6	5	4	65
	40	65	115	233.6	112.5	181.6	66	118.3	7	7	6	5	4	961

All figures estimated in M$ of 2002

Table C.2: Costs for Scenario2: Fossil found on Mars. Estimation in analogy to [483]

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Σ
Rovers	50	100	100	50							300
Launch(Russia)				70							70
2 Cruise Stages(Russia)				20							20
Insurance(12%)				44.4							44.4
Orbiter				15	25	5					45
Launch(Russia)						35					35
Insurance(12%)						9.6					9.6
Operations				7	10	7	6	5	4	3	42
	50	100	100	206.4	35	56.6	6	5	4	3	566

All figures estimated in M$ of 2002

Table C.3: Costs for Scenario3: Evidence for life on Mars. Estimation in analogy to [483]

Appendix D

Planetary Protection

D.1 COSPAR Categories

Definition of categories for target body/mission type taken from the Report on the COSPAR, IAU Workshop on Planetary Protection [477].

The five categories for target body/mission type combinations and their respective suggested ranges of requirements are described as follows, and in Table 5.1. Assignment of categories for specific mission/body combinations is to be determined by the best multidisciplinary scientific advice. For new determinations not covered by this policy, such advice should be obtained through the auspices of the Member National Scientific Institutions of COSPAR. In case such multidisciplinary committee formed in consultation with its Member National Scientific Institutions and International Scientific Unions:

- **Category I** includes any mission to a target body which is not of direct interest for understanding the process of chemical evolution or the origin of life. No protection of such bodies is warranted and no planetary protection requirements are imposed by this policy.

- **Category II** missions comprise all types of missions to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could jeopardize future exploration. The requirements are for simple documentation only. Preparation of a short planetary protection plan is required for these flight projects primarily to outline intended or potential impact targets, brief Pre- and Post-launch analysis detailing impact strategies, and a Post-encounter and End-of-Mission Report which will provide the location of impact if such an event occurs. Solar system bodies considered to be classified as Category II are listed in the Table 5.1.

- **Category III** missions comprise certain types of missions (mostly flyby and orbiter) to a target body of chemical evolution and/or origin of life interest or for which scientific opinion provides a significant chance of contamination which could jeopardize a future biological experiment. Requirements will consist of documentation (more involved that Category II) and some implementing procedures, including trajectory biasing, the use of cleanrooms during spacecraft assembly and testing, and possibly bio burden reduction. Although no impact is intended for Category III missions, an inventory of bulk constituent organics is required if the probability of impact is significant. Category III specifications for selected solar system bodies are set forth in the Table 5.1. Solar system bodies considered to be classified as Category III also are listed in the Table 5.1.

- **Category IV** missions comprise certain types of missions (mostly probe and lander) to a target body of chemical evolution and/or origin of life interest or for which scientific opinion provides a significant chance of contamination which could jeopardize future biological experiments. Requirements imposed include rather detailed documentation (more involved that Category III), including a bio assay to enumerate the bio burden, a probability of contamination analysis, an inventory of the bulk constituent organics and an increased number of implementing procedures. The implementing procedures required may include trajectory biasing, cleanrooms, bio load reduction, possible partial sterilization of the direct contact hardware and a bio shield for the hardware. Generally, the requirements and compliance are similar to *Viking*, with the exception of complete lander/probe sterilization. Category IV specifications for selected solar system bodies are set forth in the Table 5.1. Solar system bodies considered to be classified as Category IV also are listed in the Table 5.1.

- **Category V** missions comprise all Earth-return missions. The concern for these missions is the protection of the terrestrial system, the Earth and the Moon. (The Moon must be protected from back contamination to retain freedom from planetary protection requirements on Earth-Moon travel.) For solar system bodies deemed by scientific opinion to have no indigenous life forms, a subcategory "unrestricted Earth return" is defined. Missions in this subcategory have planetary protection requirements on the outbound phase only, corresponding to the category of that phase (typically Category I or II). For all other Category V missions, in a subcategory defined as "restricted Earth return before," the highest degree of concern is expressed by the absolute prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body or unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth. Post-mission, there is a need to conduct timely analysis of the unsterilized sample collected and returned to Earth, under strict containment, and using the most sensitive techniques. If any sign of the existence of a non-terrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure. Category V concerns are reflected in requirements that encompass those of Category IV plus a continuing monitoring of project activities, studies and research (i.e., in sterilization procedures and containment techniques).

D.2 US Requirements

Figure D.1 shows the US requirements for making planetary protection directives and guidelines. Note that these requirements are updated periodically. NASA interacts with COSPAR and accepts recommendation from the Space Studies Board of the Space Research Council.

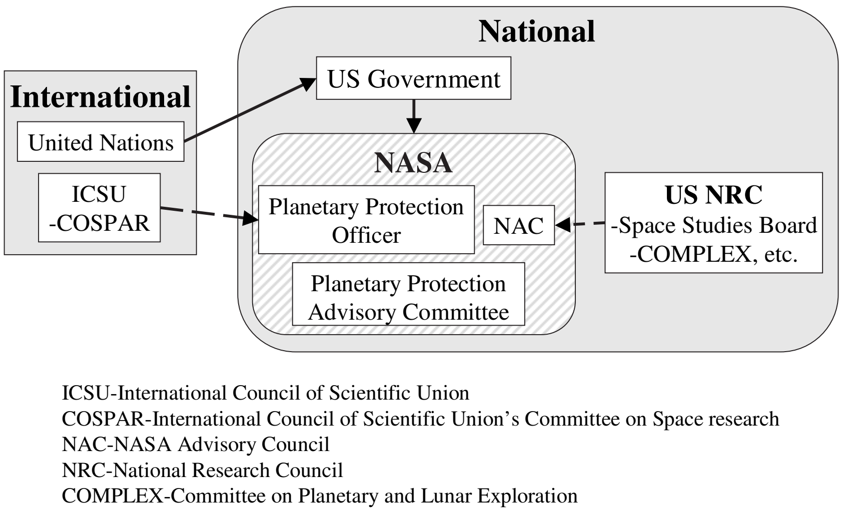


Figure D.1: US Regime for Planetary Protection Directives

Appendix E

Case Study

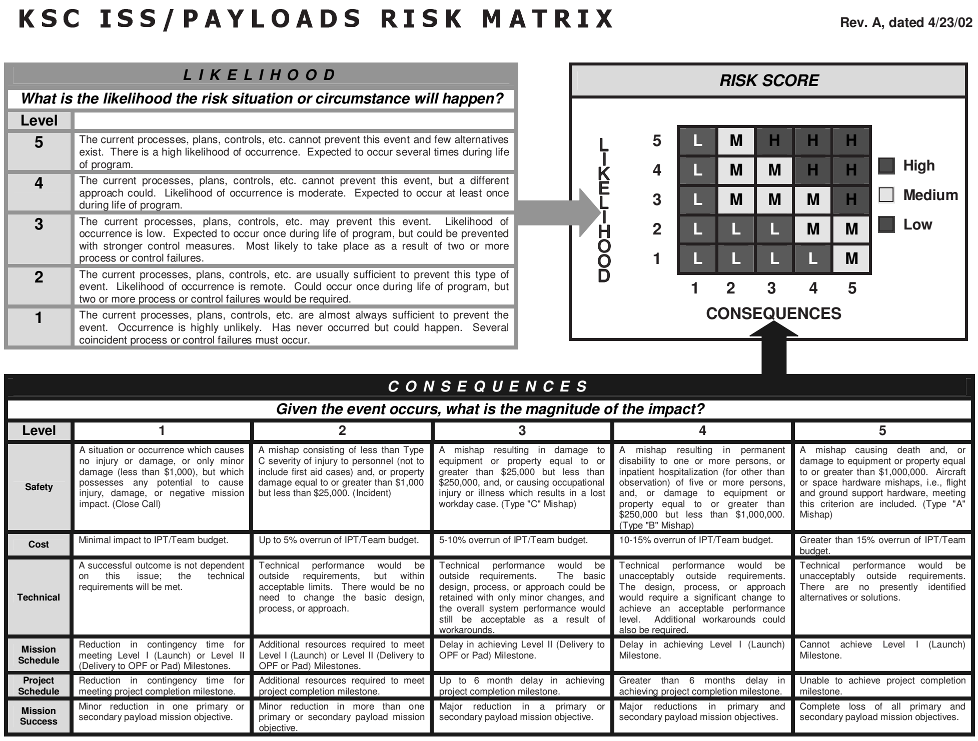


Figure E.1: NASA risk matrix

Orbiter To Lander S-Band Link			Comments
SSPA output power	2.00	W	S-Band SSPA Output Power
Output Losses	0.50	dB	Estimate of Filter and cable losses
Output Power	2.51	dBW	Calculated Output Power
Antenna Max Gain	3.00	dBi	Estimated Low gain antenna
EIRP	**5.51**	**dBW**	
Distance	10^7	m	Max range assumed = 10 000 km
Frequency	$2 \cdot 10^9$	Hz	Centre frequency
Free Space Loss	178.46	dB	Calculated
Atmospheric Polarization	0.00	dB	No Atmosphere
Atmospheric Loss	0.00	dB	
Total Losses	**178.46**	**dB**	
Boltzmann's Constant	-228.60	dB	Calculated
Data Rate	$2 \cdot 10^6$	Bits/s	2 MBits/s
Bandwidth to accommodate rate	10^6	Hz	QPSK
Bandwidth	60.00	dBHz	
kB	$-$ **168.60**	**dBKHz**	
rx G/T	**20.00**	**dB/K**	Guess of Satellite
Implementation Loss	**1.00**	**dB**	
Coding Gain	**5.00**	**dB**	Soft decision coding gain
SNR	**19.65**	**dB**	
Req'd SNR for BER = 10-5	**9.6**	**dB**	
Margin	**10.05**	**dB**	

Table E.1: Lander to Orbiter Link Budget

Orbiter To GEO Ka-Band Link			Comments
TWTA output power	55.00	W	Ka-Band TWTA Output Power
Output Losses	1.00	dB	Estimate of Filter and cable losses
Output Power	16.40	dBW	Calculated Output Power
Antenna Max Gain	58.00	dBi	Estimated Hi gain antenna. 3m diameter
EIRP	**74.40**	**dBW**	
Distance	9.00E+11	m	Max range assumed = 6Au
Frequency	3.000.E+10	Hz	Centre frequency
Free Space Loss	301.07	dB	Calculated
Atmospheric Polarization	0.00	dB	No Atmosphere
Atmospheric Loss	0.00	dB	
Total Losses	**301.07**	**dB**	
Boltzmann's Constant	-228.60	dB	Calculated
Data Rate	3.00E+05	Bits/s	300kBits/s
Bandwidth to accommodate rate	1.50E+05	Hz	QPSK
Bandwidth	51.76	dBHz	
kB	**-176.84**	**dBKHz**	
rx G/T	**55.00**	**dB/K**	Guess of GEO receive satellite
Implementation Loss	**1.00**	**dB**	
Coding Gain	**7.00**	**dB**	Soft decision coding gain
SNR	**11.18**	**dB**	
Req't SNR for BER = 10-5	**9.6**	**dB**	
Margin	**1.58**	**dB**	

Table E.2: Orbiter to GEO Satellite Link Budget

Orbiter To DSN Ground Station			Comments
HPA output power	55.00	W	Probable performance
Output Losses	1.00	dB	Estimated
Output Power per Ch	16.40	dBW	Calculated
Antenna Gain	58.00	dBi	Estimated for 3m antenna
EIRP	**74.40**	**dBW**	
Distance	$9 \cdot 10^{11}$	m	6 AU
Frequency	$3 \cdot 10^{10}$	Hz	Calculated
Free Space Loss	301.07	dB	Calculated
Atmospheric Polarization	0.50	dB	Estimated
Atmospheric Loss	1.09	dB	Estimated
Rain Loss	2.53	dB	Estimated
Total Losses	**305.19**	**dB**	
Boltzmann's Constant	-228.60	dB	Calculated
Data Rate	3.00E+05	Bits/s	
Bandwidth to accommodate rate	3.00E+05	Hz	
Bandwidth	54.77	dBHz	
kB	-173.83	**dBKHz**	
rx G/T	**65.00**	**dB/K**	Known value. [1]
Implementation Loss	**1.00**	**dB**	
Coding Gain	**7.00**	**dB**	
SNR	**14.04**	**dB**	
Req't SNR for BER = 10-5	**9.6**	**dB**	
Margin	**4.44**	**dB**	

1 deepspace.jpl.nasa.gov/dsndocs/810-005/104/104.pdf

Table E.3: Orbiter to Earth Link Budget

Activities	Budget	Partners	Product runs	Audience	Population Estimates	Perceived Impact/Benefits	Coordination budget for infrastructure	Comments on Space Agency Agenda: Audience need
Formal activities (academic institutions)								
Preassessment activities	50,000	Teachers college	3	k-12	100000	Assess public knowledge		
Vocabulary generating activities	50,000	Teachers college	3	k-12	100000	Provide vocabulary to use		
Build and design a diving robot with multiple materials	100,000	Science teachers association, LEGO	5	gr. 7 - 12	100000	Hands on activities that use design and build skills, corporate sponsor		
Careers in Science: Space has a Face	5,000	Professional engineering society	3	gr. 7 - 12	100000	Helps improve future job markets		
Curriculum kit on Radiation continuum	50,000	Project Universe	1	k-12	10,000	Designed so many countries can use it		
Curriculum kit on Contamination Concerns	50,000	Project Universe	1	k-12	10,000	Multiple languages		
Educational videos on above areas	250,000	Project Universe	1	k-12	1b	multiple languages		
Translation of selected materials in specified languages	100,000	University contracts	1			Language students translate as part of studies so hitting non scientific audience with information		Promotes immediate use of materials in partner countries
total							250,000	

Table E.4: Educational Implementation Budget Proposal

Activities	Budget	Partners	Product runs	Audience	Population Estimates	Perceived Impact/Benefits	Co-ordination budget for infrastructure	Comments on Space Agency Agenda: Audience need
Informal (after school hours)								
Information about Europa in packages for Scouts etc	20,000	NASA, ESA	1	gr 7 - 8	100,000	Earn badges for scouts, guides, astronomy clubs		
Museum activity centers	50,000	NASA, ESA	1	all	5,000,000	Multiple visits		
Science center outreach	50,000	NASA, ESA	1	all	5,000,000	Multiple visits		
translation of selected materials in specified languages	50,000	NASA, ESA	1			Caters to tourists from other countries, native language		
Total							250,000	One time Translation costs could be used years after the mission

Table E.5: Educational Implementation Budget Proposal, cont'd.

Activities	Budget	Partners	Product runs	Audience	Population Estimates	Perceived Impact/Benefits	Coordination budget for infrastructure	Comments on Space Agency Agenda:Audience need
General public outreach								
Europa Top Ten Trivia Contest in Media (mission patch)	75,000	NASA, ESA & other partners	2	gr. 7 - 12	1,000,000,000	Corresponds with what is happening schools		
Newspaper coverage of Robot Challenge			5	all	mass media	Final culminating task from schools in local-national competitions		
Magazine publishing of Science/Space related careers	10,000	Space periodicals	2	all	Mass media	exposure for perhaps less common careers		
Radiation continuum pamphlets:helpful - harmful	10,000	Cancer Society	1	households	mass media	Dual usage of radiation concept helpful radiation with sun at earth surface all the way to crashing orbiter into Europa		
Europa models, banners	10,000	Project Universe	1	all	mass media			
What if (we find life) public forum speakers series on line	10,000	Toast Masters	ongoing program	post secondary	1,000,000	Many opportunities for formal and informal debates		
High resolution photos	10,000	NASA, ESA	other partners	on going	all	Mass media & many ongoing uses of photos		
Translation of selected materials in specified languages	50,000	Community Language schools	1			International opportunities		Costs may not be as high here due to interest of various media to absorb costs
total							250,000	

Table E.6: Educational Implementation Budget Proposal, cont'd.

Appendix F

List of Acronyms

3D three dimensions

AAS American Astronautical Society

AAT Anglo-Australian Telescope

ACM Association of Children's Museums

ACP Aerosol Collector and Pyrolyser

AEB Agencia Espacial Brasileira

AFOE Advanced Fibre-Optic Echelle

AIAA American Institute of Aeronautics and Astronautics

AMCM Advanced Missions Cost Model. A simple NASA cost model for design and development of missions.

APXS Alpha Proton X-Ray Spectrometer

ASA Aerospace States Association

ASI/MET Atmospheric Structure Instrument/Meteorology package

ASJ The Astronomical Society of Japan

ASP Arizona Search for Planets

ASRI Australian Space Research Institute

ASTC The American Association of Science and Technology Centers Incorporated

AU Astronomical Unit

BAKSA Bahagian Kajian Sains Angkasa

BAMBI Bob And Mikes Big Investment. Amateur SETI.

BC Backward Contamination

BETA Billion channel Extra Terrestrial Assay. Radio telescope used to search for signals of civilisations.

BOL Begin of Life

BOSS Big Occulting Steerable Satellite

CAN Cooperative Agreement Notice

CAT Comet-Asteroid Transition Object

CEA Canadian Education association

CERN European Organization for Nuclear Research

CES ESO Coude Echelle Spectrometer

CFI CONTOUR Forward Imager

CFRP Carbon Fiber Reinforced Plastic. Composite material for structures.

CHZ Circumstellar Habitable Zone

CIA Central Intelligence Agency

CIDA Centro de Invetigacion y Difusion Aeronautico Espacial

CIDA Cometary and Interstellar Dust Analyser

CIRS Composite Infrared Spectrometer

CMES Council of Ministers of Education, Canada

CMEX Center for Mars Exploration

CNES Centre National d'Etudes Spatiales. French Space Agency.

CNSA China National Space Administration

CNTS Centre National des Techniques Spatiales

COMEST Commission Mondiale d'ethique des Connaissances Scientifiques et des technologies. World Commission on the Ethics of Scientific Knowledge and Technology.

COMPLEX The Committee on Planetary and Lunar Exploration

CONAE Comision Nacional de Actividades Espaciales

CONIDA Comicion Nacional de Investigacion y Desarollo Aeroespacial

CONTOUR COmet Nucleus TOUR

COPUOUS Committee on the Peaceful Uses of Outer Space

COROT COnvection ROtation and planetary Transit

COSETI Columbus-Ohio Optical SETI

COSPAR Committee on Space Research

CSA Canadian Space Agency

CTIO Cerro Tolono Inter-American Observatory

C Carbon

DFMI Dust Flux Monitor Instrument

DLR Deutschen Zentrum für Luft- und Raumfahrt. German Aerospace Center.

DNA deoxyribonucleic acid

DS1 Deep Space 1

DSN Deep Space Network. System large radio telescopes located around the world.

EAAE European association for Astronomy Education

EADS European Aeronautical Defence and Space Company

EANA European Exo/Astrobiology Network Associations

ECRS Earth Communication Relay Satellite. To communicate from Jupiter to Earth.

EMBL European Molecular Biology Laboratory

EOL End of Life

EPO Education and Public Outreach

ESA European Space Agency

ESO European Southern Observatory

ESRF European Synchrotron Radiation Facility

ETI Extraterrestrial Intelligence

ET Extra Terrestrial

EUVS extreme ultraviolet spectrometer

EUV Extreme Ultraviolet Spectrometer

EXPORT EXc-Planetary Observatory Research Team

FC Forward Contamination

FFT Fast Fourier Transform

FMS Fluorescent Microscopic System

FUCES Fundacion para la Ciencia y la Educacion Espacial

GAP Gas Analysis Package

GC-IR-MS Gas Chromatography-Isotope Ratio-Mass Spectrometryo

GCMS Gas Chromatograph and Mass Spectrometer

GC Gas Chromatography

GENIE Ground-based European Nulling Interferometer

GEST Galatic Exoplanet Survey Telescope

GHZ Galactic Habitable Zone

GNC Guidance, Navigation, and Control. Attitude and orbit determination and control for spacecraft.

GRS Gamma-Ray Spectrometer

HARP High Accuracy Radial velocity Planetary Search

HEPA High Efficiency Particulate Air. Describes filters and dehumidifiers used to minimize airborne microbial contamination and corrosion.

HGA high gain antenna

HPLC High Performance Liquid Chromatography

HST Hubble Space Telescope

H Hydrogen

IAA International Academy of Astronautics

IAF International Astronautical Federation

IAU International Astronomical Union.

ICAMSR International Committee against Mars Sample Return.

ICE International Cometary Explorer

ICSU International Council of Scientific Unions

IDP Interplanetary Dust Particles

INMS Ion and Neutral Mass Spectrometer

IRIS Infrared Interferometer Spectrometer and Radiometer

IR infra-red

ISAS Institute for Space & Astronautical Science

ISM Interstellar Matter

Isp Specific impulse. The efficiency of a rocket engine.

ISRO Indian Space Research Organisation

ISS International Space Station

ISU International Space University

ISYA International School for Young Astronomers

ITU International Telecommunications Union

JPL Jet Propulsion Laboratory

JSC Johnson Space Center

KAIST Korea Advanced Institute of Science & Technology

KSC Kennedy Space Center

LA-ICP-MS Laser Ablation Inductively Coupled Plasma Mass Spectrometry

LAPAN Lembaga Penerbangan dan Antariksa Nasional

LGM Little Green Men

LIDAR Light Detection and Ranging

LiU Life In the Universe

LM Lunar Module

MAP Multi-channel Astrometric Photometer

MAPS Multi-channel Astrometric Photometer and Spectrograph

MARIS Mars Advanced Radar for subsurface and Ionospheric sounding

MAWD Mars Atmospheric Water Detector

MEMS Micro Electro Mechanical Systems

META Mega channel Extra Terrestrial Assay. Radio telescope used to search for signals of civilisations.

ME Mars Express

MGS Mars Global Surveyor

Mg Magnesium

MNT Micro/Nano Technologies

MOC Mars orbiter Camera

MOLA Mars Orbiter Laser Altimeter

MOST Microvariability & Oscillations of STars

MO 2001 Mars Odyssey

MSFC Marshall Space Flight Center

MSS Masters of Space Studies

MST Micro Systems Technology

MS Mass Spectrometry

NAI NASA Astrobiology Institute

NASA National Aeronautics and Space Administration

NASBE The National Association of State Boards of Education

NASDA national Space Development Agency of Japan

NEAR Near Earth Asteroid Rendevous

NEA Near Earth Asteroid

NGIMS Neutral Gas and Ion Mass Spectrometer

NIMS Near-Infrared Mapping Spectrometer

NIS Near Infrared Spectrometer

NPD NASA Policy Directive

NRCT National Research Council of Thailand

NRC National Research Council. US scientific research council.

NSBA The National School Boards Association

NSF National Science Foundation

NGST Next Generation Space Telescope

NSPO National Space Program Office

NSRDA National Space Research & Development Agency

NSS National Space Society

N Nitrogen

OHP Haute Provence Observatory

OMEGA Infrared Mineralogical Mapping Spectrometer

OSETI Optical Search for Extra Terrestrial Intelligence

OST Outer Space Treaty. 1967 International United Nations treaty, dealing with States' space activities.

O Oxygen

PAW Payload adjustable Workbench

PCR Polymerase Chain Reaction

PFS Planetary Fourier Spectrometer

PLANET Probing Lensing Anomalies NETwork

PLUTO Planetary Underground Tool

ppm parts per million

PPPAI Past Present and Planned Astrobiology Investigations. Group name for individuals responsible for this research area.

PYR-GC-MS Pyrolisis-Gas Chromatography-Mass Spectrometry

RADAR Radio Detection and Ranging

RF Radio Frequency

RKA Russian Space Agency

ROM Rough Order of Magnitude. A rough estimate, often used to describe cost.

RTG Radioisotope Thermal Generator. Power supply for spacecraft.

S/C Spacecraft

SAL Sterility Assurance Level

SERENDIP Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations.

SETI Search for Extraterrestrial Intelligence

SIMS Secondary Ionization Mass Spectrometry

SIM Space Interferometry Mission

SIRTF Space Infra Red Telescope Facility

SLN Science Learning Network

SPARRSO Bangladesh Space Research & Remote Sensing Organisation

SPICAM UV and IR Atmospheric Spectrometer

SRF Sample Receiving Facility. A facility designed to quarantine and study samples returned.

SSP Summer Session Program

SSP Surface Science Package

SUPARCO Space & Upper Atmosphere Research Commission

TES Thermal Emission Spectrometer

THEMIS thermal Emission Spectrometer

TPF Terrestrial Planet Finder

TRIPS Trade Related Aspects of Intellectual Property Rights

TWTA Traveling Wave Tube Amplifier

UCLA Unversity of California, Los Angeles

UCSD University of California at San Diego

UFO Unidentified Flying Object

UMBRAS Umbral Missions Blocking Radiating Astronomical Sources

UNESCO United Nations Educational, Scientific, and Cultural Organization

UNISPACE United Nations Conference on the Exploration and Peaceful Uses of Outer Space

UN United Nations

USA United Space Alliance

US United States

USA United States of America

UVES Ultraviolet Visual Echelle Spectrograph

UVIS Ultraviolet Imaging Spectrograph

UVS Ultra Violet Spectrometer

UV Ultra violet

VIMS Visible and Infrared Mapping Spectrometer

VIS visible part of the electromagnetic spectrum for human beings

VLTI Very Large Telescope Interferometer

VLT Very Large Telescope

WBS Work Breakdown Structure. A graphical way to represent a work breakdown.

WIPO World Intellectual Property Organization

WTO World Trade Organization

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Index

S

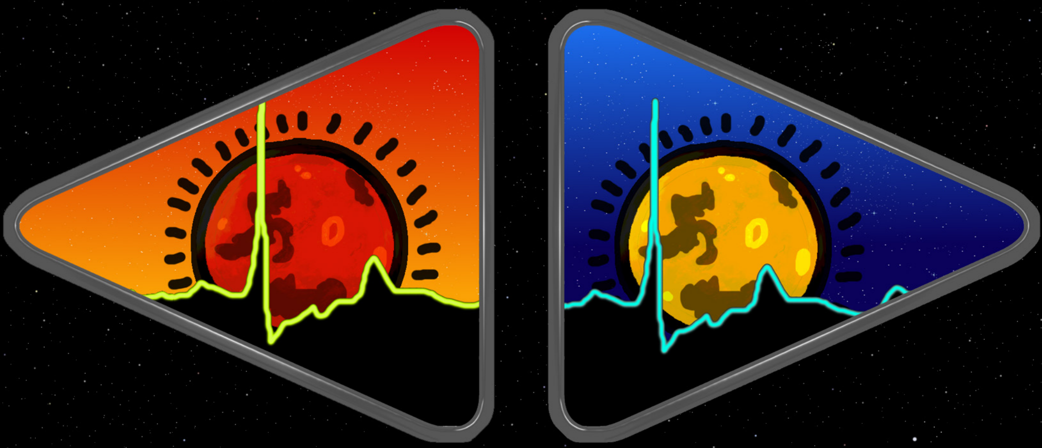
T

U

V

W

Z



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