Sujan Sengupta

Worlds Beyond Our Own

The Search for Habitable Planets

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To my daughter Roopsa and to all the kids of her generation
—Let us keep the Earth, our lonely and only home, habitable for the generations to come.

Preface

The whole universe has been a laboratory for the physicists. The motions of the planets in the solar system led Sir Isaac Newton to develop his laws of mechanics. Similarly, the theories of Special and General Relativity are tested in this cosmic laboratory. The physical processes inside a star have enriched our knowledge on nuclear and particle physics. Astrophysics is a branch of applied physics. However, in recent decades, this cosmic laboratory is used for research on chemistry and biology as well. Thus, astrochemistry and astrobiology, two subbranches, have emerged out. Astrochemistry describes the chemical processes in interstellar medium, planets, and in objects that are cooler than a normal star. Astrobiology has emerged out with the discovery of a large number of planets that appear to have an environment appropriate for the origin and evolution of life. Both the physical and chemical processes in a planet offer the possibility of initiating biological processes. Therefore, all the branches of science—physics, chemistry, biology, etc.—are applied to astronomy in order to answer an eternal question of mankind "Is anybody out there?" This exciting development that initiated a new era in astronomy has taken place due to the discovery of a large number of planets outside the solar system. These are the new worlds beyond our own. This has revolutionized our knowledge and understanding about planets, their climates, formation, composition, etc.

I am a professional astrophysicist trained to write highly technical research papers. Unfortunately, current research has become so technical that even another professional astrophysicist cannot understand a research paper fully unless she or he works on the same area of research. Such a technical research paper is reviewed, discussed, and cited by the astrophysicists working on the same area or field. However, when I deliver a lecture in a conference attended by colleagues with expertise on different aspects of astrophysics, I need to make the content quite a bit general. Similarly, when I deliver a lecture to a group of graduate students of science, I need to make the scientific descriptions and explanations even more general. Often the technical aspects are described by introducing analogy with events or objects that are easily understood by the students with basic or advance

knowledge on physics and mathematics. However, the task becomes gradually more difficult as the exposure and background of the audience change. From colleagues who work on the same area of research, to the colleagues who work on the same subject but on different area, to scientists working on different subjects, to students with background in physics or astrophysics, to students without specialization on physics, and finally to the students without any science background at all, the degree of difficulties in explaining the most recent developments in scientific research increases severalfold. Therefore, it is the most difficult job, a daunting task to describe and explain the most recent developments in science to laymen.

However, a scientist cannot escape her or his responsibility in reaching to the common people, in sharing the excitement of new discoveries to the common tax payers who contribute in funding most of the research works. On the other hand, the common men are always curious to know the newest discoveries, the newest developments in science and technology. It is no less than a thriller to most of them irrespective of their profession or academic background. As a consequence if scientists do not attempt to reach to the laymen, nonscientists often attempt to bridge the gap by writing popular science book. Once a news reporter, while interviewing me, enquired about my topic of research. I replied "I work on extra-solar planets, also on Brown Dwarfs." The next day it was published "Professor Sengupta works on extra-solar planets also known as Brown Dwarfs"! So scientific documents written by nonscientists may often have a danger of misinterpreting scientific results, even exaggerating the consequence of a new discovery and thus misleading and confusing the common people. This book is my humble effort to fulfill my responsibility of sharing the excitements of the most recent developments and discoveries on astronomy, especially on the planetary science. This is a new experience to me and so it has been a challenging task. On the other hand, by accepting this challenge, I have certainly become more vulnerable to criticism by professional astronomers.

This book is a culmination of several lectures that I delivered to a wide range of audiences—from experts working on my area of research to school students. Often I could not reply or explain several brilliant questions or inquiries by them during or immediately after my lectures. When I found an answer or a possible explanation after several days or months, I was unable to convey it to them. The frustration prompted me to think of writing this book. While writing this book, I imagined that I was delivering a lecture to an audience consisting of three different groups of people: to a group of scientists who were not aware of the current developments in the field of astronomy and in particular of the planetary science; to a group of science students or amateur astronomers who had no exposure to technical aspects and terminologies of advance research; and to a group of laymen who were averse to any unnecessary complexities and did not care about scientific terminologies and mathematical expressions. The first group of people may criticize me for not being able to explain many things properly, the second group may embarrass me by asking several questions beyond my knowledge and understanding and by contradicting my explanations, while the third group may prove that the "Emperor has no cloth." All are welcome.

This book should be read like a fiction or a story book. But unlike a fiction, all the objects and events described here are real. Also, unlike a story book, each chapter of this book is self-content. Therefore, readers may skip a chapter if it appears to be boring. For this purpose and for reminding the readers some important and related processes, some of the descriptions or explanations are intentionally repeated instead of asking the reader to go back to previous chapters. I hope the experts in this field will pardon me for this intentional repeats. I have put all my efforts to avoid any grammatical errors in the language. However, a few mistakes may still remain. I apologize for that. I hope the scientific contents of the book should dominate the mind of a reader over its literacy value if any.

At the end of the book, a list of websites has been provided. This is no way a comprehensive list but I took help from these websites. These websites may be considered as references for further reading. For the benefit of science students, some simple mathematical relationships and formulae are provided at the end. The main book, however, does not have any reference to these appendices. Therefore, readers without science background should skip these.

Quite a few publishers who invited me to write and publish a book with them strongly suggested to write a textbook and politely refused my proposal for publishing a popular science book for the laymen although astronomy is always a popular subject. I understand that the main reasons are the uncertainty in the marketing of a popular science book and my inexperience in writing any book before, text or popular. Springer has taken that risk and I am thankful to them for publishing the book. I thank Dr. Ramon Khanna, senior astronomy editor of Springer, for several suggestions and guidance.

The amateur astronomers around the world play a vital role in astronomy. Many of the comets, asteroids, and Near Earth Objects are discovered by them. They take active part in planet hunting and in the search for extraterrestrial life (SETI). While professional astronomical organizations such as NASA and European Space Agency (ESA) or European Southern Observatory (ESO) are very generous in providing permission to publish spectacular images of celestial objects, I thought publishing a few images taken by amateur astronomers would not only offer appreciation to their contributions but also might generate interest to common people towards making astronomy as a hobby. I am grateful to Mr. Efrain Morale Rivera of Aguadilla, Puerto Rico, for kindly providing permission to publish some astronomical images from his huge collection.

Ms. Sandra Rajiva, Mrs. Catherina Williams, and Ms. Aarti Dwivedi took the pain to read quite a few drafts of the manuscript and corrected the grammatical errors and suggested several changes in the language. I express my gratitude to them. Apart from the direct help that I received in completing the manuscript, a large number of astronomers motivated and inspired me. Prof. Ronald E. Taam has been a constant inspiration for me. I have learned a lot on various areas of astrophysics from him. I have learned a lot about extra-solar planets and Brown Dwarfs while collaborating with Dr. Mark S. Marley of NASA, AMES. The lengthy, penetrating, and illuminating discussions with Prof. Frank H. Shu during and after my lectures at Academia Sinica, Institute of Astronomy and Astrophysics,

Taipei, have enhanced my knowledge in great extent. I am also thankful to Prof. Vinod K. Gaur for many discussions that enriched my knowledge on the geology of the Earth and Mars. Back in my own country, working in a research institute which has the credit for the first false alarm of extra-solar planets reported some 150 years ago certainly has an advantage. I thank the present director of my Institute, Dr. P. Sreekumar, for his encouragement. Last but not the least I thank my wife Srirupa who took the responsibility of keeping the home in order single-handedly besides managing her career as a teacher.

I shall consider myself successful in this new venture if after reading this book the readers realize by their heart the urgent need of protecting our world, the Earth—an extremely rare planet born and privileged by cosmic coincidence and blessed by a divine process called life.

Bangalore, India Sujan Sengupta

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Prologue

Why Care About Other Worlds

"O thievist Night,
Why shouldst thou, but for some felonious end,
In thy dark lantern thus close up the star,
That nature hung in heaven, and filled their lamps
With everlasting oil, to give due light
To the misled and lonely traveller?"
—John Milton
(In *Comus*)

Any normal and developed brain is capable of generating curiosity towards any unknown object or phenomenon. Curiosity is generated by a conscious mind. Once it arises, one or more than one of the five major organs—eyes, ears, nose, tongue, and skin—try to find out an explanation of the object or the phenomenon. If all the organs fail to find out any satisfactory explanation or the primary explanation turns out to have no relevance to the need of the species, the curiosity dies. However, a human brain is much larger than that of any other primate and has much greater functionalities. It uses the information stored in its memory to make a logical sequence and attempts to explain the phenomenon even when the organs fail to analyze it. It is only the human species that can think. But if the information is not sufficient or intentionally not used, then the brain often uses a function—imagination which is probably unique to the human species. Imagination is also a part of thoughts. Unlike curiosity, imagination can be generated by a subconscious brain as well. Imagination gave birth to the concept of demons, gods, and subsequently religions. On the other hand, a combination of the available but insufficient information and imagination gave birth to philosophy.

The fact that the Sun makes the day and the night was realized by humans during the very primitive stage of their evolution. But nothing was known about the Sun and so people of almost all ancient or prehistoric civilizations imagined it as a powerful god. With the advent of agriculture, our ancestors started realizing that the

Sun played a more important role than just giving light and heat to the Earth. Subsequently, they realized the periodicity in the seasonal changes that affected their daily lives. The summer, the winter, and the rainy seasons appear periodically and last for a certain duration of time. So the humans could plan their activities accordingly. Sometimes the summer lasts longer causing damages to crops, sometimes little rain causes severe drought, and sometimes a longer winter causes complete freezing of rivers and lakes. The humans did not have control over such natural calamities. They imagined that the nature was controlled by some superpower, and so they resorted to appease it by prayer. However, the curiosity of the human brain could not be restricted to the surrounding natural phenomena that had direct impact upon their lives but often was extended beyond the objects and events that had no apparent or immediate consequence. In this way, the human beings got curious towards the vast empty space outside their world. They grew interest about the hundreds and thousands of small lights visible in the night sky. Regular observations of those lights provided them a little bit of information. They noticed that the relatively brighter lights moved in a periodic way in the sky while the faint and the twinkling lights remained stationary. With the passage of time, as they gathered more and more information, their understanding headed towards more and more accurate explanations. Thus, quite naturally, the eternal curiosity about other worlds beyond our own was generated. We start asking if there exists in the vast universe another place similar to the Earth, if there is life somewhere else in the universe, if there is intelligent life anywhere in the outer space, etc. As soon as it was established that the Earth was a planet rotating around a star, the Sun, we started believing that such type of planets must be there around the hundreds and thousands of stars in the sky and therefore existence of planets similar to the Earth was very much possible. But where exactly are they located and how are they? Do they harbor life? Although with the rapid advancement of science and technology, our knowledge on the outer space has been enriched enormously, the answer is still elusive. This prompted imaginations and speculations about other worlds, about different kinds of lives, about extraterrestrial intelligence, etc. These speculations or imaginations varied from time to time and from one civilization to other. More than five thousand years ago, the Sumerians imagined amphibian intelligent life with fishy heads but human feet. They were never considered as gods, but the Sumerians speculated that science, arts, and architectures all were taught to the humans by alien intelligent visitors. The Babylonians imagined that the moving lights in the sky were the homes of their gods. According to the ancient Greeks, the Moon was a home of the souls of the dead or the departed people. In fact the Greek philosophers imagined that the Moon had cities with civilized inhabitants. But we even do not know how life originated on planet Earth. The oldest imagination attributes the origin of life on the Earth to a superior being or spiritual force. Most civilizations and religions advocate such idea for the creation of the whole universe including life on the Earth. For example, the Hindus believe that gods and goddesses are superintelligent beings that created the universe, the Earth, and life on it. The speculations and imaginations that often lead to science fictions describe how extraterrestrial intelligence visited the Earth, initiated the origin and evolution

of life, and interacted with the human beings in developing various civilizations. The advent of space era has given rise to the imagination of spaceships of extra-terrestrial intelligent species visiting the Earth, and thus, Unidentified Flying Objects or UFO becomes a topic of interest among ordinary people. However, such type of speculations lacks any evidence for confirmation and is therefore beyond the scope of science. Nevertheless, the eternal question "Is anybody out there?" remains unanswered.

The whole universe, however vast it is, consists of matter and energy. Even the voids are filled by the relic of the energy that was originated during the very first few minutes after the birth of the universe. The birth event of the universe is popularly known as the Big Bang. Ordinary matter is made of two fundamental types of particles—quarks and leptons. Protons and neutrons are made of a combination of three out of the six kinds of quarks. Protons and neutrons together with electrons that belong to the lepton family make an atom. A few atoms combine to make a molecule. All ordinary matters including the living species are made up of molecules. The dynamic of everything, from the subatomic world to the whole universe, is governed by four fundamental forces—gravitation, electromagnetic, weak, and strong.

In the vast mysterious universe, we see stars, galaxies, nebulas, giant clouds of gas extended over billions of kilometers, planets, comets, asteroids, and several other celestial objects with different sizes, shapes, temperatures, and other properties. All these objects are made of atoms and molecules of various elements and compounds. However, out of all such celestial objects, nature has chosen a planet as the appropriate place for the origin, evolution, and survival of life. In other words, life in the form we recognize it can originate, evolve, and survive in an environment that is available only in a planet. On the other hand, we do not have any clue about life in a form other than what we see in our world. If life exists in a place other than a planet or in a planet that is much different than the Earth, it should have a different form and a different biology completely unknown to us. In fact, there is no way to recognize such a different kind of life if it exists elsewhere. Therefore, it is not possible to investigate or to search for life that is entirely different than that on the Earth. Under such a situation, a systematic and scientific search for life beyond our own world is restricted to the form of life that exists on planet Earth.

The subsequent chapters of this book will present our current understanding and progress towards a rational answer based on scientific analysis of information gathered by using the most advanced technologies available at present. The discovery of 51 Pegasi b, the first confirmed planet outside the solar system, has rekindled the eternal curiosity of mankind to know whether or not worlds similar to our own world exist beyond the solar system. Astronomers have detected more than a thousand of planets outside the solar system, and the number is increasing every month. This is not only taking us steps forward to answer that eternal question but also changing our concept on the nature of planets and planetary systems drastically. Many of the extra-solar planets discovered are entirely different than any of the solar planets. Our knowledge on this field is augmented by the discovery of another kind of celestial objects—"Brown Dwarfs" that very much resemble the

giant gaseous planet Jupiter. Brown Dwarfs are considered as the "missing link" between stars and planets. They are lighter than the lightest stars but at least 13 times heavier than Jupiter, although they are as small as Jupiter in size. Astronomers classify these two kinds of objects—Brown Dwarfs and planets—by a common term, substellar mass objects, because the mass of these objects is less than the mass of any star. In fact, the discovery of a large number of giant planets and Brown Dwarfs has revolutionized our understanding of planets to such an extent that the International Astronomical Union (IAU) was compelled to reconsider the definition of planets and to resolve that objects as small as Pluto, even though they orbit around the Sun just like the other large planets, could no more be considered as planets.

However, with the rapid discoveries of other worlds, our knowledge and understanding are changing beyond our imagination. Thus, a global definition of planets could be temporary. Therefore, IAU has limited the definition of planets only to our solar system. A consensus and firm definition of planets outside the solar system is yet to be worked out. In order to address the issue of the existence of life elsewhere, we not only need to find out the conditions under which life can originate, survive, and evolve but also need to address what we mean by life. Therefore, the answer to the question relies upon several factors that provide us a great realization about the uniqueness of our own world. Arthur C. Clarke commented "Two possibilities exist. Either we are alone in the Universe or we are not. Both are equally terrifying." On the other hand, in a vast galaxy containing billions of stars, most of which may have planets, finding another world that is blessed by life is extremely difficult even if the origin of life is a common phenomenon in the universe. That makes us lonely and insignificant. In the words of the anthropologist and naturalist Loren C. Eiseley (in The Immense Journey, 1957), "In a Universe whose size is beyond human imagining, where our world floats like a dust mote in the void of night, men have grown inconceivably lonely. We scan the time scale and the mechanisms of life itself for portents and sighs of the invisible. As the only thinking animals in the entire sidereal universe—the burden of consciousness has grown heavy upon us. We watch the stars, but the signs are uncertain. We uncover the bones of the past and seek for our origins. There is a path there, but it appears to wander. The vagaries of the road may have a meaning, however; it is thus we torture ourselves."