PLANETARY SYSTEMS AND THE ORIGINS OF LIFE

Several major breakthroughs in the last decade have helped to contribute to the emerging field of astrobiology. These have ranged from the study of micro-organisms, which have adapted to living in extreme environments on Earth, to the discovery of over 200 planets orbiting around other stars, and the ambitious programs for the robotic exploration of Mars and other bodies in our Solar System. Focusing on these developments, this book explores some of the most exciting and important problems in this field.

Beginning with how planetary systems are discovered, the text examines how these systems formed, and how water and the biomolecules necessary for life were produced. It then focuses on how life may have originated and evolved on Earth. Building on these two themes, the final section takes the reader on an exploration for life elsewhere in the Solar System. It presents the latest results of missions to Mars and Titan, and explores the possibilities for life in the ice-covered ocean of Europa. Colour versions of some of the figures are available at www.cambridge.org/9780521875486.

This interdisciplinary book is a fascinating resource for students and researchers in subjects in astrophysics, planetary science, geosciences, biochemistry, and evolutionary biology. It will provide any scientifically literate reader with an enjoyable overview of this exciting field.

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Contents

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978-0-521-87548-6 - Planetary Systems and the Origins of Life
Ralph Pudritz, Paul Higgs, and Jonathon Stone
Frontmatter
More information

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Preface

The inspiration for this book arises from the creation of the Origins Institute (OI) at McMaster University, which formally started operating in July 2004. Many of the greatest questions that face twenty-first century scientists are interrelated in fundamental ways. The OI was established to address several of these major interdisciplinary questions from within a broad framework of 'origins' themes: space-time, elements, structure in the cosmos, life, species, and humanity.

The origin of life has a privileged position in this great sweep of scientific endeavour and ideas. It addresses, arguably, the most surprising and most fundamental transition to have arisen during the entire evolution of the universe, namely, the transformation of collections of molecules from the inanimate to animate realm. Substantial progress in solving this great problem has been achieved relatively recently but may be traced back to ideas first proposed by Darwin. The great excitement in our era is the realization that physical properties of planetary systems play an important role in setting the stage for life, and that microbial life, on Earth at least, is incredibly robust and has adapted itself to surprisingly 'extreme' conditions. Progress can be traced to four scientific revolutions that have occurred over the last two decades:

(i) the discovery, since 1995, of over 200 extrasolar planets (one which is only 7.5 times more massive than the Earth) around other stars and the possibility that at least a few of these systems may harbour life-sustaining planets;
(ii) the discovery of extremophile microorganisms on Earth that have adapted to conditions of extreme temperatures, acidity, salinity, etc., which considerably broadens the range of habitats where we might hope to find life on other planets in our solar system and other planetary systems;
(iii) the rapid advances in genome sequencing that enable comparative analysis of large numbers of organisms at the whole genome level, thereby enabling the study of evolutionary relationships on the earliest branches of the tree of life; and

(iv) the enormous efforts being made by National Aeronautics and Space Agency (NASA) and European Space Agency (ESA) (and, more recently, the Canadian Space Agency (CSA)) to send robotic probes to search for water, biomolecules, and life on Mars and Titan and possibly the ice-covered, oceanic moon of Jupiter – Europa.

These are some of the major drivers of the emergent science of astrobiology and were the central themes explored during the two-week conference and workshop sponsored by the OI and held at McMaster University in Hamilton, Ontario, Canada, on 24 May–4 June 2005. Our conference featured invited review lectures as well as invited and contributed talks from many of the international leaders in the field (for a full list, please consult the conference internet site at http://origins.mcmaster.ca/astrobiology/).

How to use this book – a user's manual

The chapters of this book are derived from invited, one-hour review talks, as well as a few invited shorter talks, given at the conference. These constitute an outstanding set of lectures delivered by masters of fields such as planetary science, evolutionary biology, and the interdisciplinary links between the two. One of our major goals was to create a volume that would be useful for teaching an interdisciplinary audience at the level of senior undergraduate or junior graduate students. Our intent was to capture the exciting interdisciplinary research atmosphere that attendees experienced at the conference and, thereby, create a volume that is an excellent resource for research. The OI plans to use this volume for a third year undergraduate course about the origins of life, which will be offered for the first time in 2006. The authors were all aware of these two aspects of the book as they prepared their manuscripts. To accommodate and educate a broad interdisciplinary audience, we have tried to ensure that technical jargon is kept to a minimum without compromising scientific accuracy and a clear analysis of the important principles and latest results at an advanced scientific level.

The editors made every effort to keep the authors of individual chapters informed of the content of related chapters. All of the chapters in this book were peer reviewed by arm's-length experts in relevant fields. In addition to receiving useful referee reports, the authors also received comprehensive comments from the editors designed to help integrate their chapters with other related chapters. We hoped by these means to create an integrated book of the highest scientific standard and not just a collection of unrelated review talks that are typical of many conference proceedings. The users of this book will be the ultimate judges of how well we succeeded in attaining this goal.

There are three parts of this book. The first takes the reader from the domain of planetary systems and how they are formed, through the origins of biomolecules

and water and their delivery to terrestrial planets. It then focuses on general questions about how the genetic code may have appeared and how the first cells were assembled. These chapters marshal general arguments about the possible universality of basic processes that lead to the appearance of life, perhaps on planets around most stars in our Galaxy and others.

The second part – life on Earth – begins with an exploration of microbial life on our planet and how it has adapted to extreme environments. These are analogous to environments that will be explored on Mars and other worlds in the Solar System. The part then moves on to the results of genomics – as exploited by phylogenetic methods. This allows us to explore the interrelationships of organisms to try to create a tree of life. This is central to efforts designed to address what the earliest organisms might have been like, and two chapters are devoted to such issues. This part then moves on to explore ideas on how metazoans originated approximately 560 million years ago.

The topic of the final part of the book – the search for life in the Solar System – constitutes a synthesis of those from the first two parts and lies at the heart of modern 'astrobiology'. Its four chapters review the latest results on the physical environments and the search for life in the Solar System, specifically on Mars, Titan, and Europa.

Acknowledgements

There are many people to thank for helping to put together the conference out of which this book originated. Financial support for sponsoring research conferences and workshops run by the OI comes ultimately from the Office of the Vice President Research at McMaster University – Professor Mamdouh Shoukri. We are indebted to him for his keen interest and support in helping us launch the OI and this first conference.

The scientific organizing committee for the conference consists of OI members – who are also faculty members in departments across the Faculty of Science. The list of orgnanizers is:

- Professors Paul Higgs and James Wadsley of the Dept. of Physics and Astronomy
- Professors Brian Golding and Jonathon Stone (also the Associate Director of the OI) from the Dept. of Biology
- Professor Ralph Pudritz, the chair of the organizing committee, Director of the OI, and member of the Dept. of Physics and Astronomy

The hard work and scientific insights of these committee members were essential in driving the very successful conference programme, discussions, workshop, and, ultimately, the foundations of this book.

The enormous amount of work in actually organizing and running this international conference and workshop was carried out with great skill and dedication by two outstanding individuals:

- Ms Mara Esposto, administrator for the Dept. of Physics and Astronomy and part time administrator support for the OI and
- Ms Rosemary McNeice, the OI secretary and also secretary in the Dept. of Physics and Astronomy.

The design of the posters and website was carried out by:

- Mr Steve Janzen, graphic designer and media production services at McMaster, as well as by
- Mr Dan O'Donnell, an undergraduate physics and astronomy student. Dan also performed all of the many tasks needed to keep the conference website updated, and ran all of the audiovisual equipment at the conference.

Ultimately, the value of this book rests with the outstanding efforts and insights of our chapter authors, all of whom wrote admirable contributions and did a lot of extra work in addressing referee and editorial reports. The editors could not have finished this book without the outstanding services of Dan O'Donnell who performed all the LaTeX formatting required for this volume.

Finally, we wish to thank our excellent editors and assistants at Cambridge University Press for their interest in this volume, for their patience and many helpful suggestions, and for their quick responses to the many issues that came up in producing this volume. We thank in particular Miss Jacqueline Garget, who was the commissioning editor for astronomy and space science in charge of the Astrobiology series and whose early interest in our proposal helped to launch this volume. We also thank Vince Higgs, editor, astronomy and astrophysics who followed Jacqueline as well as his assistant, Ms Helen Morris (publishing assistant, physical sciences), for all of their help. Their continued support and help has been most welcome.

We close this preface with the hope that the reader of this volume will find much fascination, inspiration, and enjoyment in its pages. The scope and promise of this vibrant new area of science is extraordinary. We, as editors as well as authors, enjoyed our task and feel privileged to have worked with so many outstanding individuals during this project.