Origins of Life in the Universe

Origins of Life in the Universe traces the evolution of the Cosmos from the Big Bang to the development of intelligent life on Earth. Conveying clear, concise science in an engaging narrative it maps the history of the Universe for introductory science and astrobiology courses for non-science majors.

What is the origin of the Universe? How do stars and planets form? How does life begin? How did intelligence arise? Are we alone in the Cosmos? Physics, chemistry, biology, astronomy, and geology are combined to answer some of the most fascinating questions in science and create a chronicle of events in which the swirling vapors in the primordial cloud of the Universe evolved over billions of years into conscious life. Coverage of the latest discoveries in astrobiology give a sense of the excitement of this fast-moving field.

ROBERT JASTROW, internationally acclaimed as an astronomer and popularizer of science, was the founder of the Goddard Institute for Space Studies, a US Government laboratory charged with carrying out research in astronomy and planetary science. He has authored several books that have made science accessible to a wider audience, and has been a frequent commentator on science news. His research spanned nuclear physics, planetary science, atmospheric physics, weather and climate prediction.

MICHAEL RAMPINO is an Associate Professor of earth science and biology at New York University, and a Research Associate at GISS in New York. His research spans many areas of the earth sciences, especially the inter-relationships between Earth's changing environments and the evolution of life. He is Series Co-Editor for the highly acclaimed *Encyclopedia of Earth Sciences* (Springer) and the Editor-in-Chief of the *Earth Science Encyclopedia On-Line.*

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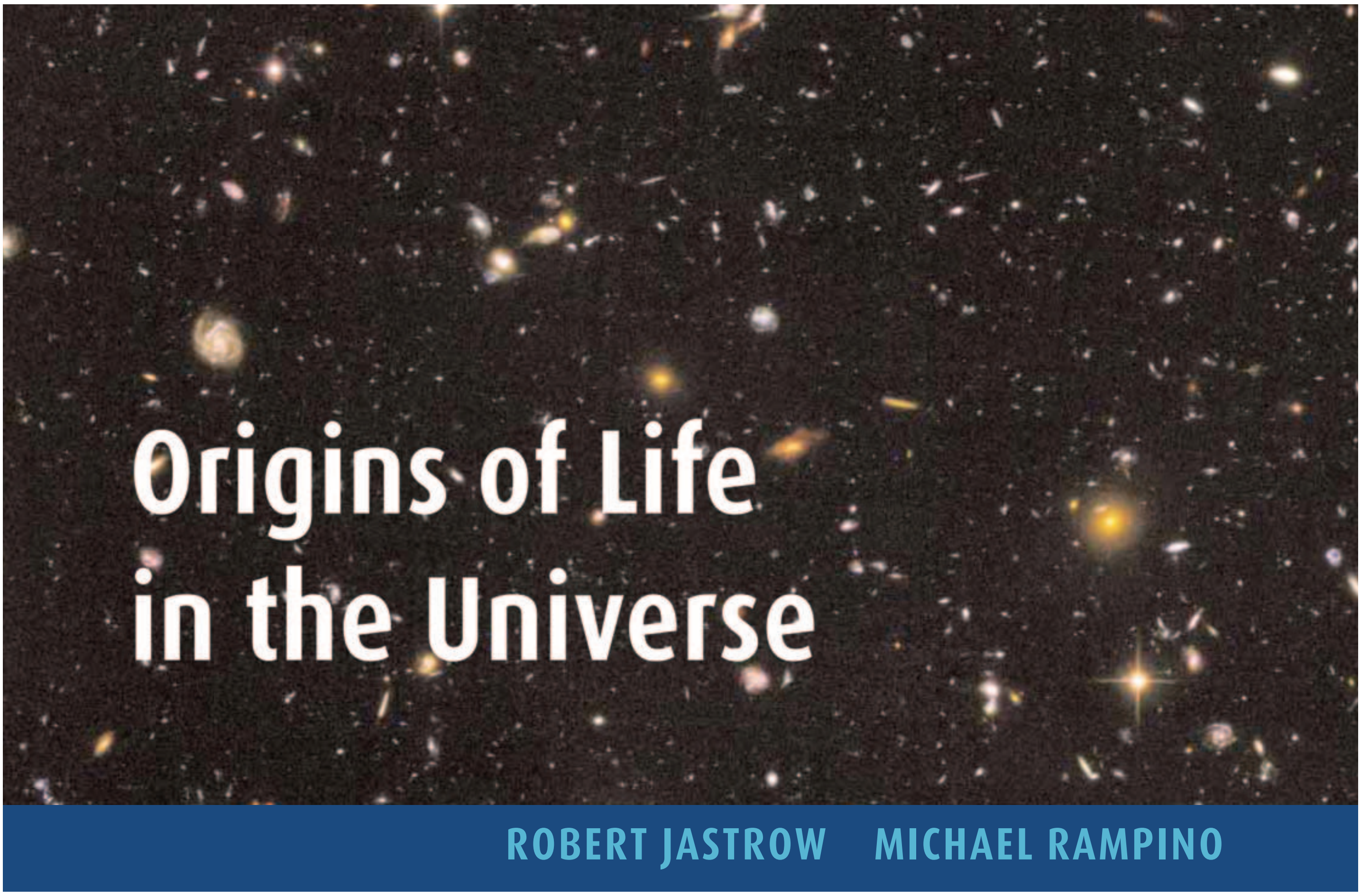

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Foreword

For most of us, our daily lives are carried out within a space of a few miles – our lifetimes measured in a few tens of years. Science enters our lives as a supplier of ever-newer conveniences for living and of modern medical treatment if we become ill. A non-scientist might choose to take these things for granted, and get on with his or her life. Why then devote time and energy to the study of science, and in particular to astrobiology and the history of the Universe?

The answer is that astrobiology will introduce you to new visions of the Universe that are grand and inspiring. Beyond Earth, lies an endless parade of glittering stars and galaxies. Among them are worlds, some like our own, others strangely different, which may also harbor life, even intelligent life. A person who is unaware of these prospects would be similar to someone who attended a concert wearing earplugs, or who traveled to a land rich in beauty and history, but stayed entirely in their hotel room.

For those who wish to take their minds on a more adventurous journey, this text will provide an admirable guide. I have known Bob Jastrow and Mike Rampino for years and admired the breadth of their interests, which range from the birth of stars to the extinction of the dinosaurs. I commend you into their expert care, and trust that you will have a magnificent trip.

Robert Shapiro
Professor Emeritus of Chemistry, New York University

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Preface

Origins of Life in the Universe deals with the developing field of astrobiology – the study of the scientific disciplines bearing on the emergence of life and intelligence in the Cosmos. It combines material from the traditional disciplines of physics, chemistry, biology, astronomy, and geology to create a chronicle of events in which swirling vapors in the primordial Universe evolved over billions of years into conscious life on Earth.

The book is written to support an introductory science course aimed specifically at non-science students. In it, the basic facts and concepts of the major scientific disciplines are taught as a connected narrative – the story of the evolving Universe from the Big Bang to the appearance of intelligent life. In this book, facts and concepts in separate disciplines are taken up in a natural sequence as needed to advance the narrative. The book addresses some of the most fascinating and fundamental questions in science: What is the origin of the Universe? How do stars and planets form? How does life begin? How did intelligence arise? Are we alone in the Cosmos?

According to the scientific evidence, the story began approximately 14 billion years ago, when the Universe expanded in the aftermath of the cosmic explosion known to astronomers as the Big Bang. In a material sense, the seed of everything that has happened in the last 14 billion years can be traced back to the moment of the Big Bang; every star, planet, and living creature in the Universe came into being as a result of events set in motion at that moment.

What was the cause of the cosmic explosion? What was the Universe like before the explosion occurred? Did the Universe even exist before that moment? These questions are at the forefront of astrophysical research. The answers remain among the greatest of scientific mysteries. In contrast, the collective labors of scientists in the modern era have yielded a detailed account of the events that followed the cosmic explosion. The Universe expanded rapidly outward from a hot, dense state, cooling as it expanded. Initially there were no galaxies, stars, or planets. But after about a billion years, the expanding cloud of matter and energy had cooled sufficiently to permit the formation of condensed knots of matter held together by gravity. These were the first galaxies and stars.

Another 8 or 9 billion years went by, and then, some 4.5 billion years ago, the Sun and its planets, including Earth, appeared as inconspicuous condensations in an undistinguished spiral galaxy – one among billions of galaxies, each containing hundreds of billions of stars.

At some point in the first billion years after Earth formed, life appeared in the waters covering its surface. We know this from the fossil record. How was that life created out of inanimate matter? A number of plausible theories exist, but we still cannot say which, if any, of these ideas is correct.

Once across the threshold of life, the scientist picks up the trail again. The remains of simple, bacteria-like organisms appear first in the record of the rocks about 3.5 billion years ago; traces of soft-bodied many-celled organisms are preserved in rocks about 600 million years old. A little later, about 540 million years ago, the remains of the first marine animals with hard shells and skeletons appear in the record. From this point on, the record of the history of life is fairly complete, until finally the remains of the first creature with a human level of intelligence are found in rocks about one hundred and fifty thousand years old.

All the larger trends in this history are clearly exhibited in the fossil record. This is particularly true of human ancestors, of whom essentially nothing was known when Charles Darwin first developed his theory of evolution by natural selection. Discoveries in recent years have filled in much of the missing record of human origins. Some gaps exist, but new finds are made nearly every year.

As scientists, we have both been involved in research in fields related to astrobiology. Jastrow, as director of NASA's

Goddard Institute for Space Studies and The Mount Wilson Observatory, directed cutting-edge research in astronomy, planetary science, and geology, and was the first chairman of NASA's Lunar Exploration Committee. Rampino has done geological fieldwork on six continents investigating volcanic activity, the record of climatic change, and role of catastrophic events in the history of life.

We hope that this book and the story it tells will convey to students the excitement and sense of wonder that we feel when we contemplate our long cosmic history. Our combined experience, based on teaching introductory college science courses over a period of 25 years, indicates that this chronological narrative of the evolution of the Cosmos strongly appeals to students with a wide variety of backgrounds and interests.

During this time, we have also developed supporting materials, including end-of-chapter questions with answers, and additional questions at www.cambridge.org/jastrow.

Many colleagues helped us with the preparation of this volume. We are particularly indebted to several people who were kind enough to take the time required for a careful reading and the preparation of detailed criticisms of individual chapters, and eventually the entire text. These include Dr. Richard Stothers and Dr. Andre Adler for the chapters on the contents of the Universe, cosmology, and the birth and death of stars; Dr. Michael Gaffey for the chapter on the Solar System; Dr. Christian Koeberl for the chapter on the Moon; Dr. Vivien Gornitz for the chapters on Mars and Venus; Dr. Dennis Kent for the chapters on the geology of Earth and plate tectonics; Drs. Andre Lapenis and Tyler Volk for the chapter on climate; Drs. Robert Shapiro, Edward Berger, and Stephen Small for the chapter on the origin of life and evolution (Dr. Shapiro made considerable contributions to that chapter); Dr. Nick Butterfield for the chapter on the early history of life; Dr. David Varricchio for the chapters on the dinosaurs and mammals; Dr. Donald Johansson for the chapter on human evolution; and Dr. Robert Shapiro for the chapter on life in the Cosmos.

Earlier versions of the manuscript were used as class notes for introductory level science courses at Columbia University,

Dartmouth College, and New York University. We thank our students and teaching assistants for their many comments and criticisms of the material as we continued to refine it.

We are especially indebted to Matt Lloyd, our editor at Cambridge University Press, whose detailed reading and criticism of the entire manuscript strengthened the book enormously.