The Search for Life on Other Planets

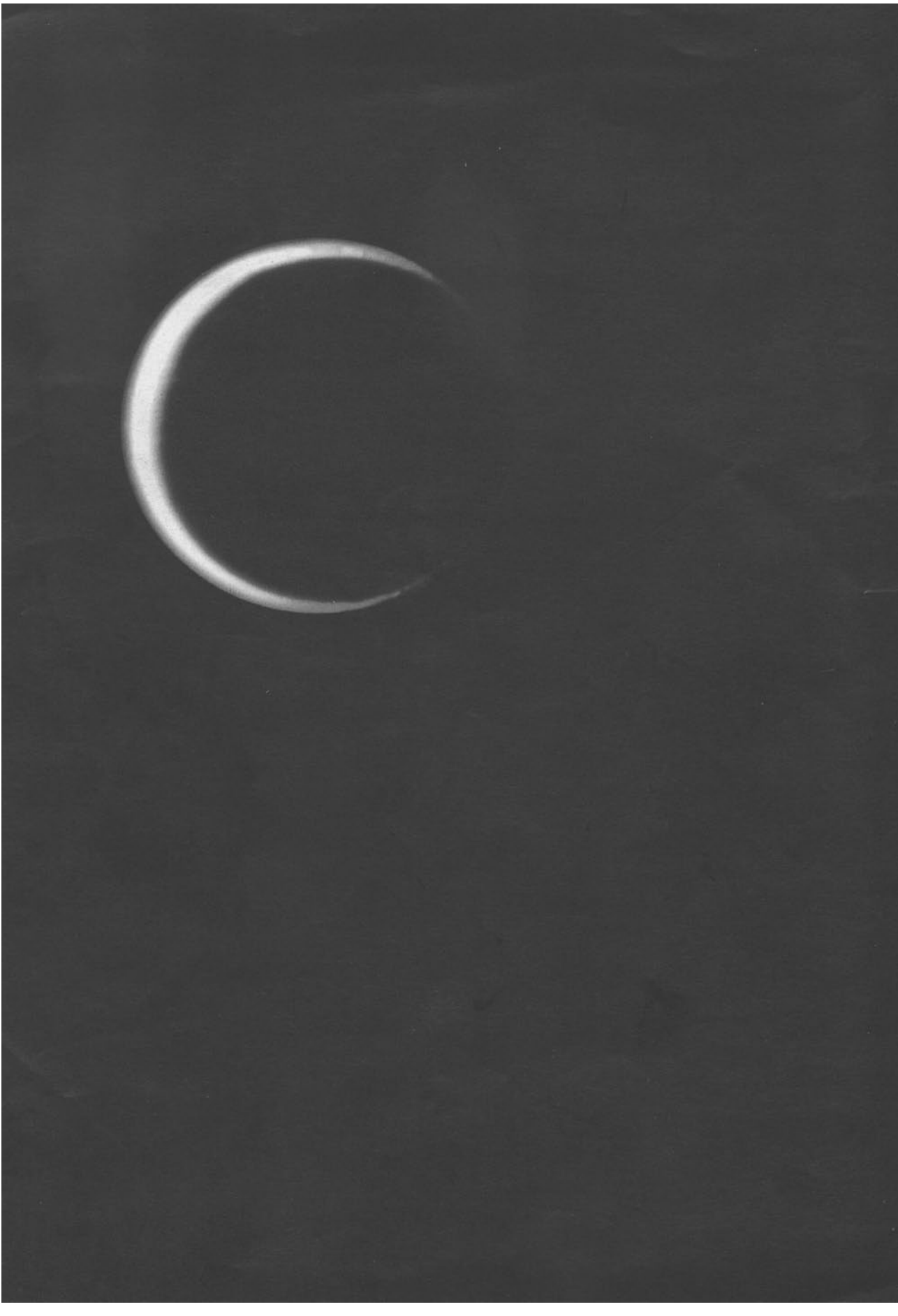
Does life exist on other planets? This topical book presents the scientific basis for thinking there may be life elsewhere in the Universe. It is the first to cover the entire breadth of recent exciting discoveries, including the discovery of planets around other stars and the possibility of fossil life in meteorites from Mars.

Suitable for the general reader, this authoritative book avoids technical jargon and is well illustrated throughout. It covers all the major topics, including the origin and early history of life on Earth, the environmental conditions necessary for life to exist, the possibility that life might exist elsewhere in our Solar System, the occurrence of planets around other stars and their habitability, and the possibility of intelligent extraterrestrial life.

For all those interested in understanding the scientific evidence for and likelihood of extraterrestrial life, this is the most comprehensive and readable book to date.

BRUCE JAKOSKY is a Professor of Geology and a member of the Laboratory for Atmospheric and Space Physics at the University of Colorado. There, he teaches both undergraduate and graduate level courses in geology and planetary science. He has been at CU since 1982, after receiving his Ph.D degree from Caltech. He began Mars research working on the *Viking* mission to Mars in 1975 as an undergraduate at University of California at Los Angeles. Today, he is trying to understand the nature and evolution of the martian climate and its volatile history, and the connection between the geology and possible biology on Mars. He has been involved with a number of spacecraft missions, including *Clementine*, *Mars Observer*, and the *Mars Global Surveyor*.

Professor Jakosky was born in Washington D.C. and grew up in Southern California. He lives with his spouse in Superior, Colorado, where he is one of the few people who don't ski.



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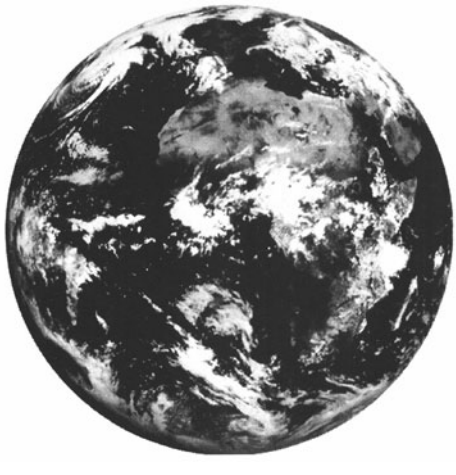

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Preface

The possibility that there might be life on other planets has become a major topic of public debate since 1995. The two specific incidents that triggered the discussions were the discoveries of planets around other stars and of possible fossil evidence in meteorites that have come from Mars for life there. Neither of these discoveries, however, provides compelling evidence for the existence of extraterrestrial life, and it is unlikely that the existence of life elsewhere will be confirmed before the end of the century. Despite these uncertainties many, if not most, scientists believe that it is very likely that life exists.

The sudden emergence of the topic of life on other planets as a major issue in our society really is more a matter of public awareness rather than of scientific advance or discovery. The issues related to life on other planets – the origin and early evolution of life on Earth, the environmental conditions required for the existence of life, the occurrence of these conditions on other planets in our solar system, the formation of planets and their possible existence around other stars, and the nature of intelligent life – have been of considerable scientific interest for a long time, and considerable efforts have been ongoing in each of these areas for decades. Within the last decade, especially, new advances in planetary science and in terrestrial biology have pointed toward the possibility of extraterrestrial life. It is only with the recent discoveries, though, that the issue has bubbled up again into the realm of public awareness.

Within the mainstream planetary science community, many of the issues related to life in the universe have, in turn, been shunned and embraced. In the years following the *Viking* spacecraft mission to Mars in 1976 to look for life, very few planetary scientists were working on questions pertaining to life on other planets and there was very little crossover between planetary science and exobiology or origin-of-life research. Since the mid-1990s, however, there has been much more crossover, and the biological questions have come to the forefront again. Although cynics will argue that this is merely a play for more funding and public attention, rather it appears to be due largely to the strength of the intellectual arguments that point to the possibility that life could exist elsewhere. These issues center on the ease with which life arose on Earth, the likely occurrence of the environmental conditions necessary for an origin of life elsewhere in our solar system, and the likely existence of planets orbiting other stars that also share these conditions.

Certainly, my own views have followed this evolution. When I became involved in planetary science research during the *Viking* era, it quickly became clear to me that the path to respectability lay in not pursuing exobiological issues. When I began teaching a decade later, my undergraduate

course in controversial issues in planetary science focused exclusively on the geological questions. The strong connection between planetary science and biology, though, became clear with the discovery that an asteroid impact must have played a major role in the extinction of the dinosaurs (and other species) some 65 million years ago. Teaching introductory geology to first-year students helped underscore to me that the connections on Earth between the geological and the biological events of the last 4 billion years were strong. Over time, the question of life on other planets pushed its way more and more into my planetary course until, this year, it was taught under the name "Extraterrestrial life".

This book grew out of the background that was necessary in order to teach the material, combined with the lack of a suitable text. My goal in writing this book is to provide an introduction to the questions of life on other planets at a level suitable for the educated public or for an undergraduate college course for non-majors. This book also should be suitable as an introduction to the major questions and an entry into the literature for graduate students, since most graduate students will not be well versed in all of the areas touched on here.

Although the question of life in the universe could be approached from the perspective of chemistry, biology, geology, or astrophysics, I've taken a "planetary" approach to it. This involves looking at the nature of the interactions between chemistry and biology and the evolution of planets as a whole. This approach should be complementary to those taken elsewhere and, especially, with the vast literature at all levels on the origin of life on Earth.

The book divides naturally up into several topics – the origin and early evolution of life on Earth; environmental conditions necessary for life; the possibility of life on other planets in the solar system; the occurrence of planets around other stars, their habitability, and the possibility of life there; and the nature of intelligent life and the philosophical implications of finding life. Some of these topics are treated in much more depth than others, consistent with our current level of understanding and with the "planetary" approach taken here.

I have not tried to reference each idea back to its original source or to use embedded references. The range of topics is so broad that, if I did, the reference list would comprise several thousand references. Rather, I've provided a representative list of references for each chapter. Some will provide introductory information for someone not familiar with the field at all, while others include some of the most important papers at the most detailed level of understanding.

I would like to take this opportunity to thank those who have helped me

to understand some of the issues raised here, sometimes explaining them to me quite patiently. In particular, I very much appreciate discussions with Tom Ayres, Sue Barnes, Mike Carr, Phil Christensen, Bill Cochran, David Des Marais, Jack Farmer, David Grinspoon, Kevin Hutchins, Chuck Klein, Paul Lucey, Jane Luu, Geoff Marcy, Hap McSween, Mike Meyer, Mark Miesch, Ken Nealson, Norman Pace, Cora Randall, Nick Schneider, Everett Shock, Bill Schopf, Steve Squyres, Glen Stewart, and Richard Zurek. I am grateful for comments on early versions of individual chapters or of the entire text to Mark Bullock, Mike Carr, Frank Crary, Kevin Hutchins, Jim Kasting, Geoff Marcy, Chris McKay, Ken Nealson, Frank Palluconi, Nick Schneider, and Len Tyler. Of course, any remaining misunderstandings, inconsistencies, or mistakes are my own. I also would like to thank Adam Black, my editor at Cambridge, for his valuable support and suggestions at all stages of writing this manuscript, and David Underwood in the Graphics Department at CU for his assistance in putting together the images and figures. In addition, I thank Heather Weisacosky for her valuable assistance at all stages of writing the manuscript, including tracking down references and papers in the literature, helping with figures, and reading and editing the entire text.

Last, but certainly not least, I am grateful to Jane Karyl for her support and encouragement during the entire writing process.

Bruce Jakosky