The Search for Life in the Universe

THIRD EDITION

DONALD GOLDSMITH and TOBIAS OWEN

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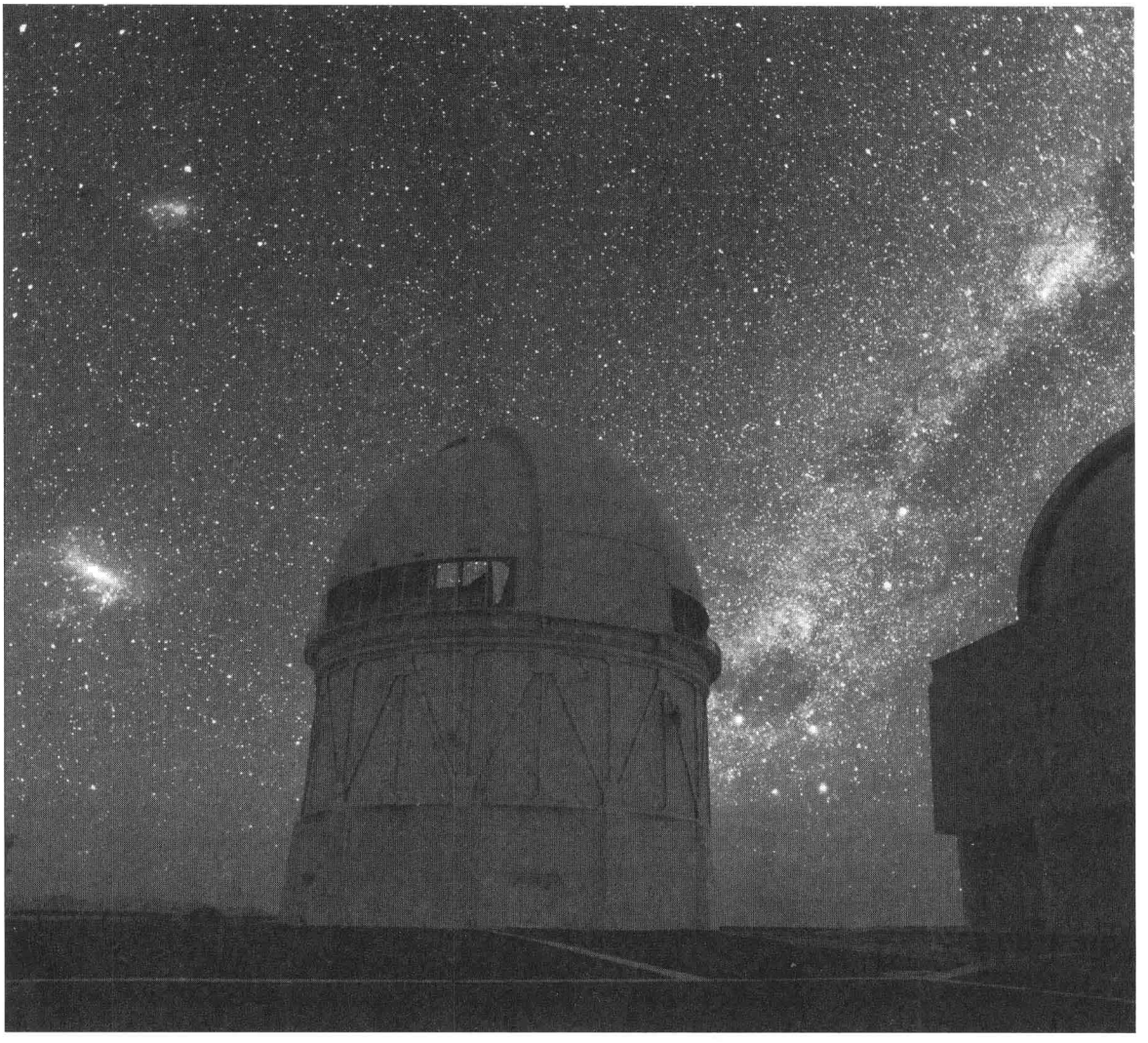

To our children—Rachel, David, Jonathan, and Kirill—
and to the memory of Giordano Bruno, burned
at the stake on February 17, 1600.
Bruno is best known to posterity for his
assertion that the cosmos contains
multitudes of inhabited worlds.

Foreword

WE LIVE IN HEADY AND EXCITING TIMES. Today scientists seriously consider whether they may soon have a sample of an alien biology to study: life from another world. Some of these scientists are old enough to remember that when the famous biologist Joshua Lederberg coined the term *exobiology,* it was ridiculed as "a science without a subject." The scientific tide has turned, and today there is growing enthusiasm for trying to find out whether life exists elsewhere in the universe.

Life as we know it is a planetary phenomenon. The Earth has hosted life and has strongly influenced its evolution for the past 3.8 billion years. Life in its turn has significantly modified its host planet. At one time, life may have called the surface of the planet Mars home, and some scientists speculate that Mars may still harbor life, deep beneath its surface, where liquid water might persist today. Europa and Callisto, two of the planet-sized moons of Jupiter, may have oceans of liquid water, and possibly even life, beneath their icy exteriors. With only our single example of terrestrial biology to guide us, our search for life beyond the Earth must start with searching for "habitable," planet-like places. As we learn more about life on Earth, and as we begin to appreciate how tough and opportunistic it is—living around the scalding-hot vents of the deep ocean floor, in sulfurous hot springs, in the radioactive cooling water of nuclear reactors, and within rock miles beneath the Earth's surface—our definition of "habitable" expands.

During the past five years, the number of planets known to be orbiting other stars like our own sun has grown from 0 to more than 50! The biases imposed by our instruments have thus far excluded detection of other solar systems like our own. Before another decade passes, however, we should know whether other worlds similar to the Earth are common or rare in our Milky Way galaxy. This is a key piece of information.

The universe is vast and old. Humans are newcomers on the scene. Throughout our short history, we have looked to the heavens and wondered whether we are alone. Over the millennia there have been many religious and secular belief systems whose leaders have offered their own answers to this question. Increasingly throughout the twentieth century and into the twenty-first, partial answers of a different kind have been pieced together. Answers based on observation, experiment, and rigorous scientific study have emerged in fields as diverse as molecular biology and high-energy astrophysics. The authors of this text, Donald Goldsmith and Tobias Owen, introduce you to our current understanding of humankind's place in the cosmos, and provide perspective by showing how our ideas have changed over time and where they are likely to change again in the future. To do this it is necessary to consider scales of space and time so vast that they are measured in the billions, as well as scales so tiny that we measure them with billionths; we must consider both the universe and the world of viruses. Some of the claims in this text may

seem quite incredible, but the authors provide the evidence to back up their claims. When they speculate, they tell you so, and illustrate the difference between *scientific* speculation and *random wild ideas*. If you take nothing more away from your interaction with this text and these authors than an enhanced capacity for critical thinking, you will be well served.

I have been fortunate enough to spend my scientific career in a search for intelligent life elsewhere. All of us working on the search for extraterrestrial intelligence (SETI) search by looking for some evidence of another technology; if we find it, we can infer the existence of intelligent technologists. Although we can and do make guesses (such as looking for radio signals), we don't necessarily have to know what that technology is. In fact, if another technology were sufficiently advanced, we would be unable to conceptualize it! But by observing the universe, it may be possible to detect anomalies for which the simplest explanation is astro-engineering, rather than astrophysics. That approach requires that we start with a good understanding of the observed universe, such as the one provided by this textbook.

The fact that radio SETI searches have been going on for over 40 years, and searches for short optical pulses for a few years, so far without success, might indicate that other intelligent civilizations do not exist, but it is far too soon to draw that monumental conclusion. It also might mean we haven't searched well enough or in the right way. We are a very young technology in a very old galaxy. Our ability to search for other technologies is quite primitive. In fact, we have yet to explore our own cosmic neighborhood systematically. Our tools are getting better, and as Giuseppe Cocconi and Philip Morrison stated in the first SETI paper to appear in a refereed journal, "The probability of success is difficult to estimate, but if we never search the chance of success is zero." I'm enthusiastic about continuing the search. Scientists and engineers may soon be able to answer this old and fundamental question, Are we alone in the universe?

So, welcome aboard! Fasten your seat belts. This textbook will take you on a fascinating journey. Along the way you will discover that supernovae, carbonaceous chondrites, nuclear fusion, "inflationary" cosmology, greenhouse gases, comets, killer asteroids, gamma-ray bursters, bipolar outflows, continental drift, orbital eccentricity, and many, many other exotic sounding things really do have something to say about how you came to be here and whether there may be microbes or minds elsewhere in the universe. Today there are many unanswered questions, but our tools to search for answers are getting better and better. Your generation will not only answer many of today's questions, but will undoubtedly raise new questions we cannot begin to imagine. Indeed, the truth is out there—and the real science behind searching for life in the universe is far more compelling than any movie or television drama. Happy searching!

Jill Tarter
DIRECTOR OF RESEARCH, SETI INSTITUTE

Preface

ASTROBIOLOGY, THE SCIENCE that deals with life elsewhere in the universe, continues to attract the attention of students, the public, and those scientists who enjoy letting their minds roam freely through several disciplines that remain an essential part of searching for life beyond Earth. Since the previous edition of this book appeared, a single rock from Mars stunned the world with the tantalizing possibility that we had found the first evidence for extraterrestrial life. Although this conclusion now seems dubious, no doubt exists that the last few years have also brought the first sure discoveries of planets in orbit around sunlike stars. In fact, astronomers have now found so many of these planets (nearly 60) that the thrill has temporarily diminished. That excitement over the detection of new worlds will return quickly on the day when we find not Jupiter-sized gas giants, the only type of planets that our present techniques can detect, but the first extrasolar planets similar to our Earth.

Two decades ago, when the first edition of this book appeared, any textbook dealing with astrobiology seemed destined for modest use, simply because this subject draws on the knowledge and methods of many disparate fields of science and even sociology. We were surprised and pleased by the large number of instructors who have happily adopted our goal of teaching the excitement of science by focusing on some of its major unsolved issues, despite not themselves being experts in all the fields of science involved. We can now see more clearly that astrobiology's appeal to students can easily override the fact that this field of study requires scientific speculation; indeed we suspect that some instructors, like ourselves, delight in showing students that the joy of science lies even more in what we don't know than in what we do. To teach critical thinking, few subjects can match the search for life in the universe, whose topics range from determining the lifetimes of stars, through attempts to judge hypotheses about the origin and evolution of life on Earth, to the assessment of the most incredible reports of extraterrestrial visitors to our planet.

This book can serve as a textbook for any introductory astronomy course with a focus on planetary science and the search for life in the universe, and for many biology and geology courses that choose to emphasize the cosmic aspects of their fields of interest. Students in courses taught by ourselves and our colleagues seem nearly unanimous in welcoming an interdisciplinary course that centers on the search for life, hardly surprising in view of the public's interest in the subject. That interest, fanned by sensational movies and television programs, starts with the human prejudice that we must be the center of the universe, the natural subject of attention of any extraterrestrial civilization. Teaching a course on extraterrestrial life takes students along a journey that science has already made, from the belief that we on Earth are immensely special, perhaps unique, to the realization that our planet orbits a representative star in the outer reaches of a typical giant spiral gal-

axy, with millions of possible sites for life. How can we realistically judge whether life has actually developed on some of those sites? If civilizations have appeared elsewhere in the Milky Way, some of them may be far more advanced than ours and may or may not be interested in making contact with us. The intellectual journey culminates with an assessment of how hard we may have to work if we hope to find other civilizations with whom to exchange our views of life, and of how long we may have to wait before any such exchange occurs.

In preparing this new edition of our book, we have changed the order of the introductory astronomy chapters (chapters 2–6) so that they follow the conventional sequence, reaching outward from the Earth to the universe at large. We have revised the biology chapters (7–10) to include new approaches to understanding the origin and evolution of life on Earth, and to achieve greater clarity in presenting the relationship between the development of life on our planet and elsewhere in the cosmos. The planetary-astronomy chapters (11–15) reflect the new results from spacecraft and other investigations of the solar system, and a new chapter (17) presents the discovery of extrasolar planets. Chapters 16–22 carry us through the universe on a quest to answer the question of how we might find intelligent civilizations, if they exist, and what conclusions we can draw from the fact that we have yet to find definitive proof that life exists anywhere beyond the Earth.

In preparing this new edition of *The Search for Life in the Universe*, we owe a particularly large debt of gratitude to Dana Backman, Barbara Bowman, Russell Doolittle, Richard Gammon, William Irvine, David Koerner, Alan Rosan, Jill Tarter, and Juliette Winterer, who took the trouble to read through part or all of our manuscript and provide us with detailed comments, which we have done our best to incorporate into this new edition. We would also like to thank other scientists who helped us with the text and illustrations for this edition: Gibor Basri, Simon Bell, Leo Blitz, Ken Brecher, Julian Chela-Flores, Alessandro Dimai, Frank Drake, Alex Filippenko, Ben Finney, Dudley Foster, Andy Fruchter, Bob Garrison, Suvi Gezari, Paul Goldsmith, David Hollenbach, Don Kripke, Monica Lazzarin, Judith Lengyel, Steve Maran, Geoff Marcy, Lynn Margulis, Larry Marschall, Marjory Martin, Chris McKay, David Morrison, Kenneth Nealson, John Oró, Guy Ottewell, Adam Riess, J. William Schopf, Eric Schulman, Seth Shostak, Frank Shu, Michal Simon, Michael Sitko, Michael Soule, Hy Spinrad, Larry Squire, Woody Sullivan, Jill Tarter, Richard Wainscoat, and Jurrie van der Woude. To work with University Science Books, and thus with Bruce and Kathy Armbruster, Jane Ellis, Robert Ishi, Hope Steele, and Susanna Tadlock, has been a special treat. Many happy hours have also been spent in consultation with Jon Lomberg, our good friend and outstanding astronomy artist, who provided the artwork for this edition.

Donald Goldsmith

Tobias Owen

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PART ONE

Why Do We Search?

To see a World in a Grain of Sand
And a Heaven in a Wild Flower.
Hold Infinity in the palm of your hand
And Eternity in an hour.

—WILLIAM BLAKE

THE HISTORY OF HUMAN AWARENESS of the universe has brought a steady increase in our desire to find the roots of our existence and to understand how humans fit into the cosmos. We now stand at the threshold of determining how life arose on this planet, and of applying what we know about life on Earth to our quest for life on planets that orbit other stars. But we should pause to ask some key questions: Why do we search? How has the search for our origins, and for evidence of our cosmic kin, proceeded in the past? And what does the search for extraterrestrial life tell us about our attitude toward the universe around us?