THE LIVING COSMOS

CHRIS IMPEY is University Distinguished Professor at the University of Arizona and deputy head of one of the largest astronomy departments in the country. Balancing a love of teaching with his work on quasars and distant galaxies, he has written more than 160 research papers and has had two dozen projects approved with the Hubble Space Telescope. Impey has won ten University of Arizona teaching awards and was selected as Arizona's Professor of the Year by the Carnegie Foundation. He has been vice president of the American Astronomical Society, and in 2002 he was chosen as National Science Foundation Distinguished Teaching Scholar. In 2007 he was a Phi Beta Kappa Visiting Scholar. *The Living Cosmos* was Chris Impey's first book of popular science. He has also written a popular book called *How It Ends* and edited a book of astrobiology interviews called *Talking About Life*, published by Cambridge University Press. He lives in Tucson, Arizona.

***The Living Cosmos* by Chris Impey**

"Lively, clear and up-to-date overview of astronomy, cosmology, biology and evolution, specifically as related to the search for extraterrestrial life . . . [Impey] does an impressive job explaining an avalanche of information, including such recent major discoveries as the first planets found orbiting distant stars. A skillful account of the universe, the nature of life and where in the universe life might occur."
Kirkus Reviews

"There has been a recent flood of books about astrobiology – the study of life in the universe – but this latest effort by astronomer Chris Impey is one of the best. It provides a solid overview of the diverse research involved . . . beautifully written."
New Scientist

"Impey has written a wonderfully readable book about the chances of life existing elsewhere in the universe . . . But *The Living Cosmos* is not about just that. It is an overview of everything you need to know about the fundamentals, including how we got here and where we're probably going. More important, the science – a word that often causes eyes to glaze over – is laid out with uncommon clarity and panache."
Sara Lippincott, ***Los Angeles Times***

"Chris Impey, one of the world's most distinguished astronomers, takes an exhaustive and illuminating look at astrobiology . . . Consistently engrossing and provocative, and frequently absolutely mind-blowing in its implications, *The Living Cosmos* is filled with scientific details but it remains accessible to readers without a background in astronomy and science. This book is most highly recommended . . ."
Book Loons Reviews

"Impey has clearly done his research thoroughly, and interviewed a great number of the key scientists whilst writing the book . . . *The Living Cosmos* is not only comprehensive in its treatment of the great breadth of astrobiology research, but is also beautifully written. Each chapter opens with an engaging account, full of imagery, of the up-coming topic. On the whole, this is a sterling attempt at making astrobiology accessible to a general audience and I enjoyed reading it immensely."
Dr Lewis Dartnell, UCL, ***The Astrobiology Society of Great Britain***

"Chris Impey provides a broad, accessible context for his thoughtful, engaging and up-to-date take on the quest for extra terrestrial life . . ."
Professor Bruce Jakosky, University of Colorado, ***Nature***

"Chris Impey surveys the state of the art in this exciting multidisciplinary field. Impey frames his book around three questions: How many habitable worlds are there? Is biology unique to the Earth? And are there other intelligent civilizations? Complete with a companion website featuring podcasts, video clips, interviews, news stories and original artwork, *The Living Cosmos* provides an eloquent summary of humankind's quest for life elsewhere."
Scientific American Book Club

"This is a book about a science that is changing our view of the universe and about what life really means and where it might exist. Impey provides us with a road map to the future of astrobiology, a map that is meant to lead us into a deeper understanding of life and man's station in the universe."
National Space Society

THE LIVING COSMOS

Our Search for Life in the Universe

CHRIS IMPEY

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To my muses, on Earth and elsewhere

CONTENTS

PREFACE TO THE PAPERBACK EDITION

SINCE *THE LIVING COSMOS* was first published in 2007, astrobiology has been in a ferment of activity. The search for life in the universe is highly interdisciplinary, and one of the best signs of the subject's rude health is the vigorous debate and questioning (with touches of incomprehension) between astronomers, geologists, chemists, and biologists at any major meeting. A young cohort of researchers who brand themselves as astrobiologists is making its way through the ranks, and is already making its mark. The research community is becoming steadily more international. Whether the topic is the exploration of Mars, extremophiles on Earth, exoplanets, or SETI, astrobiology has shown the power to capture the public's attention and fuel its imagination.

And yet, we still only know of one place in the universe with life. Does this mean astrobiology is a failure? What's the status of this young and exciting field?

The greatest progress has been made on exoplanets. The detection limit has steadily marched downwards in mass to approach the mass of the Earth. Very few of the super-Earths found so far are habitable, in a traditional sense of being able to have liquid water on their surfaces, but the Kepler satellite is poised to deliver the census of Earths. The number of exoplanets has more than doubled since this book first appeared. Exoplanet research has moved beyond counting bodies to characterizing planets and comparing observations to sophisticated models of geology and atmospheric chemistry. In little more than fifteen years, the advances have been breathtaking.

By comparison, the Search for Extraterrestrial Intelligence (SETI) has celebrated its 50th anniversary without any signal being detected. It might seem strange to compare the two fields—one announcing a new discovery almost every week, and the other suffering through a continuation of the "Great Silence." But both searches are addressing central issues of our relationship to the universe, and both are paced by advances in technology. SETI may always be vulnerable to its untested and anthropocentric assumptions, but with the increased power of radio and optical methods, the search may just be getting interesting.

I'm grateful for the tranquil but intellectually stimulating environment of the Aspen Center for Physics, where revisions for this paperback edition were

completed. I'm grateful to my editor at Cambridge University Press, Vince Higgs, for his guidance on this and our other astrobiology projects. Special thanks to Dinah Jasensky for entering my life in a most delightful way.

Readers of this book may also be interested in my recently published *Talking About Life*, also published by Cambridge University Press, which contains interviews with dozens of the scientists featured in *The Living Cosmos*. One day, I expect to give this book the most dramatic update possible.

Chris Impey
Tucson, Arizona
August, 2010

PREFACE

IT'S QUITE PECULIAR to be human. Our lives are filled with event and episode, with work and recreation, with the ebb and flow of friends and family. Seen from above, our actions would seem as purposeful as the activity of bees in a hive or squirrels in a forest. Yet we each house the awareness that we're living, conscious entities. We reflect on our existence. We know that we will die. Perhaps we share self-awareness with a few other species on Earth, but no other creature has gained knowledge of its place in the largest landscapes of time and space.

The history of astronomy has been a steady march of awe and ignominy: awe at the prodigious size and age of a universe with tens of billions of galaxies, ignominy that we have no special place among those galaxies and their countless trillions of stars. Stars and nebulae and planets are the result of natural forces. Rocks and clouds weren't created for our pleasure or benefit. The last bastion of specialness is our existence. Surely life has purpose and meaning. As the poet Stephen Crane has written,

A man said to the universe:
"Sir I exist"
"However," replied the universe,
"The fact has not created in me
A sense of obligation."

The final step in the Copernican revolution would be the revelation that we live in a biological universe. As it stands, we know of only one planet with life: Earth. But that's not a very strong statement. We've literally just scratched the surface of interesting sites for life in the Solar System like Mars and Titan. We know very little about the properties of the thousand or so planets in other solar systems or whether those solar systems also contain Earth-like planets. And our attempt to listen for signals from intelligent aliens in the vastness of space has been met with a great silence.

Astrobiology is the study of life in the universe. It's a young subject, the domain of researchers drawn from the full spectrum of biological and physical sciences. It's not immune from criticism—that it's a subject with no subject

matter, that astrobiology can only subsist for so long on hopes and promises. Yet the sense of expectation is palpable. The technological revolution that powers computers and consumer appliances has also transformed our ability to gather distant light and send sophisticated probes into space. There's every reason to believe that we'll find out within a few decades whether or not our biology is unique.

This book is a survey of the state of the art in astrobiology. It begins with the history of how we've come to know our place in the universe. Then it turns to what we know about the evolution of life on Earth and what we can learn from the diversity and robustness of terrestrial fauna. Next comes discussion of the prospects for life elsewhere in the Solar System. This is followed by exciting new research on distant planets, and the book closes by considering the potential for intelligent life elsewhere in the universe. Our knowledge is very modest, so some material is speculative. The universe has surprised us before, and it will surprise us again.

The Living Cosmos is designed for a reader with no background in astronomy. Curiosity is the trait that unites us all. Perhaps you've wondered if art and music and computers and commerce are purely human constructs, or if they have emerged in a recognizable form elsewhere in the universe. Perhaps you've wondered if evolution on other planets makes creatures similar to us in function and form or organisms so wildly different that they're beyond our imagination. The language of the book is nontechnical, and details are confined to endnotes. A reading list and set of web links is provided for further exploration. Finally, a large amount of enrichment material—including podcasts, video clips, interviews, news stories, color images, and original artwork—is available on a companion web site at http://www.thelivingcosmos.com.

Working on this book has been engrossing and at times thrilling, because it has taken me far beyond my original training in physics and astronomy. I've benefited from the expertise of many professional colleagues, but all errors, omissions, and inadvertent misrepresentations are my responsibility alone.

At the University of Arizona, I'm particularly grateful to Jonathan Lunine and Nick Woolf for filling in many gaps in my knowledge. The following people carefully read sections and provided valuable advice and feedback: Mark Bailey, Steve Benner, Nick Bostrom, Roger Buick, Guy Consolmagno, Richard Gott, David Grinspoon, Roger Hanlon, Ray Kurzweil, Geoff Marcy, Chris McKay, Simon Conway Morris, Carolyn Porco, Richard Poss, Lynn Rothschild, Woody Sullivan, Jack Szostak, and Jill Tarter. Many of them also feature in the book; their ideas and enthusiasm explain better than I ever could why being a scien-

tist is so much fun. I also warmly acknowledge George Coyne, S.J., a close friend and mentor since I was a fledgling graduate student.

To gather information for this book, I talked with and formally interviewed many scientists and deep thinkers about life in the universe, some of whom have already been mentioned above. They've each helped to shape my understanding of astrobiology, and I'm grateful for all their insights: John Baross, Ben Bova, Chris Chyba, Carol Cleland, Steven Dick, Ann Druyan, Timothy Ferris, Debra Fisher, Iris Fry, Rose Grymes, Bill Hartmann, Joe Kirschvink, Andy Knoll, Laurie Leshin, Frank Lin, Mario Livio, Renu Malhotra, Laurie Marino, Vikki Meadows, Jay Melosh, Mike Meyer, Steve Mojzsis, Hans Moravec, Pinky Nelson, Norm Pace, Richard Poss, Sara Seager, Peter Smith, Dava Sobel, Neil Tyson, Diana Wall, and Larry Yaeger.

I acknowledge the support of the Templeton Foundation for the "Astrobiology and the Sacred" project at the University of Arizona. The visitors and lectures resulting from this project broadened my scientific horizons and acquainted me with many of the people whose work is featured in this book.

Writing is a solitary activity, but no book emerges without help and support. My deepest thanks go to Katherine Larson for editing several chapters and giving excellent suggestions on the whole project and for inspiring me never to limit my imagination. I'm grateful to my agent, Anna Gosh, for her attentiveness and feedback. I thank Catherine, Ben, and Paul for their support during the initial writing of this book.