Extrasolar Planets and Astrobiology

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Foreword

This book by Caleb Scharf offers a formal exposition about an exploding development throughout the world: the merging of multiple scientific disciplines to form a compelling new field, namely astrobiology. The most profound questions posed by ancient civilizations largely remain unanswered, left for religious leaders, philosophers, and the curious among us to ponder throughout the ages. Ancient Greek philosophers intensely debated the uniqueness of our Earth and the possibility of life elsewhere, but they and their academic successors made little progress for 2400 years. Suddenly and startlingly, we stand at the brink of answering those old questions.

The answers are arriving from two directions: progress on the physical prerequisites for life, and hints of the first habitable worlds. Astronomers have found that the fundamental equations of gravity, electricity, and quantum physics (some yet to be fully understood) are the same everywhere throughout the spacetime of the universe. The atoms and molecules of which life is composed are also ubiquitous throughout the universe. The 92 naturally occurring atoms are seen in stars and galaxies by spectroscopic analysis of their light, filling the periodic table for most of the 13.7 billion year age of the universe. Those atoms combine into complex organic molecules such as alcohols and amino acids, which are found in comets, moons, and interstellar clouds. The LEGOs™ of life are everywhere. Moreover, water, the great chemical cocktail mixer, is among the most abundant of substances in the universe, found on planets, moons, and comets. Water mobilizes, destroys, and recombines the organic molecules, to create uncountable molecular permutations of great size and complexity. Few can doubt that proteins and nucleotides will form given enough time.

The energy required for life comes in many forms, including starlight, geothermal, tidal, and radioactive, offering the complex organics myriad ways to power further reactions. Chemical replication will surely occur by molecular precursors to RNA and DNA, leading to a competition for both the valuable molecular building blocks and for the free energy. The successful precursors will multiply and outcompete their neighbors, populating their environment. The blurry but inexorable transition from "prebiotic" to "living" clusters of organic molecules reveals life as a natural phenomenon, forged in the furnaces of stars.

Meanwhile, astronomers have developed techniques to detect the first habitable abodes in the universe. The subsurface water in Mars, the oceans inside Europa and Ganymede, and the geysers of Enceladus all constitute rich chemistry labs, each one percolating for billions of years. The exploration of these new worlds seems as compelling as the most courageous transoceanic voyages in human history. Should robotic probes discover the first alien lifeforms, the ubiquity of life in the universe will be established and the diversity of life sampled.

Beyond our Solar System, over 300 planets have now been discovered orbiting other stars. So far, only large ones similar in size to Jupiter, Saturn, and Neptune have been found. But new techniques are now in hand to detect terrestrial-sized planets. The Kepler mission will search for stars that dim periodically due to earths that cross in front, blocking only 1/10,000 of the starlight. Astronomers will also make precise Doppler measurements of stars to detect their reflex motion in response to the gravitational tug by terrestrial planets. Some clever astronomers are surveying the smallest stars, the red dwarfs, to detect their dimming and reflex motion, to reveal earth-sized planets.

For the future, NASA and the Jet Propulsion Laboratory have developed the Space Interferometry Mission that will use the interference of light waves gathered by a spaceborne pair of telescopes to detect earth-like planets, and measure their masses, around nearby stars. Just over the horizon are plans for a spaceborne telescope that blocks the glare of nearby stars, allowing us to take images of Earth-like planets and to determine their chemical composition from their spectra. Any worlds having oxygen atmospheres and surface oceans will smell fishy from 40 light years. This census of habitable earths will fill GoogleGalaxy with ports-of-call for our grandchildren who will send robotic probes and later themselves, at least those with extreme daring and patience. The urge to explore these new worlds comes from our anthropological roots at Olduvai Gorge two million years ago. What sets us apart from the stones and the stars is our insatiable desire to understand our kinship with both.

Geoffrey W. Marcy
University of California, Berkeley

Preface

The questions that surround the quest for an understanding of the nature of life in the universe are perhaps as diverse as life itself. Is life on Earth unique? How did life on Earth begin? Are there other planets like the Earth? Are there other systems like the solar system? Do these systems harbor life? The prospect of writing any kind of text that can be used to teach the science that is necessary to begin to address such questions is, to say the least, daunting.

I will therefore begin with some excuses as to why this book does not attempt to deal with all such questions. The original idea behind the material was to offer the analytically literate person an introduction to the emerging "interdiscipline" of astrobiology. It is absolutely *not* meant to be either complete, or definitive. In fact, I think that anyone claiming to produce a complete or definitive text (especially one for teaching) on astrobiology at this stage is probably an alien—so watch out. What this book *does* try to do is lay some of the groundwork for a few of the methods and physical principles that serve as tools for understanding questions of star and planet formation, astronomical observation, and chemical and biological modeling. As the book's title suggests, the study of planets other than our own is a central part of the material. The primary audience is therefore either a student or researcher in astronomy or physics, or possibly someone from the geophysical, chemical, or biological sciences, looking for a deeper understanding of the "astro" in astrobiology.

As the book developed, more and more purely descriptive material crept in - culminating in some of the speculative material in the final chapter. I think this speculation is entirely valid, since so much of astrobiology is (at present) speculation - albeit increasingly based on real information. I also hope that this can demonstrate to a student how speculation with some analytic basis can serve a useful purpose by stimulating further discussion and thought.

A lot of emphasis is placed in this book on the importance of not being blinded by an "Earth-centric" view of astrobiology. Earth is the best, and only, template that we have available in the present quest for life, and life's habitats in the Universe. However, most of our detailed knowledge of the Earth applies only to the last few thousand years, a tiny fraction of the time the planet, and its life, has existed. It takes, in my opinion, a lot of hubris to state that we are looking for life "like that on Earth." Thirty or forty years ago we didn't even recognize a major fraction of the terrestrial microbial population, or that much of it lives in extreme conditions. This is a good example of where different scientific disciplines may learn the most from each other. Astronomers and astrobiologists want to find extraterrestrial life, but ultimately it may be that what we stand to learn the most about from such a discovery is the nature of life here on Earth. That would be a wonderful thing.

I would like to acknowledge many people who have contributed to the process of writing this text. To start with, the students of Columbia University and Barnard College in New York who have acted as guinea pigs in taking the course that this book is based upon. Without their enthusiastic response to the subject matter I doubt I would have dared to commit this material to paper. I would also like to thank the Columbia Department of Astronomy and the Columbia Astrophysics Laboratory for their support. In particular I acknowledge the extraordinary support and encouragement of David Helfand and his tireless efforts to create a productive and enjoyable academic environment for all. The support of Columbia University through their Initiatives in Science and Engineering program has also been invaluable in enabling me to work on this text, and I thank David Hirsh for his help and support.

In my efforts to get to grips with the world of astrobiology I must acknowledge the mentoring of Michael Storrie-Lombardi - physicist, physician, biologist, astronomer, diver, and enlightened human being - you have my deepest gratitude. I must also thank the following colleagues and friends for their time, advice, and scientific discussions - in no particular order: Kristen Menou, Fernando Camilo, Eric Gotthelf, Frits Paerels, Linda Sohl, Howard Shuman, Mike Bauer, Mike Allison, Ben Oppenheimer, Daniel Savin, Dave Spiegel, Gene McDonald, and Maya Tolstoy. Also Geoff Marcy and Debra Fischer, and others, for their extraordinarily thoughtful reviews of much of this manuscript. Bruce Armbruster and Jane Ellis of University Science Books made the process of seeing this book come to press both happy and intellectually satisfying. Although I have attempted to be reasonably comprehensive in

referencing the many sources I have used in writing this book I must acknowledge those not explicitly mentioned. Bits and pieces, ideas, and scraps have inevitably been borrowed and modified from all over the place. Writing a text such as this would not be possible without relying on the accumulated efforts of the scientific community.

Finally, to Bonnie, Laila, and Amelia, thank you for everything.

Caleb Scharf
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