Cellular Origin, Life in Extreme Habitats and Astrobiology 20

Julian Chela-Flores

# The Science of Astrobiology

## A Personal View on Learning to Read the Book of Life

Springer

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The cupola in the West Atrium of St. Mark's Basilica in Venice, Italy representing the biblical interpretation of Genesis
(Cf., also pp. 215-216 at the beginning of Part 4: The destiny of life in the universe. With kind permission of the Procuratoria of St. Mark's Basilica.)

*For Sarah Catherine Mary*

# Table of contents

# THE BOOK OF LIFE

## *PART 1: THE ORIGIN OF LIFE IN THE UNIVERSE*

### CHAPTER 1.
### **From cosmic to chemical evolution**



### CHAPTER 2.
### **From chemical to prebiotic evolution**

## CHAPTER 3.
## Sources of life's origin: A search for biomarkers



## CHAPTER 4.
## From prebiotic evolution to the emergence of single cells

# THE BOOK OF LIFE

## *PART 2: EVOLUTION OF LIFE IN THE UNIVERSE*

### CHAPTER 5.
### **From the age of prokaryotes to the emergence of eukaryotes**



### CHAPTER 6.
### **The evolution of intelligent behavior**

# THE BOOK OF LIFE

## *PART 3: THE DISTRIBUTION OF LIFE IN THE UNIVERSE*

### CHAPTER 7.
### **On the possibility of biological evolution on Mars**



### CHAPTER 8.
### **On the possibility of biological evolution on the moons of Jupiter**

## CHAPTER 15.
## Why we may be unable to read the complete Book of Life



## CHAPTER 16.
## An intelligible universe with the science of astrobiology

# Preface

Since the publication of *The New Science of Astrobiology* in the year 2001, two significant events have taken place raising the subject from the beginning of the century to its present maturity a decade later (Chela-Flores, 2001). Firstly, at that time the Galileo Mission still had two years to complete its task, which turned out to be an outstanding survey of the Jovian system, especially of its intriguing satellite Europa. Secondly, the successful outcome of the Cassini Huygens Mission on its way to Saturn went beyond all expectations of the European Space Agency (ESA) and the United States of America National Aeronautics and Space Administration (NASA). Cassini had been launched four years earlier and Huygens was to land on Titan three years after the publication of our first edition.

Besides, we had no idea that another satellite of Saturn, Enceladus, was going to lure the scientific community with the most surprising jets of water exuding an air of mystery, hinting at a submerged inhabitable ocean of salty water. Ahead of the date of publication of our book was the awareness of the Earth-like surface morphology and hydrosphere of Titan with its prominent lake system. It dawned upon us that Titan was the fourth body of the Solar System that possibly contained a water ocean, thus joining our planet and Jupiter's three Galilean satellites: Ganymede, Callisto and Europa. Titan appears now to be the only planetary body besides the Earth to have persistent, almost permanent liquid bodies on its surface. These surprising aspects of Titan were unknown to us in 2001. In our first edition, at the end of Chapter 9, we anticipated the possibility of the emergence of an autochthonous biology on Titan, but left our readers with a word of caution to wait until the present post Cassini-Huygens era before advancing further hypotheses on this most basic issue of astrobiology. We now discuss this issue in Chapter 9. The new scientific landmarks of the first decade of the present century warrant a new look at the same subject matter. The urgency of this undertaking is emphasized by the much deeper insights that we have gained into the geophysics of Mars. Some remarkable events include the analysis of its surface by the Mars Reconnaissance Orbiter and the Martian water ice exposed by the Phoenix Mars Lander in 2008, not forgetting the much clearer views that are now emerging on Martian paleolimnology. Some of this progress due largely to the stunning images retrieved by ESA's Mars Express and subsequent missions to the Red Planet.

We have sadly witnessed during the three decades preceding the publication of the first edition of this book, *The New Science of Astrobiology*, a most unfortunate missed opportunity regarding the acquisition of further insights into our own satellite. In the present Second Edition this particular topic is being reviewed, namely the ongoing revolution of interest in the Moon. In October 2007, Japan sent up the Kaguya spacecraft. A month later, China's Chang'e-1 entered lunar orbit. This was followed by India's Chandrayaan-1, whose objective was to map not only the surface of the moon, but also what lies underneath. We are convinced that promising new instrumentation, such as the penetrator technology, especially the work of the British Penetrator Consortium, will be able to demonstrate in the coming decade communication and navigation technologies that will support the eventual return to the Moon and the exploration of other planets and satellites of the inner and outer Solar System.

Beyond the terrestrial planets this renewed interest in our own satellite will be useful as a platform to improve on the achievements of the Galileo Mission. The benefits will concern all the satellites of Jupiter, especially Europa's intriguing non-water elements on its icy surface that will be elucidated by the forthcoming Europa-Jupiter System Mission (EJSM). With combined efforts focused on our own satellite by India, China, Japan, Russia, the United Kingdom, ESA and NASA, *The Science of Astrobiology* has new exciting results and discoveries to review. Consequently, at the present time it is appropriate to attempt to reflect on current scientific progress with a broad canvas ranging from cosmic evolution to the implications in the humanities of the inevitable discovery of universality of biology.

There is still the challenge of taking into account the search for exo-intelligence—intelligent behavior elsewhere in the universe—with the help of the gigantic leaps in radio astronomy that are expected to come early in the 2020s from the Square Kilometer Array (SKA discussed in Chapter 11). Since the year 2001, only six years after the seminal discovery of a planet of the star 51 Pegasi that was reported in our first edition, a whole spectrum of further "exoplanets" have arisen amongst our galactic neighbors: Jovian-like gaseous giants, super Neptunes and super-Earths are constantly being added to the astronomer's catalogs. With the Kepler Space Telescope, a NASA Mission launched in 2009, Earth-like planets are now within reach of observation. Not only a large number of exoplanets are now known, but also solar systems with several planets each have been identified. The possibility of searching for exomoons will also be raised in Chapter 10. This new broad vision of the cosmos and its possible habitability has given additional strong support to the search for intelligent behavior with the tools of the bioastronomers. One of the factors of the Drake Equation—the number of possible inhabitable planets—is slowly, but steadily coming to our attention, especially with Kepler.

The many books that are now available represent another significant progress in astrobiology. In 2001 we found it difficult to identify a single-author book especially written on astrobiology. They were not generally known (not even to the present author). Now the situation is much better and our bibliography at the end of this volume is consequently much richer, providing our readers with a most enjoyable, instructive and comprehensive view of our subject (cf., the bibliographic references listed at the end of the Preface offer the reader a small sample of a growing list of books).

The writing this second edition of the book coincided in its first stages with the double anniversary of Charles Darwin, the 200$^{th}$ anniversary of his birth and the 150$^{th}$ anniversary of the publication of The Origin of Species, possibly the most influential book ever published in any branch of science. We have profited from this remarkable coincidence, in order to underline "the biology" of astrobiology (cf., Introduction). Being a multidisciplinary subject, astrobiology sometimes regretfully neglects the life sciences, as there are so many other aspects to keep in mind, such as chemical evolution, the earth sciences, the physical sciences and cutting-edge technology.

Finally, the emphasis we attempted to imprint on our previous book *The New Science of Astrobiology* made a very modest effort in setting the scientific subject appropriately amongst other sectors of culture that are the natural frontiers of astrobiology. These boundaries are philosophy and theology, branches of the humanities asking similar questions to the basic issues of astrobiology (origin, evolution, distribution and destiny of life in the universe). In the meantime I have dedicated a full volume to this aspect of astrobiology in *A Second Genesis Stepping-Stones Towards the Intelligibility of Nature* (Chela-Flores, 2009). We have tried in this new edition of *The Science of Astrobiology* to benefit from the experience gained during these last decade while enjoying the multiple fascinating aspects of astrobiology and its cultural frontiers.

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He is particularly privileged not only for having had the opportunity to devote his life to science, but his studies and research have benefitted from a fortunate opportunity that has been given to him for participating in activities in the humanities: In 1998 His Eminence Cardinal Carlo Maria Martini invited him to take part in the *Chair of Non-Believers*, in order to discuss the frontiers of astrobiology and the humanities. The same year the Venezuelan philosopher Ernesto Mayz Vallenilla invited him to hold the UNESCO Chair of Philosophy at the Instituto de Estudios Avanzados in Caracas. In addition, the author has benefitted especially from the eminent American astronomer George Coyne's participation in the Trieste events, where he discussed some of the most difficult issues at the frontier of astrobiology and the humanities, including closely-related theological issues (Chapter 13).

He would also like to thank colleagues from many nations that have helped him to appreciate the many fields that make up astrobiology. Due to either their areas of expertise, or their areas of influence, his vision of the subject has improved. He would like to mention especially the Spanish philosopher, Roberto Aretxaga-Burgos, for his collaboration over the last 7 years and particularly for our most recent one that has led to a much-improved version of chapters 13, 14 and 16. Thanks are due to the Venezuelan geneticist and astrobiologist Harold P. De Vladar, the Mexican biophysicist Moisés Santillán and the Indian physicist Santosh Chidangil for their advice in the subject matter of Chapter 12.

*The Science of Astrobiology* has also improved due to the help of the following scientists in many relevant issues of which the author was not familiar: Aranya Bhattacherjee (Physics, India), Suman Dudeja (Chemistry, India), Narendra Kumar (Condensed Matter Physics, India), Mauro Messerotti (Astronomy, Italy), Nevio Pugliese (Paleontology, Italy), Joseph Seckbach (Microbiology, Israel), Vinod Tewari (Micropaleontology, India) and Claudio Tuniz (Paleoanthropology, Italy).

For their kind and generous advice on parts of the manuscript acknowledgement is also due to the following scientists: Drs. Roberto Aretxaga-Burgos, Cristiano Cosmovici, Marco Fulle, Robert Gowen, Robert Greenberg, Mauro Messerotti, François Raulin and Giovanni Vladilo. But for anyone who is familiar with the process of preparing a manuscript of over 350 pages it should be clear that no matter how much kind collaboration his collegues and friends might offer, the work will not be free of errors, all of which are entirely the author's responsibility.

The administrative personnel of ICTP contributed significantly to this work: Johannes Grassberger and Marco Marcor (The Information, Communication and Technology Section), Ms Anna Triolo (Public Relations Office), Lucio Visentin and Dora Tirana (The Marie Curie Library).

And last, but not least, thanks are due to his wife, Sarah for her friendship, patience, perseverance, critical spirit, permanent support, guidance and encouragement.

# Recommendations to the readers

The science of astrobiology is one of the most appealing aspects of culture that we believe should be accessible to everyone. However, the personal point of view expressed in this work makes a humble attempt to insert astrobiology inside its frontiers with the other branches of our cultural heritage. While writing this second edition of our work that was published a decade ago (when astrobiology could still be qualified with the adjective “new”), we firmly believe that any reader can benefit from the level we have chosen.

However, some guidance to my readers is still necessary. We have not shied away from placing astrobiology within a real scientific context of physics down to the subnuclear level, not neglecting the implications of the still-to-gain consensus theoretical framework (Chapter 15). Right from the Introductory Chapter, we have not been timid and glossed over the wonderful clarity and simplicity provided by the science of biogeochemistry. Neither have we hidden from our readers a Chapter 4 that includes the wonderful, yet complex concept of symmetry at the frontier of molecular biology and quantum mechanics that fascinated our distinguished colleague, who shared many radical views with us at the Trieste Center in the time frame of 1986-1994: the Nobel Laureate Professor Abdus Salam. Finally, due to certain fortunate circumstances mentioned in the *Acknowledgements* he has also felt that it was possible to include three chapters (13, 14, and 16) on the critical issues that arise when astrobiology meets philosophy.

This ambition of ours that science communication is still possible at this most difficult level that we have set ourselves has, we believe, a pedagogical solution. Each chapter has been preceded with an introductory paragraph that is followed in each case by an advice to the readers to use extensively the Illustrated glossary that has been provided: It contains some 300 entries, including some images and biographies of significant scientists that have influenced his way of understanding the science of astrobiology. Most of these scientists have participated in meetings at the Trieste Center, in which the author has attended during his career, since attending Graduate School at the University of London, when he was offered the unique opportunity of participating in the 1968 Trieste *Symposium on Contemporary Physics* (Salam, 1969). Some of the scientists that appear as protagonists of the physical sciences, as well as in the birth and growth of astrobiology, were participants in the events organized at the Center. The astrobiology meetings were organized with his colleagues Tobias Owen, Cyril Ponnamperuma and Francois Raulin (cf., Epilogue).

In addition, we have provided a rich General Index that contains a detailed list of over one hundred illustrations and almost 50 tables, besides the traditional name index. There is also an extensive bibliography supporting the text and also including suggestions of supplementary readings in each chapter to give the opportunity to the readers to go deeper into the wide range of topics that are relevant. Taking into account all of these additions to the 16 chapters, Introduction and Epilogue, we believe that the readers will be able to make sense of the fascinating topics in the physical, space, earth and life sciences that together make up the science of astrobiology.

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# THE SCIENCE OF ASTROBIOLOGY

# Introduction

## The cultural and scientific context of astrobiology

*Our main objective in writing this book has been to present the science of astrobiology in a manner accessible to non-specialists, but attempting at all stages to insert its scientific achievements in an adequate cultural context. We return to the beginnings of the subject in a brief historical account. In fact, a difficult task confronts the student of astrobiology in trying to comprehend the gradual emergence of our subject. The basic questions that astrobiology has to face have been with us since the beginning of culture itself. At the same time the reader would have cause to complain if we had not dwelled on the origins of astrobiology, since it is one of the most fascinating aspects of the history of science. We complete the introduction with an account of astrobiology in a spectrum ranging from the humanities to the space, earth and life sciences.*

The reader is advised to refer especially to the following entries in the Illustrated glossary:
*Apollo Program, biogeochemistry, Book of Life, chert, Crick (Francis), Galileo Mission, isotopic fractionation, Keynes (Sir Richard Darwin), mass-independent fractionation, Schopf (J. William).*

### I.1 Early attempts to read the Book of Life

Attempts to read the "Book of Life", the ever-present wish to comprehend the position of humans in the universe, have been a deep concern of humanity since the beginning of civilization. Going back to the Greek Golden Age we could have already separated the Book of Life in several chapters that covered the origin, evolution, distribution and destiny of life in the universe. Only in recent times the Book of Life has also been an objective of a scientific discipline. It coincides with the subject matter of the present book *The Science of Astrobiology*. In ancient times its first pages were beginning to be comprehensible even to our earliest ancestors, when agriculture arose soon after the end of the last glacial period. We began to understand the plant kingdom. In the Milesian School (6th century BC) we find attempts to read several other pages. Later on in the 4$^{th}$ century BC both Plato and Aristotle raised relevant questions still unanswered to the present day. At the end of the Middle Ages, Giordano Bruno expressed views that are still at the center of astrobiologist's main focus of research. We will come back to this great thinker below. Before the recent emergence of astrobiology perhaps the largest steps ever taken in our search for the position of humans in the universe were provided by Nicholas Copernicus in the 16$^{th}$ century and by Charles Darwin in the 19$^{th}$ century. In addition, about one hundred years later Francis Crick and James Watson with their contemporaries interpreted for us key issues that deal with the molecular mysteries of life (cf., Chapter 4, Sec. 4.7). The historical development of the basic concepts that astrobiology has made its own, can best be appreciated against the historical background of the whole range of sciences of the universe. We begin our account by returning, once again to Classical Greece.

## ARISTARCHUS OF SAMOS AND HIPPARCHUS

The first important contribution to our present understanding of the science of astrobiology can be traced back to ancient Greece. Aristarchus of Samos lived approximately form 310 to 230 BC. He was one of the last of the Ionian scientists that founded the studies of philosophy. He lived over 23 centuries before our time, and 18 centuries before Copernicus. In spite of such vast time gaps, Aristarchus already formulated a complete Copernican hypothesis, according to which the Earth and other planets revolve round the Sun; but in so doing, Aristarchus asserted, the Earth rotates on its axis once every 24 hours. A lunar crater is named for him.

The heliocentric theory did not prosper in antiquity. Instead, the influential astronomer Hipparchus, who flourished from 161 to 126 BC, adopted and developed a non-heliocentric theory ("epicycles"), which was going to dominate the ancient world right into the Middle Ages. Indeed, Hipparchus went beyond Aristarchus geocentric cosmology with a spherical Earth at the centre of the universe. From his point of view, all of the solar system bodies including the Sun, rotated around the Earth daily. Ptolemy defended the final form of the ancient model of the Solar System in the second century AD.

## NICHOLAS OF CUSA (CUSANUS)

The Italian cardinal Cusanus (1401-1464) flourished in the middle of the 15th century AD. He had been ordained a priest about 1440. Pope Nicholas V had made Cusa a cardinal in Brixen, Italy. At the time of his priesthood he published a significant work: *De Docta Ignorantia* ("On learned ignorance"). In this book he described the learned man as one who recognizes his own ignorance. But perhaps from the point of view of the evolution of our concepts of the cosmos we should underline that Cusanus denied the one infinite universe centered on Earth, thereby anticipating the heliocentric revolution of Copernicus Digges and others the following century.

He also claimed that the Sun was made of the same elements as Earth. He spoke of "a universe without circumference or center". The work of Cusanus touched on a theological question. In his system, all celestial bodies are suns representing to the same extent the manifestation of God's creative power. Such dialogue between a scientific question (cosmology) and theology (divine action) would lead in the subsequent century, to a conjecture that anticipated the formulation of the central question of astrobiology: the existence of a plurality of inhabited worlds.

## NICHOLAS COPERNICUS

The Polish cleric Nicholas Copernicus (1473-1543) published his heliocentric theory in 1543. During his stay at the University of Padua from 1501 to 1503, Copernicus had been influenced by the sense of dissatisfaction of the Paduan instructors with the Ptolemaic and Aristotelian systems (Bertola, 1992). The new century was a time in which scientists were requiring a sense of simplicity that classical philosophy could no longer provide. The main work of Copernicus, *De revolutionibus orbium coelestium* ("On the revolution of the heavenly spheres") was published a few months before his own death in 1543. In this influential work Copernicus placed the Sun at the center of the Solar System and inserted both the Sun and planets inside a sphere of fixed stars (cf., Fig. I.1).

Copernicus deliberately appeared to accept the tenets of Aristotle's universe, as proposed in his *De Caelo,* a cosmos inserted within a system of revolving planets, surrounded by a sphere of fixed stars. There is ample evidence that the Polish scientist knew of the heliocentric hypothesis of Aristarchus. Indeed, Bertrand Russell argues that the almost forgotten hypothesis of the Ionian philosopher did encourage Copernicus, by finding ancient authority for his innovation (Russell, 1991). It would, of course, be Johannes Kepler, who was born in Germany in 1571, the scientist that would initiate a breakthrough with the discovery of the elliptical orbit. Subsequently Isaac Newton would provide the theory of gravitation that put the heliocentric theory of Copernicus on solid mathematical bases.

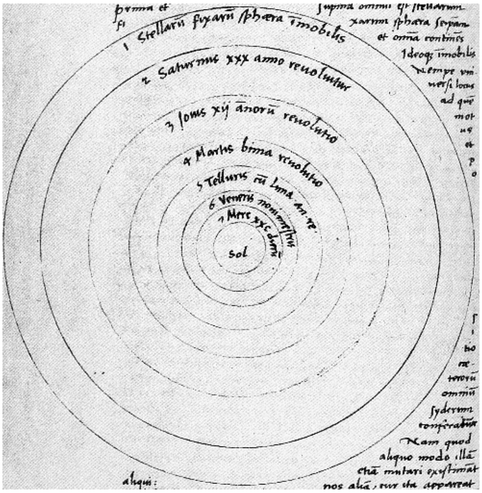


**Fig. I.1** The heliocentric view of the universe according to Copernicus, in which he included a sphere of fixed stars (Bertola, 1995). This last difficulty with the Copernican universe was discussed in the writings of Giordano Bruno.

## GIORDANO BRUNO

Giordano Bruno (1548-1600) was a philosopher, astronomer, and mathematician. He is best remembered for intuitively going beyond the heliocentric theory of Copernicus, which still maintained a finite universe with a sphere of fixed stars. As we have already seen in Chapter 10, from the point of view of astrobiology his anticipation of the multiplicity of worlds has been amply confirmed since 1995. In that year the first detection of extrasolar planets was announced. But what is more significant regarding Bruno's intuition is that he also conjectured that such worlds would be inhabited by living beings. Astrobiology, the science of life in the universe is just concerned with this key question, still without a convincing answer. Bruno was influenced by the philosophy of Cusanus (cf., previous Section). According to Hilary Gatti (Gatti, 1999) his attention on the philosopher that preceded him was probably due to the clarity of the concepts stated by the 15th century cardinal. (An articulate expression of Bruno's