

## Preface

One of the most exciting questions for mankind is whether we are alone in the universe. That intelligent nonhuman beings exist was commonly believed in prehistoric times as well as in antiquity. Creatures such as giants, centaurs, angels, and fairies were essential and universally accepted parts of Greek, Jewish, and Germanic mythologies. Although no fossil traces of such beings have ever been found, most of us firmly believe that nonhuman intelligent beings do indeed exist. This conviction is derived from the staggering size of the universe with roughly 100 billion times 100 billion ( $10^{22}$ ) stars, which makes it inconceivable that we could be the only intelligent society in the universe. Indeed, modern science has shown that since the Copernican revolution all attempts to define our position as an exceptional one in the universe have failed dismally.

But if other intelligent civilizations do exist, how can we find them? Why is there no terrestrial or astronomical trace of them, despite great technological advances in recent centuries and especially in modern times? Why have we never found artifacts discarded by visiting aliens, which would convincingly prove the existence of nonhuman intelligent beings? Is the number of planets on which life is able to evolve too small, or is the formation of life – and particularly intelligent life – an extremely rare event? Could these intelligent societies face insurmountable difficulties in traveling over large galactic distances, or do they no longer exist?

Recent advances in search techniques for planets, in the theory of planet formation, and particularly in biochemistry, molecular, and cell biology are about to give answers to these questions: how life appeared and how many planets can be expected in the universe on which life, and eventually intelligent life, developed. New in this book is the argument that, by thinking carefully about the future development of mankind, one can gain insight into the nature of extraterrestrial civilizations.

The book consists of three parts: planets, life, and intelligence. In *Part I*, Chaps. 1–3 discuss stars, galaxies, and the origin of chemical elements, our recent planet formation theories, the search methods for extrasolar planets and what has been found so far. Chapter 4, “Planets suitable for life”, describes what constitutes an Earth-like planet and how many of them can be expected in the universe. In *Part II*, Chaps. 5 and 6 outline life and its

origin on Earth, how it evolved, and how intelligent life developed. Chap. 7 discusses the search for extraterrestrial life and intelligent societies. In *Part III*, Chap. 8, “The future of mankind”, gives possible insights into what can be expected about the nature of extraterrestrials. Finally, Chap. 9, on extraterrestrial intelligent life, constructs a likely picture of these beings and attempts to answer the question of why they don’t interact with us.

Heidelberg, June 2002

*Peter Ulmschneider*

# Contents

---

## Part I Planets

---

<b>1</b>	<b>Stars, Galaxies, and the Origin of Chemical Elements</b> . . . . .	3
1.1	The History of the Universe . . . . .	3
1.2	Molecular Clouds . . . . .	6
1.3	The Pre-Main Sequence Evolution of Stars . . . . .	8
1.4	The Post-Main Sequence Evolution of Stars . . . . .	11
1.5	Element Composition and Dating . . . . .	13
1.5.1	Population I and Population II Stars . . . . .	13
1.5.2	Dating with Radioactive Clocks . . . . .	15
<b>2</b>	<b>Planet Formation</b> . . . . .	19
2.1	Accretion Disks and Planetesimal Formation . . . . .	19
2.2	Terrestrial Planets . . . . .	21
2.3	Jovian Planets and Kuiper Belt Objects . . . . .	24
2.4	The Migration of Jovian Planets . . . . .	24
2.5	The T-Tauri Stage . . . . .	26
2.6	The Formation of the Moon . . . . .	27
2.7	The Planetological History of the Early Earth . . . . .	29
2.7.1	Comets . . . . .	29
2.7.2	Ocean–Vaporizing Impacts . . . . .	30
2.7.3	The End of the Heavy Bombardment . . . . .	32
2.8	The Environment on the Early Earth . . . . .	33
<b>3</b>	<b>The Search for Extrasolar Planets</b> . . . . .	39
3.1	The Recently Discovered Planets . . . . .	39
3.2	Direct Search Methods for Planets . . . . .	41
3.3	Indirect Search Methods . . . . .	42
3.4	Circumstellar Disks . . . . .	44
3.5	New Search Strategies . . . . .	46
<b>4</b>	<b>Planets Suitable for Life</b> . . . . .	51
4.1	Habitable Zones . . . . .	51
4.1.1	The Solar Habitable Zone . . . . .	52
4.1.2	Habitable Zones Around Other Stars . . . . .	54

VIII Contents

4.2	Planetary Mass and the Evaporation of the Atmosphere . . . . .	55
4.3	The Lifetimes of the Stars . . . . .	58
4.4	Tidal Effects on Planets . . . . .	59
4.5	The Increase in Solar Luminosity and the Continuously Habitable Zone . . . . .	61
4.6	Instabilities of the Planetary Atmosphere . . . . .	62
4.6.1	The Greenhouse Effect . . . . .	63
4.6.2	The Carbonate Silicate Cycle . . . . .	64
4.6.3	The Runaway Greenhouse Effect . . . . .	64
4.6.4	Irreversible Glaciation . . . . .	65
4.7	Axis Variations of the Planets . . . . .	67
4.8	Biogenic Effects on Planetary Atmospheres . . . . .	70
4.9	The Requirements for Continuous Habitability . . . . .	71
4.10	The Drake Formula . . . . .	72
4.11	The Number of Habitable Planets . . . . .	73

---

**Part II Life**

---

<b>5</b>	<b>Life and its Origin on Earth . . . . .</b>	<b>79</b>
5.1	What is Life? . . . . .	79
5.2	The Special Role of Organic Chemistry . . . . .	80
5.3	The Elements of Biochemistry . . . . .	80
5.3.1	Proteins, Carbohydrates, Lipids, and Nucleic Acids . . . . .	81
5.3.2	The Genetic Code . . . . .	86
5.3.3	ATP, the Energy Currency of the Biochemical World . . . . .	86
5.3.4	Synthesizing RNA, DNA, and Proteins . . . . .	87
5.4	Cells and Organelles . . . . .	89
5.5	Sequencing and the Classification of Organisms . . . . .	91
5.5.1	Classification by Sequencing . . . . .	91
5.5.2	The Molecular Clock . . . . .	91
5.5.3	The Evolutionary Tree of Bacteria . . . . .	92
5.5.4	The Timetable of the Evolution of Life . . . . .	93
5.5.5	Sequencing and the Complete Genome . . . . .	95
5.6	The Stage for the Appearance of Life . . . . .	96
5.6.1	The Origin of the Genetic Code . . . . .	96
5.6.2	The Urey–Miller Experiments . . . . .	98
5.6.3	The Search for the Last Common Ancestor . . . . .	99
5.6.4	Summary: The Boundary Conditions . . . . .	100
5.7	Abiotic Chemical Evolution and the Theories How Life Formed . . . . .	101

<b>6</b>	<b>Evolution</b> .....	105
6.1	Darwin's Theory .....	105
6.2	The Development of Eukaryotes and Endosymbiosis.....	107
6.3	Geological Traces of Evolution .....	108
6.4	Oxygen as an Environmental Catastrophe .....	110
6.5	The Cell Nucleus and Mitosis .....	111
6.6	Sexuality and Meiosis .....	112
6.7	Genetic Evolution .....	114
6.8	Multicellularity, the Formation of Organs, and Programmed Cell Death .....	116
6.9	Problems of Life on Land .....	119
6.10	The Great K/T Boundary Event .....	122
6.11	The Tertiary and the Evolution of Mammals .....	127
6.12	Primate Evolution .....	127
6.13	DNA Hybridization .....	135
6.14	Brain Evolution and Tool Use.....	137
6.15	Stone Tool Culture .....	139
6.16	Diet and Social Life.....	141
6.17	The Logic of the Human Body Plan .....	142
6.18	Evolution, Chance, and Information .....	145
6.19	Cultural Evolution .....	148
<b>7</b>	<b>The Search for Extraterrestrial Life</b> .....	149
7.1	Life in the Solar System .....	149
7.2	Europa's Ocean .....	150
7.3	Life on Mars .....	152
7.3.1	Early Searches .....	153
7.3.2	The Viking Experiments .....	154
7.3.3	Mars Meteorites.....	156
7.4	The Early Atmosphere of Mars.....	159
7.5	Future Mars Missions .....	161
7.6	Life Outside the Solar System.....	162
7.7	UFOs .....	164

---

**Part III Intelligence**

---

<b>8</b>	<b>The Future of Mankind</b> .....	169
8.1	Predicting Mankind's Future.....	169
8.2	Settlement of the Solar System .....	170
8.2.1	The Space Station .....	171
8.2.2	Moon and Mars Projects .....	172
8.2.3	Asteroids and Meteorites .....	175
8.2.4	Space Travel .....	179

8.2.5	Near-Earth Asteroids and the Mining of the Solar System . . . . .	181
8.2.6	Space Habitats . . . . .	182
8.2.7	Cultural Impact of Space Colonization . . . . .	186
8.3	Interstellar Travel . . . . .	187
8.4	Mastering the Biological World . . . . .	189
8.4.1	Creating Life in the Laboratory . . . . .	189
8.4.2	The Decoding of the Human Genome . . . . .	190
8.4.3	Understanding Intelligence . . . . .	191
8.5	Androids and Miniaturization . . . . .	191
8.6	Connected Societies . . . . .	192
8.7	Fear of the Future . . . . .	193
8.8	The Dangers for Mankind . . . . .	194
8.8.1	Bacterial or Viral Infection . . . . .	195
8.8.2	Episodes of Extreme Volcanism . . . . .	195
8.8.3	Irreversible Glaciation and the Runaway Greenhouse Effect . . . . .	196
8.8.4	Comet or Asteroid Impact . . . . .	196
8.8.5	Supernova Explosions and Gamma Ray Bursts . . . . .	199
8.8.6	Irreversible Environmental Damage . . . . .	200
8.8.7	Uncontrollable Inventions . . . . .	201
8.8.8	War, Terrorism, and Irrationality . . . . .	202
8.9	Survival Strategies . . . . .	203
<b>9</b>	<b>Extraterrestrial Intelligent Life . . . . .</b>	<b>205</b>
9.1	Does Extraterrestrial Intelligent Life Exist? . . . . .	205
9.2	What is the Hypothetical Nature of the Extraterrestrials? . . . . .	207
9.3	The Drake Formula, the Number of Extraterrestrial Societies . . . . .	210
9.4	The Lifetime of an Extraterrestrial Civilization . . . . .	212
9.5	Distances to the Extraterrestrial Societies . . . . .	213
9.6	SETI, the Search for Extraterrestrial Intelligent Life . . . . .	215
9.6.1	Radio Searches for Extraterrestrial Civilizations . . . . .	216
9.6.2	Possible Contact in the not too Distant Future . . . . .	220
9.7	The Fermi Paradox: Where are the Extraterrestrials? . . . . .	222
9.7.1	They do not Exist . . . . .	223
9.7.2	Technically, a Visit is not Possible . . . . .	223
9.7.3	They are Nearby, but have not been Detected . . . . .	224
9.7.4	They are not Interested in Us . . . . .	225
9.8	The Zoo Hypothesis . . . . .	226
	<b>References . . . . .</b>	<b>229</b>
	<b>Author Index . . . . .</b>	<b>241</b>
	<b>Subject Index . . . . .</b>	<b>245</b>