

Understanding Life in the Universe

The two most fascinating questions about extraterrestrial life are where it is found and what it is like. In particular, from our Earth-based vantage point, we are keen to know where the closest life to us is, and how similar it might be to life on our home planet. This book deals with both of these key issues. It considers possible homes for life, with a focus on Earth-like exoplanets. And it examines the possibility that life elsewhere might be similar to life here, due to the existence of parallel environments, which may result in Darwinian selection producing parallel trees of life between one planet and another. *Understanding Life in the Universe* provides an engaging and myth-busting overview for any reader interested in the existence and nature of extraterrestrial life, and the realistic possibility of discovering credible evidence for it in the near future.

Wallace Arthur is an evolutionary biologist with an interest in how life evolves on other planets, and in particular how similar the life forms that evolution produces on one inhabited planet may be to those on another. He is the author of *The Biological Universe* (Cambridge University Press, 2020) and *Understanding Evo-Devo* (Cambridge University Press, 2021).

Cambridge University Press & Assessment
978-1-009-20736-2 — Understanding Life in the Universe

Wallace Arthur

Frontmatter

[More Information](#)

The ***Understanding Life*** series is for anyone wanting an engaging and concise way into a key biological topic. Offering a multidisciplinary perspective, these accessible guides address common misconceptions and misunderstandings in a thoughtful way to help stimulate debate and encourage a more in-depth understanding. Written by leading thinkers in each field, these books are for anyone wanting an expert overview that will enable clearer thinking on each topic.

Series Editor: Kostas Kampourakis <http://kampourakis.com>

Published titles:

<i>Understanding Evolution</i>	Kostas Kampourakis	9781108746083
<i>Understanding Coronavirus</i>	Raul Rabadan	9781108826716
<i>Understanding Development</i>	Alessandro Minelli	9781108799232
<i>Understanding Evo-Devo</i>	Wallace Arthur	9781108819466
<i>Understanding Genes</i>	Kostas Kampourakis	9781108812825
<i>Understanding DNA Ancestry</i>	Sheldon Krimsky	9781108816038
<i>Understanding Intelligence</i>	Ken Richardson	9781108940368
<i>Understanding Metaphors in the Life Sciences</i>	Andrew S. Reynolds	9781108940498
<i>Understanding Cancer</i>	Robin Hesketh	9781009005999
<i>Understanding How Science Explains the World</i>	Kevin McCain	9781108995504
<i>Understanding Race</i>	Rob DeSalle and Ian Tattersall	9781009055581
<i>Understanding Human Evolution</i>	Ian Tattersall	9781009101998
<i>Understanding Human Metabolism</i>	Keith N. Frayn	9781009108522
<i>Understanding Fertility</i>	Gab Kovacs	9781009054164
<i>Understanding Forensic DNA</i>	Suzanne Bell and John M. Butler	9781009044011
<i>Understanding Natural Selection</i>	Michael Ruse	9781009088329
<i>Understanding Life in the Universe</i>	Wallace Arthur	9781009207324

Forthcoming:

<i>Understanding Species</i>	John S. Wilkins	9781108987196
<i>Understanding Creationism</i>	Glenn Branch	9781108927505
<i>Understanding the Nature–Nurture Debate</i>	Eric Turkheimer	9781108958165

Understanding Life in the Universe

WALLACE ARTHUR

Emeritus Professor of Zoology, University of Galway, Ireland



Cambridge University Press & Assessment
978-1-009-20736-2 – Understanding Life in the Universe
Wallace Arthur
Frontmatter
[More Information](#)

CAMBRIDGE UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, VIC 3207, Australia
314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India
103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781009207362

DOI: 10.1017/9781009207355

© Wallace Arthur 2023

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2023

Printed in the United Kingdom by TJ Books Limited, Padstow Cornwall

A catalogue record for this publication is available from the British Library.

ISBN 978-1-009-20736-2 Hardback

ISBN 978-1-009-20732-4 Paperback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

‘A fascinating overview of life on Earth and the prospects of finding parallel forms of it on habitable exoplanets. Wallace Arthur provides an engaging, yet scientifically accurate, overview of the current knowledge and what to expect from the next Copernican revolution looming on the horizon of astronomy.’

Avi Loeb, Professor of Science, Harvard University, USA

‘From the origin of the universe through to the search for oxygen biosignatures on exoplanets, this book is a marvellous and broad introduction to our efforts to find out if this fascinating replicating material we call life is to be found elsewhere in the universe, and where we might find it. It will appeal as much to a professional seeking a good review as to the layperson wanting an introduction to the subject.’

Charles Cockell, Professor of Astrobiology, University of Edinburgh, UK

‘Beginning with a guided tour of life on Earth, Wallace Arthur reaches out to explore the possibility of alien life deep in the cosmos. In this provocative but scientifically argued treatise, he describes what form such life might take and the technological means by which we might discover it. A thoughtful and riveting read that excites like science fiction yet rests on science.’

Addy Pross, Emeritus Professor of Chemistry, Ben-Gurion University of the Negev, Israel

‘A tremendously broad and comprehensive look at the whole panoply of issues surrounding our search for extraterrestrial life. A very useful text for anyone just starting on an exploration of the possibilities of life in the universe.’

Arik Kershenbaum, University of Cambridge, UK, author of *The Zoologist's Guide to the Galaxy*

Contents

Foreword	page xiii
Preface	xv
Acknowledgements	xvii
1 The Search for Extraterrestrial Life	1
Are We a Privileged Generation?	1
A Brief History of the Search	3
The Importance of Telescopes	5
A Working Definition of Life	10
A Working Definition of Intelligence	15
Two Key Questions	17
2 Where in the Universe to Look?	20
What Is the Observable Universe?	20
Cosmic Structure: Galaxies	23
Stars: The Powerhouses of Life	27
Planetary Systems	31
The Fourth Dimension: Time	34
Two Perspectives on the Search	37
3 Evolution – Here and Elsewhere	39
Controversy and Strategy	39
Origins of Life	40
Proliferating Microbes	44
Evolution of Multicellularity	49

x CONTENTS

Evolution of Complex Plants	55
Evolution of Intelligent Animals	56
4 The Key Concept of Habitability	61
Habitable by What?	61
The Habitable Zone	63
Time for Evolution	65
From Habitable to Inhabited	68
A Galactic Habitable Zone?	71
Millions of Inhabited Planets	72
5 Life in the Solar System	77
A Unique Opportunity	77
Distances from the Sun	78
The Atmosphere of Venus	80
Mars in Deep Time	82
Moons of Jupiter and Saturn	85
Visitors to Our System: 'Oumuamua	87
Conclusions: How Many Inhabited Bodies?	89
6 Life in Other Planetary Systems	91
The Excitement of Exoplanets	91
An Ideal Planet?	94
The Most Promising Planets So Far	96
Analysing Atmospheres	99
Oxygen as a Biosignature	101
How Long Until Discovery?	106
7 The Nature of Extraterrestrial Life	108
Conflicting Hypotheses	108
Parallel Basics and Autosperma	111
Parallel Natural Selection	114
Parallel Trees of Life	116
Talking About Selection	121
Harvesting Light	123
Becoming Intelligent	126

8 Intelligence – Here and Elsewhere	129
Stages in the Life of a Planet	129
Human Evolution on Earth	131
Human Technology	135
Intelligence and Technology Elsewhere	138
From Project Ozma to Breakthrough Listen	140
Other Technosignatures	143
The Fermi Paradox	144
Concluding Remarks	151
Summary of Common Misunderstandings	154
References and Further Reading	157
Figure Credits	169
Index	170

Foreword

Are we alone in the universe? Is there anybody out there? These are questions that have preoccupied humans for a long time, with answers provoking both excitement and fear. The possibility of the existence of alien life, and the consequences of encountering it, have been the topics of many popular films – in fact, science fiction is to a large extent devoted to such matters. Whereas there are no definitive answers yet as to whether there is any kind of life in the universe beyond Earth, we now know which questions we should ask and how to try to find answers to them. This has been made possible because during the last century or so our understanding of the universe, and our methods for studying it, have advanced enormously. The book you are holding in your hands is a *tour-de-force*, which summarizes current knowledge and understanding about the possibility of life in the universe. Wallace Arthur has skilfully brought together knowledge and conclusions from various disciplines to produce a concise and coherent account of what we currently know, what we might know in the future, and what we are likely to never know. The outcome is a fascinating and informative read that will take your thinking about life in the universe from speculative science fiction to the magnificent science of our times.

Kostas Kampourakis, Series Editor

Preface

The aim of this book is to give you a broad scientific base against which to consider the search for extraterrestrial life, along with the possible nature of that life and its possible distribution across the universe. As is appropriate for books of this series, I have aimed my explanations at a general readership. Hence I've tried not to assume too much. When in doubt, I've erred in the direction of including the scientific basics rather than omitting them. Thus the 'educated layperson' should be able to read the book in sequence from start to finish and make sense of it, without frequent digressions to other sources.

The book is an interweaving of three main strands, one of which is the detective work of the search itself (including space probes to local planets and the analysis of light from exoplanets), one of which is biological (with particular reference to evolution via Darwinian selection), and one of which is astronomical (including planetary science, with its key concept of habitability). The biological strand is focused on the possible *nature* of extraterrestrial life, in other words its chemical basis, mode of construction, overall body form, and so on. The astronomical strand is focused instead on its possible *distribution* across the observable universe – particularly our local part of it, which is the easiest to search.

Naturally, these two things – the nature and distribution of life – are interconnected. We can't set out to search for evidence of life in particular places without making some assumptions about what it's like. In particular, we typically search for two things – biosignatures, which indicate possible metabolizing life, and technosignatures, which indicate possible intelligent life. Arguably, the best biosignature to look for is atmospheric oxygen: this assumes

xvi PREFACE

that there is alien photosynthesis. And arguably, the best technosignature to look for is one that has been deliberately broadcast into space in the form of radio signals: this assumes intelligent life with an advanced technology.

Looking at the interconnection the other way round, it's unwise to speculate on the possible nature of life without some idea of where it might be found. In the twenty-first century, we're pretty sure there are no large life forms on any planet (or moon) other than Earth in the solar system; but we haven't yet ruled out the possibility of alien microbes, for example in the subsurface oceans of Saturn's moon Enceladus. However, in other planetary systems, large complex life forms may be as common as they are here on Earth, or indeed more so.

I've structured the book to reflect the interconnections between these three issues – the search for life, its nature, and its spatial distribution. So we weave our way back and forward freely between them. Also, there's much herein about life on Earth, interspersed with considerations about its possible extra-terrestrial counterparts. Note that the book isn't called *Understanding Extraterrestrial Life*. The title *Understanding Life in the Universe* was chosen instead for two reasons. First, the idea that at this stage in the game we can actually 'understand' alien life is a bit presumptuous, to say the least. Second, despite the protestations of some sceptics, life on Earth gives us clues about what we're likely to find elsewhere. The difficult thing, of course, is to distinguish those aspects of Earth life that are likely to be specific to our home planet from those that may be widely applicable across the universe.

At the end of the book are references and suggestions for further reading. These are organized by chapter. Within each chapter, they are divided according to the topics they address, given in the sequence they follow in the chapter concerned. Within each topic, sources are ordered alphabetically. I should stress that these chapter-by-chapter lists are only small samples of a vast literature that covers several branches of science, from cosmology to evolutionary biology, and several levels of detail, from books in the popular science genre to primary research papers. My criteria for inclusion of sources were varied. They ranged from citing papers that describe particularly important discoveries, to pointing you in the direction of highly readable treatments of particular topics, to including some sources that are of historical importance in our ever-evolving search for life in the universe.

Acknowledgements

I would like to thank the following for their help at various stages from inception to publication. Katrina Halliday, for the invitation to write this book for the *Understanding Life* series. Jessica Papworth and Olivia Boulton, for editorial advice. Fred Stevenson, for reading the draft manuscript with an astute astronomical eye. Kostas Kampourakis, for suggesting what became the final title, for reading the manuscript, and for writing the foreword. David Catling, Mike Guiry, and Steve Selesnick, for their helpful comments on an earlier version of the manuscript. Bridget Bravo, for transforming my rough scribbles into professional illustrations. Jenny van der Meijden and Aloysias Thomas, for overseeing a smooth production process. Hugh Brazier, for clarifying unclear parts of my text at the copy-editing stage, as he has done for several of my earlier books. Many thanks to you all. The draft manuscript for a book is the individual work of the author, but the final printed product is very much the work of a team.