THE BIOLOGICAL UNIVERSE

Are we alone in the universe, or are there other life-forms 'out there'? This is one of the most scientifically and philosophically important questions that humanity can ask. Now, in the early 2020s, we are tantalizingly close to an answer. As this book shows, the answer will almost certainly be that life-forms are to be found across the Milky Way and beyond. They will be thinly spread, to be sure. Yet the number of inhabited planets probably runs into the trillions. Some are close enough for us to detect evidence of life by analysing their atmospheres. This evidence may be found within a couple of decades. Its arrival will be momentous. But even before it arrives we can anticipate what life elsewhere will be like by examining the ecology and evolution of life on Earth. This book considers the current state of play in relation to these titanic issues.

Wallace Arthur is an evolutionary biologist who is fascinated by the possibility of evolution occurring on other planets. His first book on this subject was *Life through Time and Space* (Harvard 2017), which the Astronomer Royal Sir Arnold Wolfendale described as 'brilliant and thought-provoking in every way'. *The Biological Universe* is the sequel.

'Wallace Arthur addresses the most exciting question in science: "Are we alone?" His brilliant exposition argues convincingly that we are likely to go through a Copernican revolution regarding the biological universe and discover that we are not at its centre.'

- Avi Loeb, Chair of the Harvard Astronomy department

'Working his way up from first principles of physics, chemistry, and biology, Wallace Arthur asks what is needed for life to exist. In his familiar readable style, he then asks whether these requirements are likely to be found elsewhere in the universe, and answers with a resounding "Yes". Anyone who works on the evolution of life on Earth will have asked themselves similar questions. Arthur's presentation of the questions, and of the answers, is both enjoyable and eye-opening.'

- Ariel Chipman, The Hebrew University of Jerusalem, Israel

'An engaging, well-informed, and accessible guide to one of the great questions. Thoroughly enjoyable and unputdownable.'

- Peter Atkins, Emeritus Professor of Physical Chemistry, University of Oxford, and fellow of Lincoln College

'Wallace Arthur takes us on a fascinating journey to discover whether and how our living planet is unique in the universe. In his characteristically engaging style, he propels his story with sharp questions, arresting details, and vivid explanations, so that we arrive, via photosynthesis-stealing slugs and the extremes of extraterrestrial atmospheres, at a new understanding of ourselves and our world.'

- Ronald Jenner, Natural History Museum, London, UK

'*The Biological Universe* performs a fascinating dissection of our tree of life, asking which of its features we might share with other such trees on worlds throughout the galaxy. A truly unique perspective on finding life in the universe, which starts with who is eating whom in the soil under our feet.'

- Elizabeth Tasker, author of *The Planet Factory*

‘In this thought-provoking book, Arthur’s deep knowledge of life and its myriad manifestations, coupled with a cosmologist’s understanding of the cosmos at large, enables him to explore one of science’s greatest mysteries – how the biological and physical universes relate to one another. Does life exist beyond this planet? What form would it take? How could we detect it? Arthur musters fact, logic, and intuition, in his far-reaching attempt to nail down life’s place within the wider cosmic dimension.’

- Addy Pross, Ben-Gurion University of the Negev, Israel

‘Wallace Arthur’s book *The Biological Universe* is highly significant. We will soon know whether we are alone in the universe. The next few years could provide us with this long-sought answer. This book, extremely well written, tells us how.’

- Simon ‘Pete’ Worden, Executive Director, Breakthrough Initiatives, Luxembourg and USA

The Biological Universe

Life in the Milky Way and Beyond

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It now appears that most stars host a planetary system. Many of them have a planet similar in size to our own, basking in the 'habitable zone' where the temperature permits liquid water. There are likely billions of Earth-like worlds in our galaxy alone. And with instruments now or soon available, we have a chance of finding out if any of these planets are true Pale Blue Dots – home to water, life, even minds.

Yuri Milner *et al.*,
launch of the Breakthrough Initiatives, 2015

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PREFACE

The aim of this book is to consider the possible extent and nature of the biological universe, in other words the subset of the physical universe that consists of life-forms. One day, perhaps, we humans can aim to describe the actual biological universe, or at least a sample of it that includes a large number of inhabited planets. But that day is, at best, in the distant future. To achieve the more limited aim that I've set myself here – of 'considering the possible' – the book proceeds through four steps. First, I describe life on Earth, with a focus on the variety of habitats it is found in and the ways in which organisms survive there; and I consider the possible implications of terrestrial habitats and survival strategies for life elsewhere. Second, I examine the current state of knowledge about planetary systems, with a focus on habitability; and among other things I produce an estimate of the number of planets in the Milky Way that are likely to host life. Third, I consider the possible nature of extraterrestrial life, our ongoing search for it, and the link between the two. It's hard enough to find a needle in a haystack, harder still to find a tiny object of unknown shape and composition; and our galaxy is a very large haystack. Finally, I broaden the scope of discussion from its earlier focus on the Milky Way to encompass the universe as a whole.

The structure of the book is based on these four steps. They are taken sequentially in Parts II, III, IV, and V – preceded by Part I, which is an evolutionary and galactic lead-in. Each part is prefaced by a statement of its key hypotheses. The book fits squarely into the genre of popular science, and is written accordingly. Its subject area would best be described as astrobiology, a branch of science that's still in its infancy.

Astrobiology will only come of age when we find our first evidence for extraterrestrial life-forms, something that I expect

will happen in the next couple of decades. But infancy is a fascinating stage in the development of a branch of science, just as it is in the development of a person. And this particular infant has a longer history than might be expected: human contemplation of the possibility of extraterrestrial life goes back beyond the Age of Enlightenment to Giordano Bruno in sixteenth-century Rome; probably much further back to ancient Greece, where the heliocentric solar system of Aristarchus pre-dated that of Copernicus by about 1800 years; and possibly further still – perhaps the first members of our species had thoughts about distant life as they contemplated the stars above Africa.

In case you've already read my 2017 book *Life through Time and Space*, or are thinking of reading it, I should point out here both the connections and the distinctions between that book and this one. Both combine astronomy and biology, but they do so in very different ways, and with different foci. A central theme of the earlier book was origins. More than half of its chapters were focused on how things originated; and those 'things' were as diverse as planetary systems, the animal kingdom, and the nervous system of a human embryo. The current book focuses on the present rather than the past. For example, it asks not about how planetary systems arose but what are their prospects for hosting life – in much more detail than the latter issue was dealt with in *Life through Time and Space*. Also, while that earlier book spanned the cosmos right from the start, most of the present one focuses on our home galaxy, the Milky Way, because this is the realm in which we can most easily undertake searches for life.

ACKNOWLEDGEMENTS

The writing of a mainstream science book covering all the subjects that I touch on here would require a team of authors with the following specialisms: evolutionary biology, ecology, geology, atmospheric science, planetary science, astronomy, astrobiology, astrophysics, cosmology, and philosophy. However, for a *popular science* book, the uniformity of style that a single author can provide is highly desirable. Also desirable is a lack of technical detail, though such an approach carries with it a risk of the treatment being too superficial. One solution to this problem is for the author, who is necessarily a specialist in only one field (in my case evolutionary biology), to read widely in the others before putting proverbial pen to paper, and also to arrange for specialists in the other fields to scrutinize the draft manuscript and provide critical comments. This is the approach I have adopted here. I am enormously grateful to the following friends and colleagues, all of whom have read one or more draft chapters: Chris Arthur, Andy Cherrill, Mark Davies, Mike Guiry, Ernst de Mooij, Dave Newton; and I must say a special thanks to Jim Kasting and Fred Stevenson, both of whom read the whole manuscript and made numerous helpful suggestions for improvements to the text. As is the time-honoured tradition in this situation, I should emphasize that I rather than they am fully responsible for any errors, omissions, or failures of clarity or depth that have somehow escaped the net and filtered through into print.

As well as receiving help from the subject experts listed above, I have also had considerable assistance from publishing and artistic professionals of various hues. At Cambridge University Press, Dominic Lewis was enthusiastic from the moment I first approached him about this project, and guided me through the review process. Sam Fearnley took over from Dominic when

things moved from review to production, and efficiently took me through the whole production process. Hugh Brazier cast his inimitable editorial eye over the manuscript and drew my attention to various issues throughout, which together we fixed through an interaction that was at the same time productively serious and great fun. My son Stephen Arthur produced almost all of the final artwork from what can only be described as my amateurish initial scribbles. The only illustration he had no hand in was Figure 18, the Hubble Ultra-Deep Field, which was produced at Cambridge from the NASA original. It's wonderful that all those beautiful NASA photographs of our universe are in the public domain.