

A Fortunate Universe

Life in a Finely Tuned Cosmos

Over the last 40 years, scientists have uncovered evidence that if the Universe had been forged with even slightly different properties, life as we know it – and life as we can imagine it – would be impossible.

Join us on a journey through how we understand the Universe, from its most basic particles and forces, to planets, stars and galaxies, and back through cosmic history to the birth of the cosmos. Conflicting notions about our place in the Universe are defined, defended and critiqued from scientific, philosophical and religious viewpoints. The authors' engaging and witty style addresses what fine-tuning might mean for the future of physics and the search for the ultimate laws of nature.

Tackling difficult questions and providing thought-provoking answers, this volume challenges us to consider our place in the cosmos, regardless of our initial convictions.

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‘My colleagues, Geraint and Luke, take you on a tour of the Cosmos in all of its glory, and all of its mystery. You will see that humanity appears to be part of a remarkable set of circumstances involving a special time around a special planet, which orbits a special star, all within a specially constructed Universe. It is these sets of conditions that have allowed humans to ponder our place in space and time. I have no idea why we are here, but I do know the Universe is beautiful. *A Fortunate Universe* captures the mysterious beauty of the Cosmos in a way that all can share.’

*Brian Schmidt, Australian National University,
Canberra; Nobel Laureate in Physics (2011)*

‘Geraint Lewis and Luke Barnes provide a breath-taking tour of contemporary physics from the subatomic to the cosmological scale. Everywhere they find the Universe to be fine-tuned for complex structure. If the quark masses, or the basic forces, or the cosmological constant had been much different, the Universe would have been a sterile wasteland. It seems that the only reactions are either to embrace a multiverse or a designer. The authors have constructed a powerful case for the specialness of our Universe.’

Tim Maudlin, New York University

‘The Universe could have been of such a nature that no life at all could exist. The anthropic question asks why the constants of nature that enter various physical laws are such as to permit life to come into being. This engaging book is a well-written and detailed explanation of all the many ways these physical constants affect the possibility of life, considering atomic, nuclear and particle physics, astrophysics and cosmology. It then discusses in an open minded way the variety of explanations one might give for this strange fine-tuning, possible solutions ranging from pure chance, existence of multiverses, or theistic explanations. The book is the most comprehensive current discussion of this intriguing range of issues. Highly recommended.’

George Ellis, University of Cape Town, South Africa

‘Lewis and Barnes’ book is the most up-to-date, accurate, and comprehensive explication of the evidence that the Universe is fine-tuned for life. It is also among the two most philosophically sophisticated treatments, all the while being accessible to a non-academic audience. I strongly recommend this book.’

Robin Collins, Messiah College, Pennsylvania

‘... charming, intelligent and exceedingly well-written ... a gentle stroll through the details of the Standard Model of particle physics, as well as the Standard Model of cosmology, but [the authors] lead us with such a light hand, a streak of humour and a lack of pedantry that the information is easily absorbed ... Lewis and Barnes show us how small changes lead to a variety of disasters. (‘Ruining a universe is easy’ Mr. Barnes quips) ... Is [our universe] a happy coincidence, as the authors ask each other in an amusing mock debate modeled on one Galileo wrote 400 years earlier, or is there some deeper reason? Where does science go from here? Does what has been popularly called a theory of everything exist? Is there a multiverse? Must we be satisfied with an anthropic principle? The authors discuss these questions and more in a final dialogue.’

Gino Segrè, The Wall Street Journal

‘*A Fortunate Universe: Life in a Finely Tuned Cosmos* by Geraint Lewis and Luke Barnes, is a nice up to date book for the general (educated) public on modern physics and cosmology. It covers modern cosmology and some of the Big Questions of our times, in particular the issue of anthropomorphism how ‘fine-tuned’ our Universe is.’

Steinn Sigurðsson, ScienceBlogs
(www.scienceblogs.com)

‘... what is truly unique about this book is that it presents the data at a popular level so that the material is accessible to anyone interested in this topic ... As I read the book, I was awestruck by the finely tuned constants and conditions that had to be just right to get a universe that

would permit life ... This evidence should move each one of us to ask, what is the best explanation of this incredible fine-tuning?’

Tim Barnett, Stand to Reason (www.str.org)

‘*A Fortunate Universe* is basically a book of physics, written by two scientists who are fascinated by the question ‘Why are we here?’ The language is straightforward, the style is easy, often witty, with short digestible paragraphs, and yet the subject-matter is inevitably dense and demanding ... It is pleasing to come across the line ‘we do not know’ so regularly in this book about the fundamentals of science, which echoes the book of Job ... When science reaches its limits, we have to consider a different kind of explanation for why the laws of nature are as they are, and why they are so finely tuned for the emergence of intelligent life. ... [The authors] wonder if classical arguments for the existence of God have anything to say about the fine-tuning of the universe, speculating whether God is a necessary being and whether our sense of truth and morality hint at God’s inevitable existence.

Adam Ford, Church Times

‘The title claims that the Universe is finely tuned for the existence of life. The authors provide evidence for this, investigate various possible explanations, and rebut the most common criticisms ... the book provides an opportunity to learn more at an accessible level ... The case is well made that the Universe is finely tuned for life; the interesting question is why. It could be coincidence ... Or could the Universe be no other way? ... Was it designed? Did it evolve? Or are there many universes in a Multiverse, and we shouldn’t be surprised that we live in one which allows life? ... The arguments are clear; references are provided for those wishing to delve deeper; essentially all points of view are presented ... This is an important topic and the book is a good summary of the field. I enjoyed reading it and recommend it to those interested in the Big Question.’

Phillip Helbig, The Observatory

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‘It is the vivid, direct tone and writing style of a friendly physics lecture that perhaps most sets this text apart among popular-level science books about ‘big questions’ ... [The book] provides a big picture of the physics of fine-tuning, mostly accessible in lay terms, and gives aspiring philosophers of physics a taste of the tone and intellectual style one can find at cosmology conferences. Beyond that, it does so by showing the readers that a response from philosophers might be welcome. Because the authors make clear how their thinking is informed by works in metaphysics, philosophy of physics, epistemology, and the philosophy of religion, they tell the readers how they think philosophy does or could contribute, and where they think they do not know enough to see how it might.’

Yann Benétreau-Dupin,
Notre Dame Philosophical Reviews

‘This book is for anyone who has ever wondered: ‘Why is it so?’ With colourful analogies and admirably accurate simplifications, Geraint and Luke have succeeded in making much of modern physics and cosmology comprehensible ... They address the biggest questions of science. What is dark energy? What is dark matter? Why is there something rather than nothing? Why is there more matter than antimatter? Where did the laws physics come from? Do we live in a multiverse? Do we live in a simulation? How different could the universe have been? If God is omnipotent, why does evil exist? ... Not even the popular scientist and writer Paul Davies tries to address so many important big questions in one book ... I enjoyed the book a lot, but I disagreed with the main thesis. No matter what your religious beliefs are, this book will make you think.

Charley Lineweaver, The Conversation
(www.theconversation.com)

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Geraint

*To slightly misquote The Mamas and the Papas, this is
dedicated to the ones we love.*

Luke

*To slightly misquote R.E.M., this is dedicated to the ones we
love.*

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Foreword

Like a Bach fugue, the Universe has a beautiful elegance about it, governed by laws whose mathematical precision is meted out to the metronome of time. These equations of physics are finely balanced, with the constants of nature that underpin the equations tuned to values that allow our remarkable Universe to exist in a form where we, humanity, can study it. A slight change to these constants, and poof, in a puff of gedanken experimentation, we have a cosmos where atoms cease to be, or where planets are unable to form. We seem to truly be fortunate to be part of Our Universe.

A seemingly perfectly rational argument to come to terms with this streak of good luck is that, since we exist, we must therefore live in a Universe where we can exist. But this idea has at its heart the notion that ours is selected from a multitude of universes – and there is no evidence for, or against, such a construct of nature.

Our Universe is the only one we have, and this presents a remarkable problem for those of us who study it. Why is it the way it is? Science is founded on using ideas, often called theories, to make predictions. But what happens when, as with our Universe, there is only one thing to observe? Is a theory able to make a prediction when it is either right or wrong on one count?

My colleagues, Geraint and Luke, in *A Fortunate Universe*, take you on a tour of the cosmos in all of its glory, and all of its mystery. Along the way you will learn about the fundamental equations of quantum mechanics that govern our existence, about the concepts behind energy and entropy (and don't be fooled by their description of Canberra, which has far more free energy in it than any Sydney-sider will ever realize), and of course about gravity, which is the primary governor of the Universe on planetary and larger scales.

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On your journey with Geraint and Luke, you will see that humanity appears to be part of a remarkable set of circumstances involving a special time around a special planet, which orbits a special star, all within a specially constructed Universe. It is this set of conditions that has allowed humans to ponder our place in space and time. I have no idea why we are here, but I do know the Universe is beautiful. *A Fortunate Universe* captures the mysterious beauty of the cosmos in a way that all can share.

Brian Schmidt
Australian National University
Canberra

Preface

To a human, living on Earth feels just right. Of course, many of the human race face challenges, such as poverty and sickness, on a daily basis, but it can feel like our planet was made for us.

We find ourselves in a neatly placed orbit around a stable, middle-aged star, with the strength of our bones nicely matched by the Earth's gravitational pull, allowing us to ramble freely over the planet. There is oxygen to breathe, and we can power ourselves through the digestion of many tasty plants and animals that inhabit the surface. We would last but a few seconds if we were dropped onto our neighbouring planets. We would be crushed and roasted on the surface of Venus, or left gasping and freezing in Mars's tenuous atmosphere. For humans, the Earth is a special place, a relative cosmic paradise where the conditions are just right for life, including our human life.

But over the past few centuries, we've come to discover how we came to be so nicely suited to conditions on Earth. Our physical properties, our bone structure, our organs, our senses, result from life continually changing and evolving over the last 3.5 billion years, adapting to the conditions that surround us.

The realization that the Earth is not unique changes our view of our place in the Universe. Driven by the continual advancement of science, we have found that humans are part of the web of life, that the Earth is just one of a myriad of planets, and the Sun is but a boringly typical star. Our place in the Universe is just like many, many others, and in no way unique.

Peering more deeply into these same scientific advances, examining the basic make-up of the Universe, reveals that we are not as mediocre as it seems. The fundamental particles from which

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everything is constructed, and the fundamental forces that dictate interactions, appear to be fine-tuned for life. Minor tinkering with either would leave the Universe dead and sterile.

With every step forward in science, these fine-tuning issues have become more significant. We find ourselves questioning the nature of many of the things we take for granted, from the fabric of space and time, to the mathematical underpinnings of the Universe. At every level, we find that our Universe's ability to create and sustain life forms is rare and remarkable.

The discussion of this cosmological fine-tuning for life has found a very broad audience, from philosophers and physicists in the halls of academia, to religious believers who see the mysterious hand of the divine. It has captured the attention of the popular media, and generated random frothings in various recesses of the internet. All too frequently, the science, and what it is actually telling us about the fine-tuning of the Universe for life, is lost in the noise.

The goal of this book is to present the scientific viewpoint of the fine-tuning of the laws of science, and delve into its implications for the inner workings of the Universe. We will call upon the latest academic and philosophical musings to clarify what fine-tuning actually means and to set the scene for what we can conclude from our existence as life forms.

This book has been a long time in gestation, with the original idea coming from many rambling conversations between the authors and others, the kind of discussions and arguments that lie at the heart of science. Sitting around the table, we wondered about the expansion of the Universe, the nature of electrons, and how many different kinds of universes there could be. We scratched our heads over the make-up of dark matter and dark energy, and wondered deeply about how things could have been different. This quickly leads to the realization that life would be very difficult, if not impossible, in the vast sea of possible universes.

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Our hope is that this book crystallizes these discussions, reflecting the rollercoaster of the scientific journey. We hope it gets you thinking about the question that drove us, the question that has dogged humans from the earliest times, the question that we hope we are on the road to answering: why are we here?

Acknowledgements

‘Why don’t you?’ With these words, this book was born. They were uttered by science communicator extraordinaire, Dr Karl Kruszelnicki, when Geraint stated that he had always wanted to write a book. Since this initial conversation, Dr Karl has been a continual source of information, inspiration and enthusiasm.

Writing this book presented a challenge. But the act of getting this book into print presented a mystery, especially to two cosmologists with no understanding of the book industry. But a coffee at the lovely Michaelhouse Cafe with Vince Higgs from Cambridge University Press set us firmly on the road to publishing. His support and professionalism to bring us to this point have been exemplary, and he deserves our greatest thanks.

Many colleagues, both near and far, contributed to the development of this book. Thanks to Mike Irwin and Rodrigo Ibatá for astronomical images, and Pascal Elahi for cosmological simulations. There are many more with whom we have chatted, argued and harangued over the question of fine-tuning, far too many to name here. We hope we have convinced you that this apparently trivial problem is not as trivial as it might seem.

For the brave souls who volunteered to read early drafts of this book, we thank you. Thank you Nick Bate, Jon Sharp and the anonymous CUP reviewers. We would also like to thank Robin Collins, Trent Dougherty, Allen Hainline, Osame Kinouchi, Tom Murcko, Matt Payne, Josh Rasmussen, Brad Rettler, Mike Rota, Daniel Rubio and Stuart Starr.

Friends are a vital part of life, and Geraint thanks Matt and Jon for the sporadic meetings over the last thirty years, meetings that have led to much laughter and adventure. Rodrigo is thanked for his

friendship and intellectual jousts, from physics to economics, history to biology, and many, many hours debating Gott's Domsday hypothesis.

Through our families we have received immeasurable love and support. Words can be inadequate, but Bryn and Dylan, you have been the most important and wonderful things in Geraint's world from your first seconds on this planet. Except for Zdenka, you are simply more wonderful and more important. To my parents and brother, I hope this book explains what I actually do for a living!

Luke would also like to thank Geraint for inviting him to be a co-author, and for his dependable and unique brand of grumpy enthusiasm. A special thank you to all the audiences who have interacted with his talks about fine-tuning, and especially the philosophers at the 2011 and 2015 St Thomas Summer Seminars in Philosophy of Religion, run by Mike Rota and Dean Zimmerman. Luke is supported by a grant from the John Templeton Foundation. The opinions expressed in this publication are those of the author and do not necessarily reflect the views of the John Templeton Foundation.

Luke thanks Bernadette, to have a wife who is willing to support book writing, travelling, Saturday afternoon cricket, and bass ukulele playing is 'worth far more than rubies'. You are amazing. To my kids, for being the cutest 5- and 2-year-olds on the planet, and insisting on a cuddle, kiss and high-five every morning before I leave for work. To my parents and siblings, for their constant love and support; 'photons in a box' are explained in detail in Chapter 6.

If there are any words we can give to budding authors, it's seize the day, open that crisp new document, send those emails, and remember that fortune truly does favour the brave.