

additional detail about Apollo, and other more current programmes, and it has to be said some rather ghoulish accident information.

After over 60 years of human excursions beyond the atmosphere of our planet, perhaps it is time to make an evaluation of what we have learned; what benefits have accrued to those left on the ground, and to make a judgement on whether it has all been worth the vast outlay of earthly resources and to answer the question; is the project worth continuing? With his wide experience in communicating space science, Peter Bond is perhaps a well-placed writer to do that. I lost count of the number of times he reports astronauts taking part in experiments to do with human physiology, or making use of various furnaces and electron guns to study metallurgy or crystallography, although rather few results are described. Experiments to test antibacterial and antiviral materials are apparently useful for application in the design of lift buttons. However, other than those examples and some generic statements about the development of high-tech industry and associated jobs and of course the few satellite-repair missions, this book does not address any major developments that have resulted from people doing science in microgravity.

Space research is currently being funded by national governments and the four wealthiest private-enterprise organizations the world has ever seen. This book does not tell us how any of those organizations suggest putting people into space will assist in solving the major problem currently facing humanity: the relentlessly warming planet. In the 65 years since Gagarin's flight the world annual CO₂ emissions from fossil fuels have increased from around eight billion tonnes to 38 billion tonnes and the average global temperature during the summer months has increased from 15.6 °C to 16.8 °C and with each decade that increase is accelerating. Space research has certainly been absolutely central to our knowledge of those numbers but almost exclusively by the use of sophisticated unmanned satellites. There is a very good case to be made that humanity has gained enormous benefits from the use of unmanned satellites through all sorts of remote sensing: Earth observation, astronomy, telecommunications, navigation, *etc.*, *etc.* — it is less clear that such obvious returns can be seen from manned spaceflight.

The case is not made in this book, which does not claim to be a book of analysis but a very thorough compilation of historical facts arranged in thematic chapters and as such it is a very good and often surprising resource. One must admire the research involved in assembling this detailed listing of components, processes, and interactions; there is, however, no attempt at understanding of purpose other than getting done the job of putting humans into space — there is no 'why'. It is a book of comprehensive listing and description of salient facts without addressing the current overarching purpose, and perhaps that is a true reflection of the space agencies' and private-enterprise ambitions. To use the coarse language of our times: is manned spaceflight any more than expensive 'willy wagging'?

In a book so full of facts I spotted just a few errors, and really only one worthy of comment. Unfortunately, it is on the first page of the first chapter, where we read that rocket propulsion is based on the principle of "Sir Isaac Newton's third law of *thermodynamics*" [my emphasis]. I guess an autofill-suggested word had slipped in, unnoticed by the author, it was then missed by the copy editor, and also missed again at the pre-publication proof stage. Maybe it is churlish to complain that in a book overflowing with facts I found only a few that bothered me — but but but, "Newton's third law of thermodynamics". Mr. Bond, I was "shaken and not stirred". Hopefully it will be corrected for the paperback edition of this thoroughly enjoyable, excellent compendium of the whole range of human space adventures. — BARRY KENT.

The Physics of Interstellar Travel, by Coryn A. L. Bailer-Jones (Cambridge University Press), 2026. Pp. 358, 26 × 21 cm. Price £55 (hardbound; ISBN 978 1 009 68392 8).

For many years now, unmanned space probes have been traversing the Solar System. Some have landed on, or gone into orbit around, some of the planets and their satellites. The very

earliest, *Voyager 1*, is already (since 2012) moving into the interstellar medium (ISM) but will take some 77 000 years to get to the distance of our nearest star. Manned spaceflight is currently largely confined to the Moon, although there are ambitions to build a base on Mars.

Interstellar travel is still a dream, despite *Voyager 1*, but of course if humans are ever to emulate science fiction and journey to other stars then we should be thinking about what it would involve. That's precisely what Bailer-Jones's book addresses. The author makes a systematic study of the physics of the medium through which any space probe would pass and the hazards that it would encounter. The treatment is mathematical and is suitable for a reader with a good understanding of physics at the level of an undergraduate degree.

There is a short introductory chapter, setting the scene and outlining the contents of all 17 chapters, before moving on to Chapter 2, which considers motivations for interstellar exploration, gives essential background information, and talks briefly about the nearest stars and time-scales. It becomes clear that any chance of reaching other stars in a reasonable time requires interstellar probes to be moving at some fraction of the speed of light, say $0.1\ c$.

Chapters 3 and 4 cover the theory of rockets and discuss orbital mechanics while chapters 5, 6, and 8 discuss various types of rocket engine, from thermal- and ion- to nuclear-powered, with relativistic effects on motion (with a clear discussion of the twin paradox) and on their effects on what we see (aberration and the Doppler effect) covered in chapters 7 and 9. Chapter 10 introduces the concept of solar sails, with a clear discussion of the practical difficulties. The next chapter considers using a laser rather than the Sun as a driving mechanism for the sails.

Of course, that kind of probe is light and easily affected by the ISM so the author here inserts a chapter on the ISM, considering the effects of impacts and the resultant drag and explaining the principle of the ramjet, which he regards as very speculative at this stage. Chapter 13 covers more exotic forms of sails, involving magnetic and electric fields.

The next question that arises is how to make sure the interstellar probe goes in the right direction and knows where it is in some inertial frame. Bailer-Jones spends Chapter 14 discussing navigation in general. Within the Solar System, where light-travel times are relatively short, it is a solved problem, with an agreed reference frame (ICRF — the International Celestial Reference Frame) based on the Solar System barycentre (SSB), using radar ranging. Out in the ISM ranging becomes impractical and the probe must do its own navigation. Instead of ranging, the probe must use other reference points, such as bright stars with precisely known positions and velocities in the ICRF. Alternatively, it is possible to use pulsars, but that is more complicated, as he explains.

Back on Earth, meanwhile, we would like to know what the probe is finding, so the final problem is getting the information back. Once the probe is well out into the ISM, two-way communication is unrealistic and even getting data back is slow — it may take months or years to send the information back at a low bit rate because the probe doesn't have the power to transmit faster. Chapter 15 discusses all the ramifications. Chapter 16 discusses possible payloads, including what instruments might be used. The mass of those instruments would have to be small, especially for sail-driven probes, so one option might be to send out swarms of probes, each with a different instrument, and some redundancy built in to avoid losing everything if a probe is lost.

Finally, Chapter 17, 'Outlook', starts by considering very briefly (and dismissing) wilder ideas such as wormholes before going on to real-life challenges and possible solutions. Bailer-Jones then considers broader issues: Should we undertake interstellar travel? Is it ethical? Is it dangerous? And — where do we go from here? None of the technology required currently exists, but some is within reach in the next half-century or so.

This book is clearly written, with useful summaries at the end of each chapter. The mathematics is deliberately simplified to enable the basic principles to be explained without obscuring them by the detail that would be needed in a realistic description. One comment

is that, although he does occasionally mention the power needed to make and send such probes, he does not discuss the fact that it is well beyond current world power usage. But that would be straying into politics, so he's probably wise to avoid that. The book is really an answer to the question: if we want to send out probes into space at $0.1c$, what are the physical requirements? This would be a useful book for anyone thinking about a career in astronautics, and is also of general interest. — ROBERT CONNOR SMITH.

The Multiverse: When One Universe Isn't Enough: Uncovering a Universal Mystery,

by Brian Clegg (Icon Books), 2025. Pp. 190, 20 × 13 cm. Price £10.99 (paperback; ISBN 978 1 8377 3236 7).

Brian Clegg is a well-known popular-science writer and I've reviewed^{1,2} a couple of his previous books^{3,4} in these pages. The Multiverse is the subject of several books⁵⁻¹⁰ reviewed¹¹⁻¹⁶ in this *Magazine*, so this book was an obvious choice for one of the dozen books I bought at an English-language bookstore after attending a thesis defence in Amsterdam a few weeks ago. Already in the acknowledgements (which is mostly a preface), Clegg mentions his sceptical stance on the Multiverse. Perhaps because he is not trying to convince the reader of the reality of the Multiverse, the chapters illuminate various ideas related to the Multiverse rather than working together towards some goal. We get brief descriptions of a motley collection of topics: the idea of the Multiverse, our Universe (one definition of the Multiverse is the sum of observable universes — the sum being Tegmark's Level I Multiverse —, each of which is smaller than the (possibly infinite) ensemble, though usually as used by other authors 'Universe' refers to Tegmark's Level I Multiverse), the simulation hypothesis, imaginary numbers and quaternions, fine-tuning, inflation, the many-worlds interpretation of quantum mechanics, string theory, the ekpyrotic model, the holographic principle, Tegmark's mathematical universe, and pop-science YouTube personality Sabine Hossenfelder. Sometimes I agree with Clegg's sceptical take, *e.g.*, when discussing inflation (though he omits the strongest argument for inflation: a mechanism for the origin of primordial density fluctuations). More often, though, his scepticism seems to be due mostly to a matter of taste (in the acknowledgements/preface, he mentions his sadness when the Steady State model was ruled out, possibly because he was a fan of Hoyle's science fiction).

The book is well-written with few typos; Clegg knows his trade. On the whole, the book is a good (but very brief) introduction to the topics mentioned above. However, whether intentionally or not, the combination of the trivially true, very speculative, and everything in between tends to cast a too sceptical light on things which are almost consensus; maybe Clegg hopes that the reader will come to dislike the same things he does once they've become tainted by association with the Multiverse. There are also a few common misconceptions, such as the ideas that dark energy causes the expansion of the Universe (and it seems to be implied that a negative cosmological constant would lead to contraction) and that inflation is basically faster-than-light expansion. The discussion of the Strong Anthropic Principle is confusing at best. His discussion of the inverse gambler's fallacy is somewhat unorthodox, perhaps to aid his comparison of it to the idea of the Multiverse (while at the same time not even mentioning other reasons for believing in some sort of Multiverse). That discussion is inspired by Philip Goff, who is known primarily for his belief in panpsychism. While people can be right about some things and wrong about others, Goff seems like a strange bedfellow for someone like Clegg pushing a less speculative and more down-to-Earth view.

There are a few footnotes, no photos, and the main text is followed by three pages of suggestions for further reading (many by Clegg, but also many presenting different points of view on the idea of the Multiverse) and a four-page small-print index.

In a review of another book by Clegg, I wrote "I would like to give the book a better recommendation, since it is generally well written and manages to give a good overview". My desire with regard to this book is somewhat less, because in addition to mistakes I detect an agenda. It's not a problem that I disagree with his opinion; rather, my impression is that