paper, but by the same token there would be no need to cite the rebuttal. Also, in order to show that a paper is wrong, one has to know the material better than the person who wrote the original paper. (There is also the problem that if one shows that the original paper is correct, many journals won't publish such a confirmation, even though that is also an essential part of science, thus reducing the motivation for exploring a topic without knowing the outcome, which of course is the way it should be done.)

What can we expect in the future? I doubt that all of the suggestions (except perhaps the one, correct suggestion) will be shown to be wrong on their own terms (as opposed to being a good theory which is merely ruled out) on a case-by-case basis. Solutions for which some testable prediction is confirmed could be seen as more likely, and of course those with failed predictions could be ruled out. Many of the solutions are *ad hoc* in the sense that it was the Hubble tension itself which led to their proposal; that is not necessarily an indication that they must be wrong, and sometimes there is some additional justification. I'm happy to be corrected, but as far as I know there was no theory which *predicted* the current Hubble tension of about 6 km/s/Mpc (with statistical uncertainties claimed to be much smaller); while technically postdictions are just as good, predictions are more impressive.

Whether the solution turns out to involve interesting new physics or some banal explanation, perhaps the most interesting result will be that a consensus on the cause of the Hubble tension will rule out all of the other proposed explanations with one fell swoop.

Yours faithfully,
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REVIEWS

The Reinvention of Science. Slaying the Dragons of Dogma and Ignorance, by Bernard J. T. Jones, Vicent J. Martinez & Virginia L. Trimble (World Scientific), 2024. Pp. 493, 23 × 15·5 cm. Price £45 (paperback; ISBN 978 1 80061 360 7).

Most readers of *The Observatory* would be able to construct a historical timeline of our subject: perhaps by an ordered list of the kings and queens of our particular realm, and at least for the western story, the list goes something like: Babylonians, Greeks, Anaximander, Aristarchus, Ptolemy, Aristotle, Copernicus, Tycho, Kepler, Galileo, Newton, Einstein — then boom: the explosion of knowledge and us.

A few learned souls might add Giordano Bruno or the oddly named medieval Oxford scholar Robert Grossetestes — but even fewer know Copernicus's publisher and by what process he was selected. The authors tell us he was chosen *via* a centuries-long thread that starts with a text book on optics based on the writings of the Islamic scholar Alhazen in about the year 1000. This original work tumbled through the early centuries of the second millennium and along the way got translated into Latin and was subsequently published by Petreius in Germany in 1535. That published book was acquired by a friend of Copernicus and shown to him and thus he approved the publisher. It is that extra depth that makes this *Reinvention of Science* so different from many other history-of-science volumes and such a pleasure by which to be enveloped. You may also note that my list of kings and queens does not in fact include any queens and the authors would be very keen to correct that error. I should at least add Henrietta Leavitt, Cecilia Payne, Marie Curie, and Mary Anning. But wait! — Mary Anning was a fossil hunter not an astronomer. Indeed, the book is titled *The Reinvention of Science*, and although mostly told through the story of the unravelling of the evolution of the Universe, its much larger remit covers all of the relevant physics and thus geology and the ancient history of the Earth — including dinosaurs.

The opening chapter starts not with the Babylonians, as most traditional science histories do, but with Albert Michelson assembling his interferometer in the basement of a building borrowed from Edward Morley (his own laboratory, that he had been setting up for four years, had been destroyed by fire). Michelson and Morley were attempting to measure the Earth's movement through the luminiferous ether, and as we now know, no such movement was detected and also no such ether. The ether is the first of the Dragons, the slaying of which this book describes. Dragons are here defined as invisible, undetectable entities that are required to support the prevailing scientific consensus on the nature of the Universe at the time they were first postulated. The Crystalline Spheres holding up the stars is another, much earlier one. As the authors remind us such spheres were not such a crazy idea in a world in which unseen forces, like gravity, acting over long distances were unknown. If not crystalline spheres what else could fit the observations? The same rationale guides our thinking to this day.

As well as slaying Dragons the authors also challenge Dogma, one such being the requirement for the right sort of man to be engaged in and to write papers about science. This dogma excluded the acknowledgement of women's contributions for centuries and for just about as long, maybe longer, people of the wrong colour or social class. The authors are at some pains to ensure that the relevant women are mentioned, and celebrated, and also the common folk of whatever gender. For example, Milton Humason, Edwin Hubble's poorly educated mule driver, removal man, and telescope handler, who through determination and delicacy of touch, developed into the key scientist in recording the spectra of faint galaxies to enable the expansion of the Universe to be deduced.

In my reviewing notes for this book I find I often comment on the clarity of description. The overall tone is measured and scholarly and yet also light. For example, there is a beautifully concise description in Chapter 1 of Epicurean thought finding its way into the western world and giving us the concept of atoms and even the idea of heat as movement of atoms and almost the first inklings of Brownian motion. Another beautifully concise passage of just over two paragraphs, in Chapter 17, covers the description of the contents of the

Universe. As a further example of the extra detail provided, this passage notes that of the everyday baryonic matter which makes up just about 5% of stuff in the now-standard description of the Universe, just 0·5% is luminous objects: stars and galaxies, and 4·4% is non-luminous other stuff. The remaining dark matter is non-baryonic and about which we currently know very little. We are equally clueless about the almost 70% of stuff described as dark energy.

The authors' lightness of touch is seen in references to popular culture — The Simpsons and The Flintstones being offered as examples of how one side of a debate can become unquestioned dogma in a serious discussion on the causes of the extinction of the dinosaurs. As every school child knows, meteorite impact is the accepted cause, and yet the case for an extended demise through vulcanism is currently an equally strong candidate. This section also notes the advantage of having a good publicity machine when competing for limited publicly funded research money, but also the potential disadvantageous effect of bandwagons illustrated by a Walt Disney film that popularized the erroneous myth of lemming suicides.

Not just the past, but the present and future are also covered with the same measured tones. The final half of the book deals with the current state of physics, with detailed descriptions of the recent detections using the new techniques of gravitational-wave astronomy, and the search for polarization of such waves as signatures of primordial gravitational radiation. The final chapter deals, perhaps a little too uncritically, with the march of the machines and the possibilities of artificial intelligence as a potential tool for assisting in the analysis of forthcoming huge data sets.

In addition to the main text there are 73 pages of notes, and I had great fun checking and following links to the web pages; there is a ten-page index of names and 26 pages of subject index. So as well as clarity, detail, and scholarship one can also add thoroughness. At £45, however, this is quite expensive for a paperback, even one of 493 pages, and as a physical item the appearance may not reflect that price. Textually there are just a couple of obvious typos and the proof reading or editing goes awry for a few pages in the middle section. A huge omission for such a general title would seem to be that, other than a glancing mention of the Egyptians and China in the first chapter, the parallel history of science in non-western countries is barely mentioned. However, within the context of current science the content is very good — the layout and text are beautiful and there is so much wisdom and pleasure contained within these pages that I believe the price to be worthwhile.

All of us who paddle in the streams of scientific enquiry have our toes and our souls soaked in the search for fundamentals. Some in sleek clipper ships crash through the deepest oceans of abstruse mathematical scholarship while others paddle in the muddy, murky waters of experiment and instrumentation — all of us believing that we follow a flow, a direction to the one path of truth. But is finding truth the same as finding the good?

In conclusion I was tempted to quote the final philosophical sentence of the last chapter, but that would be as crass as giving away the ending to a detective novel. I will instead quote from the very beginning. In the preface Neil deGrasse Tyson, the director of the Rose Planetarium in New York, has said on Twitter and television "science is true whether or not you believe in it",

I can only add that in looking for the good as well as the truth this book offers both, a scientific truth and a book that is very good — almost excellent. — Barry Kent.

The Allure of the Multiverse: Extra Dimensions, Other Worlds, and Parallel Universes, by Paul Halpern (Basic Books), 2024. Pp. 308, 23 × 13 cm. Price $30·00 (about £24) (hardbound; ISBN 978 154160217 5).

[*The Observatory* has received two reviews of this book and the Editors feel that our readers will enjoy both, coming as they do from our two most prolific and experienced reviewers.]

Most people…many people…well, anyhow your present reviewer, sometimes wish they had done some things differently, rent or buy, accept that job instead of this, maybe even marry someone else*. This must be part of the attraction of the idea of reincarnation. Could it also be part of the charm of multiverses? Maybe you don't get to try the other fork in the road, let alone a spoon†, but somewhere/when another 'you' does. This frivolous thought is just about the only motivation for multiverses not addressed in this volume by the science historian and author Paul Halpern, professor of physics at St. Joseph's University.

Not that the book is wholly solemn! If you enjoy a chase sequence, I recommend pp. 174–175, the lead up to inflationary cosmology, and there are leaking balloons among his highly original analogies. *Allure* is organized in a semi-historical fashion. Chapter 1 starts with Kepler. Later chapters each take one sort of multiverse idea and follow it down to extinction of viability or the present. These include additional dimensions (with a fine explanation of Kaluza–Klein theories); Hugh Everett's many-worlds interpretation of quantum mechanics (in which everything that can happen does happen, just mostly not on our time line, so that somewhere, Schroedinger's cat lives to be at least a 100); anthropic and Mixmaster universes; inflation, strings, and cyclic universes. As well as many ideas, many people appear, some with firm views pro or con on the ideas. Stan Deser, for instance, appears just before page 1 saying "I think we have enough *tsuris* with one Verse." Deser had in common with Halpern childhood knowledge of Yiddish from parents and grandparents. With some embarrassment, I found myself on page 24 (part of the Introduction) quoted on the 'pro' side, on the grounds that there have turned out in the Universe to be many planets, many stars, many solar systems, many galaxies, clusters, and superclusters thereof, so why not many universes? (I meant to count the number of people indexed and the fraction you might have been expected to have heard of before (in a sort of inverse of *Wer zaehlt die Voelker — nennt die Namen*) but kept getting interested in what Halpern had to say about my favourites and so never got past the middle E's (Queen Elizabeth II and George Ellis) with the count.) So, acquire the book, count how many of your scientific and other heroes are mentioned, and generally enjoy it all! — Virginia Trimble.

Paul Halpern, professor of physics at St. Joseph's University in Philadelphia, has written 18 popular-science books, though this is the first I have read. In

*Not your present reviewer, who continues of the opinion that Joseph Weber (who makes a cameo appearance in this volume as a participant in the Chapel Hill conference on General Relativity, later called GR1) was unquestionably the best husband in all the possible multiverses.

†The suggestion "when you come to a fork in the road, take it," is attributed to Yogi Berra. Stanley Deser made use of the phrase in a recent autobiography reviewed in these pages (143, 242, 2023), but we are saving him for a quote later about multiverses.

contrast to some other books mainly about the Multiverse[1–3] or dealing with it to some extent[4,5], some reviewed in these pages[6–9], this book is somewhat less technical and takes a broader perspective (*e.g.*, pointing out that the term 'Multiverse' was coined by William James, though in the context of moral philosophy rather than cosmology); as such, it is perhaps a good first book on that topic (but shouldn't be the last). The introduction sets the stage, introducing various types of Multiverses and discussing historical ideas. The first chapter is basically an overview of classical physics, starting with the idea of recurrence, which is a sort of Multiverse in time rather than space, including ideas which were once taken more seriously than they are now, such as a putative connection between spiritualism and the fourth dimension. The second chapter is devoted to the first serious attempt to incorporate higher-dimensional space into physics (though not — yet — in the context of a Multiverse), Kaluza–Klein theories, the idea being to describe electromagnetism as well as General Relativity in the language of a geometrical theory with one more spatial dimension, and explaining quantization by having that dimension curled up. It is a very good non-technical description. While such theories themselves are now a backwater in the history of physics, they later influenced other ideas such as string theory. The next two chapters cover quantum mechanics and cosmology, providing an overview of those aspects relevant to the idea of the Multiverse. The next few chapters discuss various ideas which lead to the concept of a Multiverse, such as eternal inflation, string theory, and cyclic cosmologies (again, more a Multiverse in time than in space). Chapter 8 explores time travel, which in some interpretations can lead to multiple universes if a traveller returns to the past: one in which he returned to the past and one in which he didn't, perhaps because he had killed his grandfather (or taken some less drastic but just as effective measure).

The first three of Tegmark's[1] four Levels of Multiverses are all discussed: the part of our Universe beyond our horizon, different universes of which ours is but one example, and the many worlds of the many-worlds interpretation of quantum mechanics. The idea of a universe splitting due to the actions of travellers in time is a new aspect. However, the emphasis is not so much on different types of Multiverses but rather on different ideas which can lead one to the concept. On the other hand, Tegmark's Level II Multiverse — which is probably the one (apart from the trivial Level I) most are most willing to accept — is discussed mostly in the context of eternal inflation, although the general idea is much older (*e.g.*, ref 10). In general, the title is a good description of the book: it is about the allure of the Multiverse, *i.e.*, what makes it an attractive idea in various contexts, rather than more technical aspects. As such, the necessary background material blends well with and complements those parts more about the Multiverse *per se*.

The final chapter, somewhat misleadingly entitled Conclusions, spends, in my view, too much time discussing the general idea of a Multiverse, or parallel worlds, in popular culture. While Halpern makes it clear that such ideas have practically no overlap with the scientific ideas of the Multiverse, by the same token they really don't belong here. Towards the end, though, is a good summary, emphasizing the fact that in many other contexts most are content to accept things which are not *directly* observable (*i.e.*, the interior of black holes, the inflaton, the 'dark ages' of the Universe), even though they might use the lack of direct detectability as an objection to the Multiverse.

My copy is an uncorrected page proof, courtesy of the author, though presumably very close to the final product since, apart from figure captions at the end of the book rather than accompanying the figures, it looks very much like a normal book; the contents as well appear to be almost final. There are only a few actual typos and a couple of phrases which probably read other than intended. As usual, I would have phrased a few things differently, but on the whole the book is well written and one notices Halpern's experience as an author — not just in terms of style, but also with regard to presenting everything at the right level. Although it is not a highly technical book, there are none of the typical oversimplifications often encountered in popular-science books. All but one of the 22 black-and-white figures scattered throughout the book are of people. There are no footnotes and endnotes are all references to sources such as articles and interviews, most by Halpern himself with the scientists he writes about (a frequent contributor to this *Magazine* also makes an appearance). There is no index (a possible difference from the final version); the further-reading list (three-and-one-half pages of small print) is particularly thorough.

This is an enjoyable book which manages to weave well together the concept of the Multiverse, current ideas in physics related to it, and the (sometimes quite old) history of those concepts. — PHILLIP HELBIG.

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Scientific Debates in Space Science. Discoveries in the Early Space Era, by Warren David Cummings & Louis J. Lanzerotti (Springer), 2023. Pp. 264, 24·5 × 16 cm. Price £64·99 (hardbound; ISBN 978 3 031 41597 5).

Although the subtitle of this book is 'Discoveries in the Early Space Era', it might equally have been 'The Scientific Method in Theory and Practice', for its focus is not so much on informing us of present understanding of a number of high-profile topics principally in planetary and space-plasma physics, but unusually and interestingly on providing an account of how such status was achieved through the contentions of past years. Typically, the time-frame considered spans the 1960s to the 1990s, some controversies lasting longer than others, with emphasis on the protagonists involved, many now deceased, and their mutual interactions. To this purpose, the authors have evidently immersed themselves at length in the literature of the period, allowing the proponents to speak directly for themselves by quoting short sections verbatim from key published works, illustrated by original figures. Each topic is rounded out, however, with a 'Continuing Understanding' coda, bringing things briefly up to date.

Of the topics considered, three lie in the field of space-plasma physics, two of which concern the solar wind. The first deals with the nature of the outflow, whether supersonic as proposed by Gene Parker or subsonic as suggested by Joseph Chamberlain, an issue debated in the late 1950s and early 1960s before being quite rapidly resolved in favour of the former by the first thermal-plasma measurements by Soviet and US spacecraft. However, the subsequent issue of the distance to the shock that terminates the supersonic outflow, and from thence to the heliopause boundary with the interstellar medium beyond, was only resolved by *Voyager* particle and field data during the past ~20 years, following a debate that lasted for almost 50 years. The third issue covered in space-plasma physics concerns the properties of the Earth's magnetosphere, whether magnetically 'open' as proposed by Jim Dungey in 1961 or closed as argued by Alex Dessler, on which indirect evidence in the 1960s and 1970s and direct evidence principally in the 1980s and 1990s ruled in favour of the former.

In addition to briefer discussions of some less-controversial topics such as the discovery of the Earth's radiation belts by James Van Allen, the book also covers four significant debates in planetary physics. The first two concern the origin of the Earth–Moon system, the subject of many past hypotheses but now considered to have resulted from the impact between a Mars-sized body and the early proto-Earth, and, much later in Earth's history, the cause of the Cretaceous–Paleogene mass extinction event and its association with the Chicxulub asteroid-impact crater originated by Alvarez *père et fils*. A related topic concerns the depth of the dust layer on the lunar surface produced by meteorite bombardment, which Tommy Gold in 1955 suggested might be sufficiently deep in some locations that astronauts would disappear up to their armpits or beyond, a speculation happily disproved by space missions preparatory to the Apollo landings.

More infamously, in 1986 Lou Frank proposed on the basis of spacecraft ultraviolet imaging initially intended for auroral studies, that the Earth's upper atmosphere is being continuously bombarded (several per minute) by small cometary bodies that would have profound significance for Earth's water budget. This assertion triggered 17 years of lively debate involving no less than 32 papers, comments, and rebuttals published by Frank and colleagues, together with experimental studies by others, that ended with the general perception that these signals were, after all, due only to instrumental effects within the auroral-camera system, a conclusion that appears never to have been acknowledged by the proponents. As the contents of this fascinating book make clear, though the 'scientific method' of testing, verification, and refutation does eventually sift the scientific wheat from the chaff, the length and nature of that process may depend significantly on the human personalities involved. — Stanley W. H. Cowley.

The Era of Multi-Messenger Solar Physics, edited by Gianna Cauzzi & Alexandra Tritschler (Cambridge University Press), 2023. Pp. 160, 25 × 18 cm. Price £120/$155 (hardbound; ISBN 978 1 009 35288 8).

This volume is the Proceedings of IAU Symposium 372, co-ordinated by IAU Division E with other working groups, which was held in Korea in 2022 August at the tail-end of the Covid pandemic. The nearly 80 contributors were mostly from Asia but with some from the US. The main motivation for the meeting was the recent solar space missions, *Solar Orbiter* and the *Parker Probe*, and the *Daniel K. Inouye Solar Telescope*, largest ground-based solar observatory in the world, still in its commissioning phase at the time of the conference. The 'multi-messenger' of the conference title refers to the way these and other solar observatories are gaining knowledge of, for example, the connection of the magnetic fields in the distant solar atmosphere with the magnetic field at the solar surface.

With such new observatories in operation, or about to be, I expected review articles that summarize the subject for those not immediately involved, but it was surprising that there was only one of real use, putting things into a historical context. There are, however, extensive original research articles on novel techniques like machine-learning, the association of coronal mass ejections with flares using statistical methods, and the capabilities of the Atacama millimeter-wave *ALMA* array applied to solar observations. Among the many short contributions from participants was one that caught my eye, connecting avalanches of MHD waves to nano-flare heating of the corona.

The high price tag of this slim volume will obviously be a deterrent to prospective buyers including even university libraries, and there is also the factor that many of the papers in these proceedings will now have appeared in solar physics journals. The quality of production is high, as would be expected from this publisher, but there are no coloured figures which would have been welcome for interpreting the many detailed images of the solar surface in some of the papers. — Ken Phillips.

On the Origin of Time: Stephen Hawking's Final Theory, by Thomas Hertog (Penguin), 2023. Pp. 326, 23·4 × 15·2 cm. Price £10·99 (paperback; ISBN 978 180499112 1).

Belgian cosmologist Thomas Hertog was one of Hawking's last collaborators; the book was written, at Hawking's request, to popularize their joint work, which goes against some of Hawking's earlier work. In some sense, it is similar to another book[1] recently reviewed[2] in these pages in that it is about Hawking, working with Hawking, and the results of that work, though this book concentrates more on the science. An undergraduate at the Flemish-speaking Katholieke Universiteit Leuven (Georges Lemaître was associated with the mostly French-speaking Université catholique de Louvain, which moved to Louvain-la-Neuve when the old site became Flemish-speaking in 1968), and after master's and doctoral degrees in Cambridge (the latter with Hawking), Hertog, after working in the USA, France, and Switzerland, returned to Leuven as a professor in 2011 (and is now head of the theoretical-physics group at the department of physics and astronomy). His collaboration with Hawking extended essentially until the latter's death in 2018.

The basic idea of Hawking and Hertog (H&H) is that, similar to biological evolution, the Universe — not just the outcomes of the laws of physics but the laws themselves — is best understood as the contingent result of (quantum) branchings during its history (perhaps influenced by future events), rather than something which one could, at least broadly, derive from first principles, thus going beyond the classical difficulty of computing deterministic outcomes *in practice* and even beyond quantum indeterminacy. If that sounds vague, then that is because it is, at least to me. Those interested in a short summary (but too long to reproduce here) by Hertog himself can read the section starting with the last third of p. 188.

Hertog does a good job of providing a necessary overview of the history of cosmology, especially since the advent of relativistic cosmology somewhat more than a century ago, with the narrative becoming narrower and deeper as the main topic of the book is approached. A longer-than-normal preface introduces Hawking and the H&H collaboration before the first chapter gives some necessary background on cosmology, from ancient times until today, and black holes. It is a good and interesting overview, and also discusses biological evolution and how one usually makes sense of it by following it backward in time. Then follows an overview of (the history of) relativistic cosmology, which is not too biassed in favour of Lemaître but perhaps still gives Friedmann somewhat too short a shrift. (Lemaître was a very important figure, but it might be reading too much into his works when it is claimed that he was the first to engage in quantum cosmology, not just metaphorically, but also that he foresaw Everett's many-worlds interpretation of quantum mechanics, 'decoherence', and even the H&H top-down approach to cosmology.) That sets the stage for an overview of quantum mechanics and the concept of duality, which will play an important role later on, and the no-boundary proposal of Hawking and Hartle according to which in some sense time turns into space in the early Universe and that space is curved so that asking what was before the Big Bang makes as little sense as asking what is north of the north pole. Modern inflationary cosmology and the idea of the Multiverse are introduced before noting that Hawking in his later years distanced himself from the latter. (Unfortunately, the Multiverse discussed is only that of eternal inflation; there are different types of Multiverses, some of which have been discussed in books[3–5] reviewed in these pages[6–8].) The meat of the book is in Chapters 6 and 7, the two longest chapters, which discuss quantum cosmology and the holographic principle, often in the context of the H&H top-down approach to cosmology. The final chapter, much shorter than the others, is much more philosophical in outlook, which to some extent feels tacked on, something I have encountered before[3,6]. Whatever one thinks of the ideas of Hannah Arendt and H&H, it seems a bit of a stretch to invoke the former in support of the latter.

The book is reasonably well written with about the usual number of typos and questionable style choices. Some things seem a bit confused, such as referring to the CMB as a "cosmological horizon" and the light deflection at the surface of the Sun as seen from Earth as less than "a few arc seconds" (it is about 1″·75). While Dicke was already doing science in the 1930s, I don't think that he was thinking about the Anthropic Principle (AP) then. Hertog's teleological description of Carter's formulation of the AP contrasts starkly with that of Lewis and Barnes[9,10], who claim that Carter has often been misinterpreted. A galaxy "nugget" instead of "core" was presumably garbled somewhere in translation, but is at least amusing. Of course General Relativity is concerned with gravitational waves, not gravity waves, and by now we should all know that Wheeler didn't coin the term 'black hole' (though he did popularize it). I don't know why Hubble's equation $v = Hr$ should be "infamous"; more important is that it is very general, not just in the case of a constant rate of expansion. It is certainly true that Einstein initially thought that non-static cosmological models were irrelevant mathematical curiosities; I don't know why the same claim is made about Friedmann. I'm not sure why Faraday is claimed to be Scottish; perhaps confusion with Maxwell. Our backward light cone converges primarily due to the expansion of the Universe, not due to the presence of matter within it. Zwicky wasn't the first to contemplate dark matter, not even the first to use the term (though arguably the first to claim that there is more of it than of ordinary matter). Regarding traditional observational cosmology, the description is wrong in a way strikingly similar to (but probably independent of) that in another book recently reviewed in these pages[11]. There are a few other things which are at best confusingly formulated and some interpretations with which I and many others disagree (though most of the latter are not important for the main narrative).

There are a few black-and-white figures scattered throughout the book as well as eight pages of slick-paper colour plates, most of which I haven't seen elsewhere. Particularly interesting are hand-made sketches and plots by

Lemaître and a Dutch-caption cartoon of de Sitter, in the shape of (the mirror image of) λ (symbol for the cosmological constant) blowing up the Universe like a balloon, noting that the cosmological constant is responsible for the expansion.* The bibliography is not a list of references (which appear in the end notes) but more a (good — I've read almost half) list of suggestions for further reading. Endnotes (24 pages) contain references, additional information, or both; there is a 15-page small-print index.

I didn't find the book convincing; whether that is the fault of Hertog or my own I don't know. The work of H&H not only goes against some earlier work by Hawking but also takes a definite stance on two rather hotly debated topics, namely the AP and the Multiverse.† A common criticism of those two topics is that they (can) explain (everything) in hindsight but lack in predictive power. That is also true of the H&H top-down approach to cosmology. (As my late history teacher used to say, just an observation, not a judgement.) Their comparison with Darwinian evolution is apt (and the title is a reference to Darwin's *On the Origin of Species*); details are not predictable from the theory itself, because randomness (mutations in the former case, quantum effects in the latter) plays a key role. Of course, the theory of evolution is good science, but differs from traditional physics theories in that the goal is not a series of increasingly fundamental explanations. (Reductionism also applies to evolution, of course, in the sense that mutations and so on are understood at a low level. The difference is that, at least in practice, that reductionism cannot be used to predict the higher levels.) The difference from other high-level topics in physics (chaos, complex systems, *etc.*) is that H&H claim that not just the outcomes of the laws of physics are emergent, but also the laws of physics themselves. That certainly qualifies, in the words of Carl Sagan, as an extraordinary claim which requires extraordinary evidence. The idea of H&H might work in some sense, but it remains to be shown that it works better than the AP and/or the Multiverse in cases where both approaches claim to be able to explain the same phenomena. Although even staunch supporters of the AP usually reject a strong version‡ which claims that observers (whether human or not, whether sentient or not) in some sense cause the Universe to exist, it is strange that H&H, while rejecting even the weak AP (which some would regard as a trivial tautology), have their own bizarre idea, namely that a delayed-choice double-slit experiment[16] can be explained by the choice affecting the past ('retrocausality', an interpretation not shared by Wheeler, who suggested that and other similar experiments); strange enough for explaining non-intuitive aspects of quantum mechanics, but quite a stretch for explaining the origin of the laws of physics.

There are two related problems which sometimes occur with (semi-)popular books about topics which are relatively new. One, which doesn't apply here, is that it is often not clear what is new and/or controversial and what is consensus. The other is more common: on the one hand, there are technical monographs, original papers, theses, and so on, and on the other (semi-)popular books and articles, with nothing in-between. The latter is difficult to avoid, perhaps

*That is actually not the case. There are expanding and contracting universes with and without a cosmological constant (which could be positive or negative). Historically, the first relativistic cosmological model was Einstein's closed-space static universe and the second de Sitter's flat model with exponential expansion, both of which have a positive cosmological constant (but of course Einstein's didn't expand). That was a time when even experts were confused.[12,13]

†My own view is that a significant fraction of the debate on those topics is due to confusion of terminology, people talking past one another, and so on; I discuss that in a recent article[14]. (Of course, there is genuine difference of opinion as well.)

‡Bostrom[15] counts thirty versions of the AP.

because of the lack of sufficient readership. Although a generic problem, it also applies here: those interested in more details have few if any options other than delving into the (sometimes very) technical literature. As it is a generic problem, the author is not to blame, but it is something which the reader should keep in mind.

Despite my reservations, the book succeeds in its goal of presenting the basic idea of top-down cosmology for a more general readership and can be a first step for those interested in the topic — it just shouldn't be the last step as well, but a big jump will be needed between the first and last steps. Other modern ideas such as the holographic principle and the black-hole information paradox are explained well, so it can be a jumping-off point for those interested in modern ideas in quantum cosmology and related fields. — PHILLIP HELBIG.

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The Einsteinian Revolution. The Historical Roots of His Breakthroughs, by Hanoch Gutfreund & Jürgen Renn (Princeton University Press), 2024. Pp. 249, 23 × 15 cm. Price £28/$32 (hardbound; ISBN 978 0 691 16876 0).

The Einstein industry marches on, almost 70 years since it was begun by the sorting of the mass of papers he left in Princeton at the time of his death in 1955. Those papers and the rest of Einstein's estate were left to the Hebrew University of Jerusalem, which still owns copyrights and such, though the on-going 'publications of everything' (the Einstein Papers Project) is now headquartered at Caltech, under the general editorship of Diana Kormos Buchwald. This enables the present authors to cite everything he wrote in the form CPAE* Vol. Number, Document Number, Page Number. We thereby gain access to the actual texts of letters he wrote to his first wife, to his friends Michele Besso and Marcel Grossman, and to very many of the other physicists and mathematicians who were his contemporaries. An unfortunate result is that the published Einstein papers also end up being cited in the form CPAE 2, Doc. 3 and CPAE 6, Doc. 21, rather than by year, volume, and page number

*CPAE is the Collected Papers of Albert Einstein in *Annalen der Physik*. Those two are *Zur Elektrodynamik bewegter Körper* (from the wonder-year of 1905) and *Die Grundlage der allgemeinen Relativitätstheorie* (published in 1916).

Authors Hannoch Gutfreund and Jurgen Renn have already made, jointly and severally, major contributions to the Einstein industry. What new insights are they now providing? Their major claim is that, for all the 1905 contributions and GR, Einstein adopted a new point of view to existing data and ideas, in the way that Copernicus had revolutionized astronomy in 1543 by adopting a Sun-centred rather than Earth-centred point of view. The authors describe such revolutions as "Copernican". The contrast is with "Galilean Revolutions," which arise from new data. At least that was true for Galileo's influence on astronomy, though his pioneering thoughts about motion were of the Copernican type, and these two sorts, the authors conclude, are a better match to what has happened in science than are the "paradigm shifts" of Thomas Kuhn. Einstein himself is quoted as saying that "A theory can be tested by experience [that is experiments and observations], but there is no way from experience to the construction of a theory."

I found particularly interesting the 1905 Einsteinian advances, for each of which the authors point out (p. 135) someone else who formulated some of the same physics, but without the very broad range of knowledge (scientific and philosophic) that AE brought to bear: for statistical mechanics, Josiah Willard Gibbs (of Yale); for the light quantum hypothesis, Paul Ehrenfest; for relativity theory, Henri Poincaré (who dispersed his insights among several papers, without managing to bring them together as Einstein did); and for Brownian motion, Marian von Smoluchowski*. This left to Einstein the tasks of formulating these four topics (as well as some earlier arguments for the reality of atoms) in more or less the way we now understand them.

Gutfreund and Renn also look backward to the Newtonian revolution (the establishment of classical physics), which they regard as also of the Copernican form, for which the shift in point of view was to regard motion on Earth and motion in the cosmos as the same sort of thing, rather than distinguishing 'forced' and 'natural' motion. They mention in passing other past revolutions: the chemical (periodic table); the Darwinian (evolution by natural selection); the geological (mantle convection, plate tectonics, and continental drift) in the past; and more recently the molecular-biology revolution and the artificial-intelligence (AI) revolution.

Many more insights and examples are to be found in *The Einsteinian Revolution*, but I want to use the AI revolution as an excuse to focus for a paragraph or so on a prime mover in Einstein scholarship — Gerald Holton, Mallinckrodt Professor Emeritus of Physics and History of Science at Harvard. He was there at the beginning, having been sent to Princeton to help Helen Dukas sort through that wilderness of papers in Einstein's home and office. He has written (to paraphrase) "only Einstein, only there, only then". And just last week, when I e-complained that a new computer was being fractious, he e-warned me to stay on good terms with it, because this might be the first warning that machines are going to take over the world. — VIRGINIA TRIMBLE.

*Marian von Smoluchowski (1872–1917), the person you are least likely to have heard of before, of those mentioned here, remained an Einstein correspondent up to the time of his death.

Lithium Across the Universe, by Eduardo Martín (IoP Publishing), 2022. Pp. 214, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 3621 5).

Appearance of the element lithium in astronomical locations occasions so much spectroscopic examination and theoretical pondering that this IoP book (also available as an e-book) by Eduardo Martín should be welcomed by astronomers across the age spectrum from fresh research students through the experience continuum to retirees. This reviewer, now off the top end of the age spectrum, learnt a lot about the abundance of lithium in a wide variety of astronomical environments.

The origins of my interest in lithium in stars were stimulated through an encounter over a cup of tea with John Alexander at an RAS meeting in Burlington House. John told me of his idea that lithium in a red giant's atmosphere could be augmented if the giant were to capture terrestrial planets from its 'solar' system. John's idea is detailed in Correspondence to this *Magazine* (**87**, 238, 1967). Just imagine if John's proposal had then initiated an observational search for stars hosting planets!

Martín's book discusses the major astronomical environments in which lithium atoms are spectroscopically detected and the likely controlling influences on the lithium abundance in those environments are aired. Open issues are often adequately highlighted. Just two areas are mentioned here: the Big Bang and Li-rich red giants. Hopefully these and other open observational and theoretical issues will soon attract enthusiastic inquisitive individuals on the young portion of the age spectrum.

One key environment is, of course, the Big Bang. With completion of accurate mapping of the cosmic microwave background, key cosmological parameters are now so well known that the post-Big Bang composition may be rather securely predicted: almost pure hydrogen composition with contaminants D, He-4, He-3, and Li-7 may be safely predicted. Except for Li-7, as measured from the Spite plateau provided by the Li I resonance line at 6707Å in metal-poor dwarfs, these predictions may be deemed to match observations traceable to the Big Bang. Li-7/H on the Spite plateau is about a factor of a few below its predicted value. Martín refers to this situation: "The jury is still out on the resolution of the cosmological lithium problem." As an observer, one expects the resolution will come from observations!

Martín's text also discusses stars exhibiting lithium abundances — almost exclusively Li-7 —where the inferred surface abundance is not yet fully understood. Historically, the initial example was provided by the very strong 6707Å Li resonance doublet first reported decades ago in photographic spectra of certain carbon giants: Martín illustrates a segment of Sanford's (1950) classic atlas showing the strong Li doublet in the N-type carbon star WX Cyg. A large range in Li abundances among K and M giants is also now known with very Li-rich examples an infrequent occurrence. The statistics for surface Li abundances in red giants are aired by Martín but, I feel, the likely required combination of 'nuclear' origins of a Li enrichment in a stellar interior and the transport of that synthesized Li to the surface are provided an inadequate airing. Lithium synthesis is quite appropriately named as 'the Cameron–Fowler' mechanism but a reader new to this fascinating topic and hoping to resolve outstanding issues would be challenged by reading just this book to explain how the Cameron–Fowler mechanism is expected to enrich red giants in lithium. Of course, exploration of published literature is to be encouraged. New observational and theoretical results are sure to be presented at RAS meetings in coming years! — David Lambert.

Annual Review of Earth and Planetary Sciences, Vol. 51, 2023, edited by R. Jeanloz & K. H. Freeman (Annual Reviews), 2023. Pp. 695, 24 × 19·5 cm. Price $511 (about £400) for institutions; $122 (about £95) for individuals (hardbound; ISBN 978 0 8243 2051 5).

This year's volume of *Annual Review* opens with a remarkable autobiography of Estella Atekwana, biogeophysicist, to which the present writer can personally relate and recommend to all aspiring scientists who face challenges. I hope it is also read by those in positions to lighten the burdens of such colleagues.

The regular scientific-article section as usual covers a broad range of topics within Earth science including Solar System, climate change, the trendy new subject of machine learning (is this an oxymoron?), and the solid, liquid, and gaseous spheres of Earth. There is room herein to comment on only too few of these excellent papers. We are seeing increasing treatments of the interface between society and Earth science these days and I would particularly highlight a beautifully written chapter on 'Communication and Behavior Science' to improve the ability of society to make decisions regarding climate change, by authors Maibach and others. The recommendations, *e.g.*, simple, clear messages, have, however, clear application elsewhere in scientific writings! Another favourite I recommend is the chapter on 'Machine Learning in Earthquake Seismology' by Mousavi and Beroza. This short but to-the-point chapter provides a helpful primer and summary for those who might be wondering what this subject is and whether it is useful. Another of my pet favorites is the chapter 'The Mid-Pleistocene Climate Transition' by Herbert. It boldly states upfront and throughout that a complete explanation of the pattern of climate oscillations during the Pleistocene is still out of reach. Continued study of the interplay of multiple environmental processes, rather than focussing on Earth's orbital variations alone, is the present trend. I am glad scientists have not given up on this stubborn problem! I have room only to mention one more favourite and, after some hand-wringing, it has to be the chapter 'The Rock-Hosted Biosphere' by Templeton and Caro. There are 10 000 times more cells in Earth's crust than there are stars in the Universe, so this little-emphasized subject is not insignificant. In addition to summarizing the current state-of-play in the subject, the text emphasizes what we don't know, which is certainly enough for a fair few PhD projects, to say the least. A good read for aspiring students then. Abject apologies to the authors of the other excellent papers in this year's volume. Readers of this short report will just have to go out and purchase of a copy of their own (highly recommended)! — Gillian Foulger.

Planetary Systems Now, edited by Luisa M. Lara & David Jewitt (World Scientific), 2023. Pp. 425, 23·5 × 16 cm. Price £130 (hardbound; ISBN 978 1 80061 313 3).

We are currently in the middle of a revolution in our understanding of planetary systems. There is now a dauntingly large amount of knowledge for the new student embarking on the study of planets. *Planetary Systems Now* attempts to provide a broad overview of the state of the field of planetary science as of early 2021. The book is based on an on-line school aimed at early-career researchers: 'Planets, Exoplanets and their Systems in a Broad and Multidisciplinary Context'.

The 14 chapters are reviews of their individual fields authored mostly by the lecturers at the on-line school. Unlike a typical textbook, the range of authors makes for a broad and diverse book and allows up-to-date results from a wide range of topics to be presented by experts in those topics. Each chapter is self-contained and understandable without having to read those preceding it. On the other hand, the book lacks consistency in symbols used and style across the various chapters. There is also, on occasion, significant overlap between chapters, particularly Chapters 4 and 5, which explore the atmospheres of terrestrial planets. Each chapter is concluded by an "abbreviated" version of the question-and-answer sessions that followed the lectures during the school. These sections are a useful addition that would not be found in a standard textbook. In general, these are interesting and provide further helpful insight, though I am not sure why the question with the answer "I can't remember" was included.

Planetary Systems Now is, in general, easy to read and contains many useful figures (often printed in beautiful full colour). It contains many examples of the latest thinking and results in each field in the pre-*JWST* era; for example, the lack of a significant spike in impact rate during the so-called 'late heavy bombardment', and a substantial chapter devoted to interstellar planetesimals — the first of which was only identified late in 2017. There are also, helpfully, many pointers to other published reviews for those looking to delve deeper. This book is probably of greatest interest to those beginning research in planetary or exoplanetary science, or existing research students seeking to broaden their background knowledge. If there is not a similar school that you can attend, I recommend this book as a good substitute. — PHILIP J. CARTER.

William Frederick Denning. Grand Amateur and Doyen of British Meteor Astronomy, by Martin Beech (Springer), 2023. Pp. 334, 24 × 16 cm. Price £34·99 (hardbound; ISBN 978 3 031 44442 5).

This is a very interesting and valuable biography of W. F. Denning, an individual who spent most of his life in Bristol, and whose work on meteor showers won him the Gold Medal of the RAS. I must take issue with 'Grand Amateur', a term invented by Allan Chapman in *The Victorian Amateur Astronomer* to describe those gentlemen who, upon retiring from business (if ever engaged upon it) devoted themselves to astronomy. They were wealthy, owned fine observatories, and had paid assistants. But Denning never fell into any of those categories, and it is not even certain that he ever enjoyed any systematic paid employment, other than as a journalist and writer. (As Beech shows, there is no proof that Denning was ever an accountant, like his father, as had once been thought.)

Beech writes very well, and gives us as comprehensive and lively a description of our subject's life that the reclusive Denning allows us at this distance in time. He has researched Denning for decades, and gives us a really good history of the rise of meteor astronomy, a summary of meteor physics, and of Denning's part in the field. Indeed, the young Denning was drawn into studying meteors by having witnessed the Leonid storm of 1866.

A lack of original Denning records is evident throughout this book. On display in its upper library, the RAS has Denning's meteor globe, donated by his family in 1942. But we know of only a few letters and notebooks. Fortunately there is an abundance of Denning in print.

Much of Denning's meteor work was conventional. His records of meteors were accurate, and his ability to sustain long watches was exceptional. In 1877 he was able to demonstrate the nightly motion of the Perseid radiant, as required by theory. But in deducing the coordinates of some meteor radiants, Denning tended to amalgamate observations over several nights instead of reducing them night by night, and in many instances he even combined observations made upon the same date over intervals of several years. In this way he deduced a great many "centres of radiation". We now know that the majority of these radiants were spurious, for he had greatly underestimated the number of sporadic meteors. Moreover, Denning put forward the idea that the radiant points of some showers, in particular the well-observed Orionids, were fixed in space. He clung to this idea till the very end of his days, even after he had served as the first Chair of the IAU Meteoritic Commission in 1922–1925, and by which time the tide had turned completely against him.

As Beech relates in detail, the rise of the American Association of Meteor Observers had brought Denning into direct conflict with its young and energetic leader, Charles Olivier, a trained scientist who insisted upon nightly data reductions. Denning had briefly seen office as the Director of the BAA Meteor Section, but his successors would adopt Olivier's principles to put their work on a sound scientific footing.

Although not mentioned in this biography, I would like to add that J. P. Manning Prentice, long-time BAA Meteor Section Director, showed convincingly in 1933–1936 exactly how Denning may have been misled in the specific case of the Orionids[1]. In fact the shower has several centres of radiation which are active over several nights and in just such a way that radiation from a certain fixed point could easily have been deduced over the period of ten days claimed by Denning.

We read about Denning's work on Jupiter (especially its Great Red Spot) and the other planets. His study of Saturn's Great White Spot of 1903 was particularly notable. Denning was also involved in the late-Victorian-era debate about large *versus* small telescopes. We then come to the matter of the short-lived Observing Astronomical Society in which Denning was closely involved: effectively a predecessor of the British Astronomical Association. Denning used to write regular summaries of the work submitted to it for the now defunct but excellent (1863–1886) periodical *The Astronomical Register*. We are presented with detailed descriptions and novel statistics and facts about the Society and its members. Denning is also remembered today as the discoverer of a comet and for being one of the discoverers of Nova Cygni in 1920. He abandoned telescopic work due to failure of his health in 1906, and by the 1920s was living in near-poverty. But he did not abandon naked-eye work, and he also studied natural history and meteorology.

The book is well printed and illustrated, using a plethora of Denning publications and a smaller amount of archival material. It is always clear and engaging, though more thorough proof reading would have helped in a few places: for instance, Denning's father's death (page 4) seems to have occurred in both 1884 and 1895.

It is sad that so few Denning manuscripts are extant, those that exist being limited mostly to the collections of the RAS and BAA. As Archivist for the latter organization I can add that the 1930s correspondence of Prentice suggests a reason. When Denning died, Prentice tried to obtain those old meteor records, intending to re-reduce them in what had become the accepted manner. But he formed the impression that Denning's family, with whom he had exchanged letters, required payment for them. As that was against his principles, Prentice did not continue the discussions.

Denning was a prolific correspondent with an international circle of pen-friends. Except in the earlier part of his career when Denning appeared and lectured in public (serving as President of the Liverpool Astronomical Society), his correspondents could only have imagined his character from his letters, and we still have to do the same today: in later life, Denning was a recluse who hardly ever met anybody. Beech gives us a detailed study of his astronomical work, with a great deal of fascinating contextual detail, and a very good outline of what is known of his private life. Concerning as it does one of history's greatest visual observers, I am sure that this reasonably priced biography will be found to be interesting and absorbing for many readers. — RICHARD MCKIM.

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A City on Mars: Can We Settle Space, Should We Settle Space, and Have We Really Thought This Through? by Kelly and Zach Weinersmith (Particular Books), 2023. Pp. 448, 24 × 16 cm. Price £25 (hardbound; ISBN 978 0 241 45493 0).

Perhaps because my parents were working for NASA at the time (my father indirectly at Chrysler, doing static testing of Saturn rockets, and my mother, who knew Wernher von Braun well, directly), as a child I developed an interest in space flight. We moved temporarily from Huntsville to Cape Canaveral for a few months around the end of 1968 and used to watch launches from the beach. When I was about 14, I started reading old-school pro-technology optimistic science fiction (initially because I had asked my father to bring me some books by Asimov — I was a fan of his non-fiction books — from the library and fiction books (ordered by author) were easier to find than non-fiction books (ordered by topic)). Despite exceptions such as Asimov's 'Ad Astra', which deals with public opposition to space flight, the general feeling was that the colonization of space would happen more or less naturally, and not that far in the future. However, it wasn't long before Apollo missions were no longer televised live, and the programme was cut short because the USA had won the space race. (Of course it was mainly about politics, and the first scientist on the Moon — geologist Harrison Schmitt — was the last person to set foot on it.) But that was seen to be a temporary setback due to distractions such as the war in Vietnam and the false dichotomy that other important issues, such as environmentalism, had to be addressed to the detriment of space flight. Though it was clear to me even then that science is better served by means not involving putting people into space (recalling Carl Sagan's description of the cost of space probes as "a penny a world for each person on Earth"), the conquest of space still seemed inevitable for other reasons, and a natural extension of the exploration and subsequent colonization of the Earth (whether by Europeans in the Age of Exploration or thousands of years earlier in various out-of-Africa migrations).

My interests then shifted. (My interest in astronomy didn't come from space flight, but rather grew out of a general interest in science, sparked initially by palaeontology. The fact that Asimov — although a biochemist by training — wrote much about astronomy was an important factor.) I still considered the general vision of the future more or less inevitable, but it was no longer clear when it would happen. More recently, things have changed, due not just to billionaire space geeks such as Elon Musk, Richard Branson, and Jeff Bezos actually doing something, but also to things such as physics Nobel laureate Gerard 't Hooft being an ambassador for Mars One[1] (an idea to send people on a one-way trip to Mars, financed *via* a proposed reality-TV show). It still seemed inevitable, but now on a much shorter time-scale, probably with permanent settlements on the Moon and Mars within my lifetime. However, I had become much less enthusiastic, due to the fear that human colonization of the Solar System would export the various problems we have on Earth, perhaps even magnifying them to some extent. (Consider the fact that former colonies of European nations are still strongly influenced by the culture of the mother countries hundreds of years ago, and there would be more contact — at least electronically, which these days is the primary route for the transmission of culture — between Earth and settlements on the Moon or Mars than there was between those colonies and their mother countries.) So it is something to be concerned with, even though, as with other causes, most individuals can do only a small amount.

Enter *A City on Mars*. The title sounds like something out of 1950s pulp fiction. The subtitle sounds much more pessimistic. I was drawn to the book because one of the authors is responsible for the SMBC web comic[2]*, which deals mainly with topics in physics, computer science, philosophy, and so on, and is obviously well informed, though not everyone will get all of the jokes. Most who believe that the conquest of space is possible and good tend to ignore potential problems, assuming that they will get solved along the way; most who are sceptical about either aspect haven't seen a reason to consider the details. What is needed is a balanced assessment and, in my view, that is what this book provides. Though written in an easy-going, humorous style, accompanied by a few comic-style black-and-white drawings, a huge amount of research has gone into this book, testified to not only by the approximately six hundred entries in the explicitly titled 'Partial Bibliography' (twenty pages of print substantially smaller than most small print) but also by the authors' collection of "twenty-seven shelves of books and papers on space settlement and related subjects." Also significant is that they didn't start out being sceptical and pessimistic: "We are space geeks. We love rocket launches.... We love visionary plans for a glorious future.... The data made us do it."

After a long Introduction about space myths, there follow twenty chapters collected into parts of two to four chapters each, the first five parts addressing biological and medical issues, possible habitats (only the Moon, Mars, and "giant rotating space wheels" are considered realistic enough to examine), artificial biospheres, space law, various scenarios (perhaps) allowed by those laws, and a final part looking at space society, expansion, and existential risk. Some readers might be surprised at just how inhospitable the Moon and Mars would be to settlers; it seems that most science-fiction space helmets are fitted with rose-tinted glasses. There is a large literature on the first three aspects, mostly optimistic and some of which I've encountered before. The last three are arguably more important: the first three might well have technical solutions (bottom line in many cases: we just don't know yet), but the last three involve politics, law, and sociology, and no quick solutions appear possible even if there were agreement with regard to the goals. As with regard to other topics as well, the easy-going narrative is backed up with copious references to the technical literature. (There are almost nine pages in very small print of end notes — in addition to the bibliography — with the disclaimer that they "contain only citations associated with quotes presented in the text and manuscripts we refer to directly".)

*Despite being a geek or nerd in some sense, I've never been interested in traditional comic books of any sort. I've also never played Dungeons and Dragons and didn't start programming until I was twenty-six.

Space law is complicated; no nation (nor person, nor any other entity) is allowed to claim anything not on Earth, though exploitation is allowed, which in some cases could result in *de facto* ownership. The authors make a good case that space law, despite its shortcomings, is still relevant, and that it is both possible and probable that it would be enforced.* Although the Outer Space Treaty essentially declares all extraterrestrial property to be commons, the stricter Moon Agreement didn't make it off the ground, so to speak. Cynics will, correctly, say that the self-interest of the spacefaring nations was the reason. On the other hand, despite self-interest, Antarctica and ocean beds are essentially treated as commons, and could be a model for extraterrestrial property. I found the ten chapters on space law and related issues very interesting, both because I hadn't read much about them and also because they are likely to be even more relevant than the more usual concerns. The authors, like many potential readers, certainly had an interest in space and so on before writing the book; the detailed yet clear legal chapters bring an important aspect to the topic.

The last part is concerned with economics (*e.g.*, the similarities and differences of space settlements and company towns), the question of the minimum population necessary for a vital independent settlement, and the possibility of space war. The same technology which can be used to deflect asteroids from Earth could also be used to deflect them towards Earth. Real or imagined benefits (many of which are debunked in the book) are often touted as a reason to settle space, but as always there is the question whether the potential benefits outweigh the potential dangers, especially as technology is evolving faster than morality. (H. G. Wells once described civilization as a race between education and catastrophe. Although one can argue that morality has significantly evolved for the better[3], for the past few decades it has been possible for one person to destroy, or at least seriously damage, all of humanity or a large fraction of it.) While the fear of law enforcement might suppress some over-ambitious tendencies, suicide bombers are clearly not thwarted by the death or any other penalty, and the fact that *Starlink*† satellites exist despite objections by the astronomical community and others demonstrates that laws and/or their enforcement might not evolve quickly enough to provide the needed safeguards.

This book covers a lot of ground (or space); navigation is aided by a thorough fifteen-page small-print index. It was an enjoyable and informative read, and is recommended not just to those with an interest in such topics (especially if they don't — yet — agree with the authors), but essentially to everyone, since the developments it is concerned with will potentially affect everyone. The arguments are clear and well documented and should convince the reader as they convinced the authors. I don't think that I can improve on the authors' summary, so I'll end this review by quoting part of it: "Our original assumption was that space settlement was coming soon.... We now believe the timeline is substantially longer and the project wildly more difficult and that the governance work to do is more about regulating the behaviour of Earthlings than designing a Martian democracy.... [W]e just cannot convince ourselves

*There are organizations which believe that they can legally sell property which they have claimed on the Moon, and there are gullible customers who buy it. That isn't mentioned in the book. Although the benefits from combating such fraudsters is presumably not worth the effort, the fact that they continue unabated does make me somewhat sceptical whether space law will be quite as binding as the authors suggest.

†Not to be confused with the former UK academic astronomical computing project of the same name.

that the usual arguments for space settlements are good. Space settlement will be much harder than it is usually portrayed, without obvious economic benefits. Attempting space settlement now may increase the likelihood of conflict on Earth in the short term and ultimately increase human existential risk.... We believe that space settlements are possible, and perhaps one day they could be done in safety. But doing something big requires us to assess the scale of the challenge. In healthy communities of thought, the [sceptics] aren't barriers on the road to progress, but guardrails.... Going to the stars will not make us wise. We have to become wise if we want to go to the stars." — Phillip Helbig.

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A General Relativity Coursebook, by Ed Daw (Cambridge University Press), 2023. Pp. 527, 24·5 × 17 cm. Price £22·99 (paperback; ISBN 978 1 00 924244 8).

Like other books on a common topic, books on General Relativity (GR) can differ in the breadth and depth of topics covered, but also with regard to being 'maths first' or 'physics first' and which sign conventions are used. This book (neither broad nor deep, maths first, 'East Coast' sign convention (−+++, 'mostly plus')) reveals another difference: level of detail. This is an introductory book, introducing the necessary tensor calculus after an introductory chapter on the principle of equivalence before moving on to the Einstein equation and three applications (the Schwarzschild solution, Friedmann cosmological models, and gravitational waves), but differs from most other GR books in the level of mathematical detail. The mathematics is not more advanced than elsewhere, but rather spelled out, with the 'work shown'. It is thus similar to a series of lectures, and is indeed derived from lectures (so are some other books, though they have often gone through a greater transformation). Ed Daw is Professor of Particle Astrophysics at the University of Sheffield, has worked on searches for dark matter and gravitational waves, and has been lecturing on GR since 2003. The book fills the gap between more qualitative introductions to GR and books which leave out the needed details (or leave them as exercises for the reader). Although, as Daw points out, it is true that tensor calculus has many other applications as well, many interested in GR will have had no prior experience.

Daw obviously knows the material, and spends some extra time on topics which often prove difficult for many students. The book is well written and clearly structured. Chapter 8, on gravitational waves, goes a bit further afield by discussing some of the technical challenges in gravitational-wave detection. The final chapter is a guide for further reading, mentioning other books, other sign- and tensor-notation conventions, and so on. (Interestingly, Daw's favourite is Hartle's book[1,2], which is 'physics first'. I tend to prefer the 'physics first' approach, though 'maths first' is sometimes more useful for introductory books[3].) I was pleased to read of the Lorenz, rather than Lorentz, gauge (something even professionals sometimes get wrong), so put the appearance of the Lorentz gauge in Chapter 8 down to a typo. Although I often quibble about matters of style, this book is not the worst offender in that respect. There are neither footnotes nor endnotes, and a few black-and-white diagrams are scattered throughout the text. My only real complaints are that the 'References' chapter (actually, more accurate would be 'sources' or 'further reading' since, as with many textbooks, there are few actual citations in the text) sometimes lists outdated editions of books, and that the index (fewer than three pages, though in small print) is a bit too brief (this is certainly a book in which readers will go back and look things up; a few times I couldn't find in the index what I was looking for).

This should be neither the first nor the last book one reads on GR. Less technical introductions are useful, as this book essentially assumes that its goals are clear, and those needing more details must consult more advanced texts. This book is useful in that it provides a bridge between the two, consisting of the details of tensor-calculus manipulations and 'Index Tricks of the Trade' (sect. 2.9). Especially for those who like to learn their maths as needed as they go, this is one of the few books which fit that need.* — PHILLIP HELBIG.

References

(1) J. B. Hartle, *Gravity: An Introduction to Einstein's General Relativity* (Cambridge University Press), 2021.
(2) P. Helbig, *The Observatory*, **141**, 303, 2021.
(3) P. Helbig, *The Observatory*, **142**, 70, 2022.
(4) W. D. Heacox, *The Expanding Universe: A Primer in Relativistic Cosmology* (Cambridge University Press), 2015.
(5) P. Helbig, *The Observatory*, **136**, 204, 2016.

You Can't See in the Dark with the Lights On, by Kevin Krisciunas, with illustrations by Brian Quiroga (Innovative Ink Publishing), 2024. Pp. 30, 25 × 20 cm. Price $8·99 (paperback; ISBN 979 8 3851 1803 8).

The author and illustrator have dedicated this booklet "for everyone young and old who has wished to experience the joy of discovery." The target readership, however, seems to be children about the age of the boy who discovers the dark night sky. He looks about twelve in one drawing and eight in another. The text is entirely in verse, four to eight lines per page. Each line contains seven 'dah DUM' patterns, ending with a one-or-two syllable rhyme. The vocabulary extends to words like 'hemispherical' and 'planetarium' which might (or might not) need translation for younger readers.

The author provides an interesting comparison of distances: the size of a baseball diamond (Yankee Stadium) to an astronomical unit is very nearly equal to the ratio of the distance New York to Timbuktu to the distance from the Solar System to Proxima Centauri. A target reader will not, of course, need to use this to figure out the size of a baseball stadium as I did!

The main message is that very dark sites are wonderful and should be preserved, and author and illustrator drop quite a few factoids about stars, the Solar System, and the Milky Way in making their main point. My only serious quarrel is with the statement that "every star there ever was is in a constellation." I know where CM Tauri is today and roughly where it was a millennium ago, but its location as a newly formed main-sequence star of 8–10 solar masses occurred something like 10 million years ago, when the only patterns we would still recognize were the globular clusters and a few of the older open ones like M 67, the Hyades, and Pleiades. Many stars that are still around today are a few billion years old, and have been around the Milky Way many times, with (I suspect) no constellation-naming species to locate them.

*Another[4] reviewed in these pages[5] covers similar ground, but only with respect to cosmology.

Conflict-of-interest statement: My copy of *You Can't See in the Dark with the Lights On* was a gift from the author, who kindly inscribed it "to the most avid reader I know." — Virginia Trimble.

Data Modeling for the Sciences, by Steve Presé & loannis Sgouralis (Cambridge University Press), 2023. Pp. 415, 25 × 18 cm. Price £59·99/$74·99 (hardbound; ISBN 978 1 009 09850 2).

Data Modeling for the Sciences is an intermediate-level book for students and researchers who wish to gain either a wide coverage of data-analysis techniques, or a deeper understanding of the underlying principles, or both. It is wide in scope, covering everything from statistical principles, to the computational methods that are now the norm for analysis of data sets, which are rarely simple enough for analytic techniques to be applicable. The book therefore takes a more data-driven approach than many. One aspect that sets this book apart is the large number of problems that it sets, the bulk of them being computational, often generating synthetic datasets and subjecting them to the analysis methods presented in the book. The book is targeted at Masters-level students in the sciences, who will typically have the appropriate computational skills that are assumed, but also at more experienced researchers, who will also find it a very valuable resource. There are some sections that are marked as advanced, and some of these would probably require some time for Masters students to absorb. Unusually for a review, I more-or-less read the book from cover to cover, as I felt that there was a lot to learn from this book, and I was right, and found it a rewarding read. I found the ordering of topics quite interesting — for example, there is a long chapter on dynamical systems, and Markov processes precede the more foundational inference chapters. It meant that sometimes one has to pause to consolidate and work out how everything fits together, but that is no bad thing. I recommend the book strongly for anyone involved with analysis of data with any degree of complexity. — Alan Heavens.

From The Library

Modern Physical Laboratory Practice, by John Strong (Prentice Hall), 1938; 15th printing (Black & Son Limited), 1949. Pp. 642, 23 × 15 cm.

Why is this an astronomy book? Well, it was deaccessioned by the RAS a while back, after living there for more than 70 years. Second are the authors: John Strong is listed as Assistant Professor of Physics in Astrophysics at the California Institute of Technology (he headed a balloon-infrared group later in life and the second of his four collaborators was Albert E. Whitford, Assistant Professor of Astronomy at Washburn Observatory of the University of Wisconsin (later director of Lick Observatory and the chairman of the first, 1962, decadal review panel that attempted to set priorities for government funding for astronomical equipment (*etc.*) for the next decade)).

Third is the content. Although Chapter I begins with glass blowing (still useful in some branches of science, though maybe not in astronomy) and Chapter XX ends with casting replicas of small items using cuttlebone (now useful only for cuttlefish), quite a lot of the middle deals with optics, measurement of radiant energy, photoelectric cells, and photography, focussing on astronomical photography with special emulsions provided by the Eastman Kodak Company, whose astro-friendly director of research, C. E. K. Mees, appears several times in the text. Also to be found tiptoeing around in the footnotes are Karl

Schwarzschild (for reciprocity failure), Hubble (on detectability of very small images), and H. N. Russell (on converting stellar apparent magnitudes to other units like lumens). The author(s) suggest using Polaris as a standard; perhaps it was not a weakly pulsating Cepheid that year.

Most fun and impressive is the figure of the sensitivity of spectrum plates available from the Eastman Kodak Company. There were, in those days, no fewer than 19, all inevitably with near-UV and blue sensitivity (to be cut off by Wratten filters if you so desired), but with their long-wavelength ends extending to anything from about 500 nm to 1200 nm (1·2 microns). The names are all letters of the alphabet, in order O J H G T D B C F S U N K R L P M Q Z (perhaps the model for the various bands of radar called S, X, and so forth). By 1973, the survivors were O J G H D E H-alpha F N and Z (B and M were panchromatic).

Are there reasons to remember these? Perhaps if you are interested in digitizing old astronomical images. And perhaps there is more than the one bit of humour that I remember, featuring a senior astronomer instructing a graduate student in a dark room. The senior chap lit a cigarette while plates were still in the developer. The student gasped in horror at the thought of losing a night's work. But the mentor said, "Is OK, Chris. They are only O plates." (which did not respond to orange or red light). Of course plates could be sensitized in various ways, after which, the authors advised said plates should be kept in an icebox. — VIRGINIA TRIMBLE.

Here and There

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The star's brightness was measured more than 300 times a second, and its diameter calculated with extreme precision from the fluctuations in its luminosity during the occultation: it's exactly 2,173 times as large as the Sun, and thus the smallest star ever measured. — *A History of the Universe in 100 Stars* (Quercus), 2023, p. 93.