of the future impact of high-tech ground-based observatories such as *Rubin* and the *E-ELT* that are coming on-stream in the present decade.

The writers have also between them authored other books in the *Kosmos* series covering the topics of *Mercury*, *Venus*, *Asteroids*, *Jupiter*, and *Saturn*. Bill Sheehan particularly has been a prolific life-long writer and his passion for Solar System studies is plain to see. It's not so surprising that this most recent publication is one of the very best to have been written with respect to the Solar System. — Richard Miles.

Discordance: The Troubled History of the Hubble Constant, by Jim Baggott (Oxford University Press), 2025. Pp. 328, 24 × 15 cm. Price £20 (hardbound; ISBN 978 019 286406 2).

Recently, I reviewed a book in these pages by Baggott & Heilbron[1]; this book is dedicated to John Heilbron, who died around the time their joint book was completed. In about 1975, I read one of the many books I've read by Isaac Asimov[2]; despite being the title of the book, the neutrino doesn't appear until about half-way through. Asimov spent the first half of the book on the history of conservation laws, which of course are essential for understanding why the neutrino was originally postulated, and why it was accepted long before it was actually discovered. Baggott follows a similar but more exteme approach, with the Hubble tension appearing only in the tenth and final chapter. The Hubble tension refers to the fact that 'local' measurements of the Hubble constant H ($\dot{R}/R$, where R is the scale factor of the Universe; often, H_0 is discussed, where, as with other cosmological parameters, 0 refers to the value today) tend to give a higher value (≈ 73 km/s/Mpc in the usual units) whereas deriving H_0 from measurements of the cosmic microwave background (CMB) tends to give a lower value (≈ 67). Older readers might remember when the tension was between 50 and 100. The situation today is different, though. The Hubble tension of a few decades ago was primarily between different groups (with Allan Sandage and his followers favouring low values, sometimes even lower than 50, and Gérard de Vaucouleurs and collaborators preferring high values), whatever methods they used. Today, it is primarily between different methods, the size of the error bars has decreased proportionally by more than the difference between the two values (resulting in a statistically significant tension), the cause of the tension is not as clear, and it is more common to see it as possible evidence of new physics. There is also tension *within* the high-value camp, with Adam Riess and collaborators preferring a somewhat higher value while Wendy Freedman and her team advocate a lower value with of course less tension with the CMB value but perhaps even without a significant statistical discrepancy.

I'm not sure why the zeroth chapter is a prologue rather than a proper chapter (at 15 pages, it is only slightly shorter than the other chapters, which average about 25); it introduces the basics of stellar astrophysics. From there, we get nine chapters which introduce enough cosmology (often in the form of a historical narrative, and including many quotations) to place the Hubble tension in the proper perspective: Leavitt's law; the scale of the Universe; the Hubble constant; Lemaître's cosmology, stellar populations, Big Bang nucleosynthesis, and the cosmic microwave background; cosmological parameters; the much larger Hubble tension of a few decades ago and the debate between the low value of Sandage and the high value of de Vaucouleurs; inflation; dark energy and the accelerating Universe; and the standard or concordance model of cosmology. Of course, many books have been written about each of those topics; the still rather long summary here is intended to set the background for the Hubble tension, but is a good summary in itself.

Baggott gets some things right which many authors get wrong, such as the explanation of the cosmological redshift. But he makes common mistakes (about which I've complained in many reviews in these pages) by recounting the relationship between geometry and destiny*

*If there is no cosmological constant, a spatially closed universe will collapse after initial expansion, whereas for a universe with no cosmological constant as if that applied in general (it doesn't, and in particular doesn't appy to our Universe) and by implying that the recession velocity of galaxies cannot exceed the speed of light c. The latter is especially strange in a book on the Hubble constant: $v = HD$ where v is the recession velocity and D is the distance; if D is large enough, v can exceed c[4,5]. He mentions that, trivially of course, a change in the rate of expansion would show up as a deviation from a straight line in a plot of the scale factor as a function or time, but also that that would lead to deviations from a straight line in "the plot of redshift vs magnitude or distance"; in the latter case, one would expect deviations from a straight line for other reasons as well. A few pages later is the huge mistake of claiming that the relativistic Doppler formula is somehow relevant for cosmology "as recession speeds approach the speed of light". While it is true that $v \approx cz$ is no longer valid at high redshift, that doesn't mean that the relativistic Doppler formula is, and it most certainly isn't. An easy way to see that is that the relativistic Doppler formula contains no cosmological parameters, not even the Hubble constant. Are we expected to believe that recession velocity as a function of redshift is independent of the cosmological parameters? (To be sure, the non-relativistic Doppler formula doesn't contain any cosmological parameters either, but it is valid because things are linear to first order.) If I were granted one wish, it might be that everyone interested in cosmology read and understand refs. 4 and 5. I give credit to Baggott for quoting from Dicke's Jayne lecture, but the discussion of the flatness problem ignores the literature on that topic after 1979, even though several well known cosmologists have questioned the standard interpretation (*e.g.*, ref. 6 for a review). Also annoying is the claim that inflation, dark matter, and dark energy were all introduced as *ad hoc* solutions to various problems. While the evidence for them might not be as strong as for other things, the truth is more complex. Other strange statements occur, such as that one can calculate the m–z relation for a flat universe with different values of the density parameter Ω_M (clearly labelled on the example figure from the literature) "with no assumptions about the value of Ω_Λ"; for a flat universe, $\Omega_\Lambda = 1 - \Omega_\mathrm{M}$.

On the other hand, it is refreshing to see a discussion of flat galaxy rotation curves start with the work of Babcock. (But crediting Zwicky as the discoverer of dark matter makes sense only if that is qualified (which Baggott doesn't do): Zwicky was the first to suggest that there could be much more dark than luminous matter, though the importance of that was not appreciated until it was realized that most cosmological dark matter cannot be baryonic.) The discussion on CMB cosmology in Chapter 9 is very good. And Chapter 10, the one actually about the Hubble tension, gives a good overview.

Familiar is the story of Hubble finding a Cepheid in what is now known as the Andromeda galaxy and thus discovering that it is far enough away to be outside the Milky Way and be a galaxy (even larger than the Milky Way) in its own right. Baggott mentions that not only had that Cepheid been discovered by Humason, but that Humason had approached Shapley, suggesting that it could be used to measure the distance to Andromeda. However, before leaving for Harvard, Shapley erased Humason's marks from the plate. That story is also told by Christianson[7], but I had forgotten it, probably because Christianson recounts many episodes in which Hubble took more than his share of the credit. Other material is more familiar, such as Lemaître publishing in French in the "obscure journal" *Annales de la Societé Scientifique de Bruxelles*, a fact that has been mentioned so many times that it

one which is flat or negatively curved will expand forever. One might thus grant some poetic licence in referring to a universe which will collapse as 'closed' — perhaps closed in time, whatever its spatial curvature. However, describing the Einstein–de Sitter universe, which is spatially flat and thus infinite in extent but with a rate of expansion which asymptotically approaches zero as having "just enough density of matter to halt the expansion and close the universe after an infinite amount of time" is going too far. On another page, it is claimed that in the Einstein–de Sitter universe, not only will expansion stop, but the scale factor will go back to zero after an infinite time; there is no interpretation in which that make sense. Interestingly, there is a long history of referring to such borderline cases as closed.[3]

has made that journal one of the most famous in cosmology! (It was also not as obscure at the time as is sometimes claimed.) While it is true that his paper on relativistic cosmology[8] had little impact at the time, that is also true of Friedmann's papers[9,10], even though they were published in German, as was much of the astronomical literature at the time, and in *Zeitschrift für Physik*, a leading journal. (Baggott does note that Friedmann overlooked the flat $k = 0$ case, first discussed by Robertson[11].[*]) Baggott gives Lemaître credit for first calculating what would later be known as the Hubble constant[†], but misses the important detail that his "of no actual interest" is almost certainly a too literal translation of *actuel*, which means 'current' in French[12].

I found the discussion of the de Sitter universe (a universe with no matter and a cosmological constant; the expansion is exponential and the Hubble constant constant in time[‡]) somewhat confusing, as it is presented as a universe with positive spatial curvature, whereas most modern cosmology books describe it as being flat. Either is correct, depending on the coordinates chosen. However, the explanation is too complicated (*e.g.*, ref. 13) to be explained in such a book; the slightly ahistorical modern description might be more appropriate.[§]

The epilogue briefly discusses a few ideas which have been inspired by the Hubble tension and/or possible explanations for it. It is not intended to be a thorough discussion but rather to put the Hubble tension in context. Three appendices cover symbols and acronyms, cosmological distances, and lookback time as a function of redshift. There are several black-and-white illustrations scattered throughout the text. A page of acknowledgements and more than three of figure and photo credits indicate what a vast undertaking such a book is, even more so because the subject is very current. Somewhat unusual is that photos (of people) and other figures are numbered separately (though of course images of galaxies taken with photographic plates are certainly photos in the normal sense of the word). There are no footnotes but a bit more than seventeen pages of endnotes, most of which are references. The bibliography of about two-and-one-half pages is a list of books for further reading and/or background material used by the author (as opposed to the explicit references in the notes). A thirteen-and-one-half-page index ends the book.

I would like to have liked this book more. The introductory chapters on (the history of) astronomy and cosmology are interesting and useful and, though tailored to the theme of the book, often present more than just the standard material. The material on relatively new observational cosmology (CMB, baryon acoustic oscillations, and the Hubble tension itself) is good. The book is well written at an appropriate level and it is useful to have such books on current topics. However, any recommendation has to be tempered by several at best misleading statements about cosmology, most of which I've seen elsewhere. That is part of the problem: I doubt that most authors make the same mistakes independently. Rather, mistakes in the source material live on in newer works, and it would be a shame if an otherwise good book by a well-known popularizer of science keeps that trend alive. It provides a good overview of the Hubble tension, why it is important, and the necessary

[*] Although that model was later discussed by Robertson and others, his doctoral thesis is certainly more obscure than Lemaître's paper in French.

[†] While the IAU voted to rename the Hubble law the Hubble–Lemaître law, the constant is still just the Hubble constant.

[‡] In general, the Hubble constant is not constant in time. However, that is not a misnomer; it is the constant in the equation $v = HD$. Thus I disagree with Baggott who claims that it should be called the 'Hubble parameter' for that reason. By contrast, the cosmological constant *is* constant in time. The de Sitter model has other features which are not true in general, *e.g.*, the Hubble radius is also the radius of the event horizon.

[§] Readers of German might want to consult a doctoral thesis[14] by the same author as that of ref. 13 for more background on de Sitter's role in the early days of relativity and relativistic cosmology. Although Eddington is well known as a champion and popularizer of General Relativity, de Sitter was as well, *e.g.*, very soon after the initial paper by Einstein[15], he wrote a 'popular' summary in these pages[16] as well as more detailed explications[17–19].

background to understand it, but readers should get their overview of cosmology from elsewhere. — PHILLIP HELBIG.

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From Stars to Life: A Quantitative Approach to Astrobiology, by Manasvi Lingam & Amedeo Balbi (Cambridge University Press), 2024. Pp. 400, 26 × 21 cm. Price £59·99/$79·99 (hardbound; ISBN 978 1 009 41121 9).

Astrobiology is perhaps the most multidisciplinary science that can be imagined. Everything, from cosmology to biology, planetary science to astrophysics, is involved at some level, and a detailed understanding of the history of life on Earth is also necessary since we have but one place where the emergence and evolution of life can be studied. In fact, if we go so far as to include the search for extraterrestrial intelligence, we must add human history and sociology to the mix. This extreme multidisciplinarity means that many textbooks that cover astrobiology take separate chapters written by multiple authors and edit them together to produce the final work. That is not the approach taken here as the authors bravely take on the vast epic that is the story of life in the Universe from the Big Bang to the present day and beyond. And in doing that they are largely successful, maintaining a coherent voice and approach throughout. The book starts with the large-scale boundary conditions provided by cosmology and then moves to the astrophysics of stars and planet formation. The Earth is then studied in detail, including its early conditions, then looking at the possible routes through which life might have originated here, and how life both affects and is affected by the terrestrial environment. The lens then zooms out to look at broader questions of habitability elsewhere, before potential astrobiological targets, inside and outside the Solar System, are discussed. The astrophysical techniques for detecting life elsewhere, including intelligent life, are then examined. The book's subtitle is 'a quantitative approach' and there is indeed a decent amount of quantitative analysis both in the text and in the included problems. However, the squishy and at times speculative nature of the field makes it inevitable that a fair fraction of the problems are more wordy than quantitative, and try to send the