

Big Bang) and the effects of inflation is good (though I disagree that the flatness problem is actually a problem (e.g., ref. 3 and references therein)). In my review⁴ of a cosmology textbook⁵, I praised the author for explicitly introducing various forms of the Robertson–Walker metric. Something similar is done in this book for various representations of S^3 in the chapter on the Maurer–Cartan description (and the connection to the RW metric in cosmology is mentioned). The author is also aware that it is the Lorenz gauge (though there is no such entry in the six-page small-print index, though there are three Lorenz-related entries.) Apart from the usual topics and those already mentioned, the discussion of black holes (Schwarzschild, Reissner–Nordström, Kerr, Kerr–Newman) also includes the cosmological constant, and there is an entire chapter on the Maurer–Cartan description.

The book is a good introduction at a reasonably high level for someone who wants the work shown and is happy to forego the history of the topic. However, I found the book rather difficult to read, primarily because of the lack of definite and indefinite articles when they should be there and *vice versa*. In general, the book could have benefitted from editing by a native (or otherwise very good) speaker of English. There is also one instance (p. 223) where some text has obviously been left out. Similarly to the previous book on General Relativity⁶ I reviewed⁷ in these pages (also from Cambridge University Press), the wider margins are always on the left; more practical is to have them always on the outside. Several pages of my copy also became unattached; hopefully that is a one-off problem and doesn't affect the entire print run.

There are only a few black-and-white diagrams, scattered throughout the text. There are neither footnotes nor endnotes nor any sort of bibliography; only preface, main text (including appendix), and index. This is a no-frills detailed introduction to General Relativity and good for those who want to learn the subject by following worked-out derivations — PHILLIP HELBIG.

References

- (1) P. G. Ferreira, *The Perfect Theory: A Century of Geniuses and the Battle over General Relativity* (Houghton Mifflin Harcourt), 2014.
- (2) P. Helbig, *The Observatory*, **134**, 214, 2014.
- (3) P. Helbig, *EPJH*, **46**, 10, 2021.
- (4) P. Helbig, *The Observatory*, **136**, 204, 2016.
- (5) W. D. Heacox, *The Expanding Universe: A Primer on Relativistic Cosmology* (Cambridge University Press), 2015.
- (6) H. Nätase, *General Relativity: A Graduate Course* (Cambridge University Press), 2025.
- (7) P. Helbig, *The Observatory*, **146**, 176, 2026.

Radio Universe: How to Explore Space Without Leaving Earth, by Emma Chapman (John Murray), 2026. Pp. 242, 23.5 × 15 cm. Price £18.99 (paperback; ISBN 978 1 529 39899 1).

I've read many popular-science books on astronomy, but this is probably the first which is mainly about radio astronomy. The author is a Royal Society Dorothy Hodgkin Research Fellow at the University of Nottingham and recipient of several awards; this is her second popular-science book about astronomy (thus only two books so far; there is another author named Emma Chapman; to add to the confusion, in the US this book is entitled *Echoing Universe*). Chapman was raised on radio, but in the BBC sense; she became interested in radio astronomy as a result of her PhD project, which involved radio observations from the Netherlands. An introduction mentions that project, tells a very brief history of radio astronomy, describes how radio telescopes work, and offers a somewhat longer exposition of the electromagnetic spectrum (including an obsolete reference to the colour indigo on p. 7). There is little about radio astronomy in the technical sense in the book; rather, it discusses the science which can be done *via* radio astronomy, sometimes containing asides about other radio-related topics.

The first six chapters are confined to the Solar System: the Moon (Apollo programme, radar, radio communications), the Sun (sunspots, James Stanley Hey, coronal mass-ejection events), Mercury (detailed discussions of its rotation, the presence of ice, why there have been only three missions), Venus (temperature, rotation, vulcanism, craters, lack of plate tectonics, high-resolution mapping), Mars (extraterrestrial life, orbital mechanics, the ill-fated *Beagle 2* lander), and the asteroid belt (introduced *via* Saturn's rings, Saturn being the current limit of radar astronomy), detecting potentially dangerous asteroids, and some history involving (later Sir) Bernard Lovell at Jodrell Bank. We then move further away to the Milky Way (the *Voyager* probes, Grote Reber, the 21-cm line, the structure of the Milky Way, astrophysical masers, *Meerkat*), black holes (detection, gravitational waves, Special and General Relativity, Schwarzschild's life (and death) and work, the *Event Horizon Telescope*, stellar-mass black holes), neutron stars (discovery of pulsars, neutron-star physics, pulsar astronomy, controversy around Jocelyn Bell (Burnell)), gravitational waves (the Hulse–Taylor binary pulsar, *LIGO*, the *Pulsar Timing Array*, kilonovae), exoplanets (formation, T Tauri stars, *ALMA*, molecular clouds), contact with extraterrestrial intelligence (SETI, TRAPPIST 1e, the Drake equation, the *Allen Telescope Array*, funding, Sagan, Tartar, METI), the high-redshift Universe (discovery of the CMB, 20th-Century astronomy including some wrong turns and dead ends, radio-source counts, physics of the CMB, first stars, the *Square Kilometre Array*), dark matter (cosmology, history of dark matter, Purcell & Ewen, modern structure-formation simulations), dark energy (more cosmology, baryon acoustic oscillations, intensity mapping), and the 'dark' side of the Moon (putting a radio telescope on the far side of the Moon). Finally we get a tourist's guide to radio telescopes, with brief descriptions of eleven such potential travel destinations. There are no figures and a few footnotes. The back matter includes extensive acknowledgements, notes (which are actually numbered references corresponding to numbered citations in the text, about eight per chapter), suggestions for further reading (both in general and a few suggestions for most chapters; I noted five which I intend to read; some should be updated to reflect more recent editions), and a ten-page small-print index.

While the topics are chosen because of the role played by radio astronomy in them, that is a jumping-off point for more general descriptions, such as a detailed account of the determination of the rotation of Mercury and Venus and the mapping of the latter.* While much of the material was familiar, I was happy to get more details on Hey and Purcell & Ewen. It is also good to have a nice overview of SETI and related topics; Chapman notes that some authors shy away from such discussions for no good reason. (Recently, SETI has become more respectable, and Michael Garrett, a prominent SETI advocate, has been the Sir Bernard Lovell Professor of Astrophysics and Director of the Jodrell Bank Centre for Astrophysics since 2016, after having been Director of the Joint Institute for VLBI in Europe and the General & Scientific Director at ASTRON.) Considering the large number of diverse topics, balance might be hard to achieve, but she does a good job, usually going into more depth only when mentioning less common (but important) details. A minor point is that I found there to be a bit too much detail on the physics behind the CMB (and to some extent on the history of the topic), but too little on why it is so important for cosmology today, *i.e.*, what one can learn from the power spectrum, though arguably that is too much physics and too little radio astronomy.

I noticed only a few mistakes. Some are easy to explain. For instance (p. 40), "Six missions carried a total of twenty-four American men to lunar orbit between 1969 and 1972, and of those, twelve set foot on the surface." There were eight, not six missions, but only six included a Moon landing. (The ill-fated *Apollo 13* went around the Moon, but didn't orbit it in the

*The most recent space-probe mapping is from the *Magellan* mission 1990–1994, with a resolution of 100 m. In 1978, the *Pioneer Venus Orbiter* had achieved one of 2 km. Amazingly, only ten years later, technology at the *Arecibo Telescope* was able to achieve that from Earth.

stricter sense.) Some are common misconceptions, *e.g.*, Special Relativity (SR) cannot deal with acceleration (p. 157) — the main difference is that SR is restricted to (flat) Minkowski space and General Relativity (GR) allows for curved space–time (to be sure, gravity curves space–time, and the Equivalence Principle relates acceleration and gravity, but nonetheless SR can describe acceleration). It is at least implied that Schwarzschild died on the battlefield; he died in hospital, away from the front, and of an auto-immune disease, not war wounds (p. 160). (She does get the history of the term ‘black hole’ correct, crediting Dicke and not Wheeler, p. 160.) Bell wasn’t yet Bell Burnell when she discovered pulsars (p. 172). The last sentence in the first paragraph of the last section in the chapter on neutron stars (p. 182) states “Sadly, Bell Burnell is less known for her scientific breakthrough than for the controversy that surrounds it.” That might well be true, but I wonder if devoting eight paragraphs to said controversy will improve the situation. At the risk of doing the same, I note that the actual discussion agrees with my assessment and correctly differentiates the question of whether she should have received a share of the Nobel Prize (including placing the decision in the context of the time and Bell Burnell’s own take on the matter) from the silly reporting by many journalists at the time. While GR indeed describes changes in the gravitational field propagating at the speed of light, not all such changes correspond to gravitational waves as usually thought of (p. 189). Since this is the third book in which I have noticed it, the idea that astronomers can somehow *measure* the radial velocity of extragalactic objects is becoming a common misconception (p. 248).

Others are more bizarre: Drake’s choice of 1679 pixels for his Arecibo message was due to it being the product of the two primes 23 and 73, but of course 1679 itself is not prime (p. 235). The description of the Hubble law is at best confused (p. 247). It is at least strongly implied that Einstein was aware of Friedmann’s work (which was done some years later) when the former added the cosmological constant in order to have a static universe (p. 248). The history of dark matter is at best too brief. P. 263: “Dark energy was proposed in the 1990s, when observations of distant supernovae revealed that the expansion of the Universe is not slowing down as expected, but accelerating.” That is literally true, but it was not *first* proposed (which seems to be implied) then, and though the *term* ‘dark energy’ was proposed then the idea is older. (Sometimes ‘dark energy’ is used to contrast it with a cosmological constant, the former having an equation of state other than $p = -\rho$ and/or the value or even the equation of state changing with time, though none of those were needed in the 1990s and probably none is needed today.) Further discussion of supernova cosmology is at best muddled (pp. 278–279).

However, most of the mistakes are related to cosmology, with which only a small part of the book is concerned, and are rather common, both of which are true of many books reviewed in these pages. I think that it is important to mention them, but at the same time the space devoted to them in this review exaggerates their importance. The rest of the book is not only (as far as I can tell) technically correct, but is well written and conveys the author’s love of radio astronomy, a topic which should get much more attention in books at this level; perhaps this book can be a step in that direction. I certainly enjoyed reading it and, despite being an honorary radio astronomer, learned many new things. — PHILLIP HELBIG.

On Time: The Physics That Makes the Universe Tick, by Jim Al-Khalili (Princeton University Press), 2026. Pp. 359, 24 × 16 cm. Price £28/\$32 (hardbound; ISBN 978 0 691 26703 6).

Al-Khalili is a well-known popular-science writer and presenter on radio and television with a background in theoretical nuclear physics; he is a professor of physics at the University of Surrey, where he also holds a chair in the public engagement of science. This is the first book by him that I have read. I’ve read many books on the nature of time and reviewed some in these pages, though they were usually more technical and/or edited volumes with several authors. In particular, this book — with an important exception mentioned below —