researchers) this last chapter is the one that should be thrust into the public gaze. With public trust in science on a knife edge in some disciplines, these are important concepts and tensions to be appreciated. Airing them more widely might help bridge the sometimes barren chasms between those sceptical of all received scientific wisdom, the unthinking 'follow the science' herd, and those in danger of infection by scientism.

Overall the book is a dense, encyclopaedic *tour de force*, which cannot be taken or read lightly. I assume it is aimed primarily at those starting out on a research career, although as a refresher for the longer-in-tooth it will contain some surprises and even more sobering reminders. For anyone willing to invest the time and effort, it is hard to see anything but significant reward resulting.

But what of the nagging road-user analogy? The UK government's Road Traffic Act (1988) Section 38 contains the following paragraph: "A failure on the part of a person to observe a provision of *The Highway Code* shall not of itself render that person liable to criminal proceedings of any kind but any such failure may in any proceedings (whether civil or criminal...) be relied upon by any party to the proceedings as tending to establish or negative any liability which is in question in those proceedings."

Although it would no doubt be a policy in danger of being labelled as draconian, what if nascent researchers were required to pass a formal 'theory test' on their knowledge and understanding (whatever those two are!) of the concepts, both philosophical and practical, presented in this text before setting out on the practicalities of post-graduate research? Their subsequent thesis and its defence would represent the final 'practical driving test', cognisant of the principles already imbued by the theory test. From a quick trawl of the internet and personal contacts, it seems that some training akin to a theory test is indeed already offered in the UK, but it appears to be sporadic and very much a minority sport at the moment. However, without such a scheme one might wonder if the awarding of the degree of Doctor of Philosophy is bordering ironic and acceptable merely as an innocent, quirky anachronism, somewhat akin to the persistent titles of some of the awards in the UK's honours system. Teplow's teaching at UCLA of courses featuring this book's material promises to be an educational green shoot heading in the right direction. Hopefully it will not be another 61 years before others catch up! — Dave Pike.

Reference

(1) John P. A. Ioannidis, Thomas A. Collins, & Jeroen Baas, 2023. bio Rxiv https://doi.org/10.1101/2023.11.23.568476

White Holes: Inside the Horizon, by Carlo Rovelli (Allen Lane), 2023. Pp. 157, 19·8 × 11·8 cm. Price £14·99/$19·49 (hardbound; ISBN 978 0 241 62897 3).

This book is a quick read, not only because of the small format (and not all that many pages), but because, like Rovelli's other books, it is very well written (more precisely, I can judge only the translation, by Simon Carnell, at least as far as the language goes; like his other popular-science books, the original is in Italian). Rovelli, an active researcher in the field of loop quantum gravity, has written several popular books, and even landed a bestseller[1] (reviewed in these pages[2]). Like many of his other popular-science books, it is a mixture of standard knowledge and his own work. The table of contents lists only the three parts, though each has five or six chapters.

The first part is mainly about *black* holes, mostly standard stuff, though it would be difficult to find a better presentation of the basics. White holes are taken up in the next part. Most readers will probably have heard of them, but most also probably have some misconceptions, which Rovelli clears up (for example, their gravity is attractive; time reversal reverses the first derivative of spatial coordinates, not the second). In practice, it is difficult to distinguish black from white holes from outside the horizon. While nothing can come out from behind the horizon of a black hole, nothing can cross the horizon of a white hole from outside. However, just as a distant observer, due to the gravitational redshift and time dilation, never actually sees anything cross the horizon from outside (and hence doesn't see the actual collapse to form a black hole), neither does such an observer actually see anything emerging from a white hole. Where Rovelli departs somewhat from standard lore is his idea that when the matter forming the black holes has been sufficiently compressed that quantum-gravity effects play a role, quantum tunnelling can transform a black hole into a white hole.

In the third part, Rovelli discusses his resolution of the black-hole information paradox as well as the concept of time and the relation between time-reversible microphysics and the macroscopic arrow of time. Hawking radiation is such a phenomenon which provides an arrow of time, and as a result white holes are not exactly time-reversed black holes. According to Rovelli, while large white holes are unstable, turning into black holes, small ones are stabilized by quantum-gravity effects. To the 'extremely interesting if true' category belongs his idea that dark matter could consist of Planck-mass white holes, which is certainly compatible with observations. Unfortunately, such dark matter would be more difficult to detect directly than most other dark-matter candidates.

The book is non-technical but takes care not to over-simplify things. Rovelli justifies leaving out technical details because the non-expert reader could not follow them while the expert reader would be bored by them; both can benefit from his personal takes on various topics. (In one case, a long end note is devoted to providing a technical explanation to a qualitative description in the main text.) There are many references to Dante's *Paradise Lost*, not just in relation to non-Euclidean geometry (something other authors have also noticed) but also in a more general sense. Those tie in with Rovelli's general view of the world, also mentioned in his other books. Whether one shares it is perhaps a matter of taste; I find it to my liking, at least as long as it regards physics. Personal reflections which stray a bit further from the main text are set apart by their lack of capitalization; while both such reflections and setting them apart are good ideas, I would have chosen another way to indicate them.

While not all might share Rovelli's more speculative ideas about physics, I noticed no actual mistakes in the book* and the language and style are a cut above most books I've reviewed in these pages. There are a few black-and-white figures throughout the text. There are no footnotes, and end notes provide footnote-style comments and/or references (usually to technical literature). The

*Well, Karl Schwarzschild didn't exactly "lose his life on the Eastern Front" in the First World War. He contracted pemphigus while serving in the army (for which, at over 40 years old, he had volunteered). Since that is an autoimmune disease, it probably had nothing to do with the war. He left military service, returned to Göttingen, died a couple of months later at 42, and was buried there. All the same, writing three papers (including one with the famous Schwarzschild solution) while suffering from pemphigus and "despite the incessant artillery fire" is impressive enough.

seven-page small-print index is especially thorough considering the length of the book.

This is a well-written and interesting book accessible to a broad readership. Although one might not agree with his more speculative points (which might turn out to be wrong), most will probably learn something from it and might be inspired to follow up the references in order to learn more. — PHILLIP HELBIG.

References

(1) C. Rovelli, *Seven Brief Lessons on Physics* (Allen Lane), 2015.
(2) P. Helbig, *The Observatory*, **136**, 155, 2016.

Io: A New View of Jupiter's Moon, edited by Rosaly M. C. Lopes, Katherine de Kleer & James Tuttle Keane (Springer), 2023. Pp. 375, 24 × 16 cm. Price £129·99 (hardbound; ISBN 978 3 031 25669 1).

Io After Galileo: A New View of Jupiter's Volcanic Moon, edited by Lopes and J. R. Spencer, appeared as a 'first edition' in 2007, but was not reviewed in these pages. This little world is a fascinating place, and all that molten sulphur takes me back to my career in the chemical laboratory. Tidally squeezed and heated, Io exhibits active volcanism and sports an exotic atmosphere. It emits 100 terawatts. Some light elements form a tail around its orbit. The sodium component of the tail is remarkably bright, and by 2023 was being successfully imaged by amateur astronomers even with small-aperture telescopes equipped with narrow-band filters.

That Io's darker poles had first been spotted by Barnard is mentioned in an historical summary early on, but the first low-resolution map made by the Pic du Midi observers in 1943–44 is not mentioned. The latter shows seven or eight intriguingly circular dark patches, of which several actually coincide with volcanoes, and I feel that it should be better known.

Early chapters discuss the moon's formation and evolution. Next comes Io's surface, where geological processes have eliminated the cratering record. I was particularly interested in Chapter 6 where Katherine de Kleer and Julie Rathbun show how, after the close of the *Galileo* mission, hotspots continued to be mapped by the limb-occultation technique, or imaged directly (with adaptive optics) by the *Keck* telescope. These data revealed four persistently active volcanoes. Different classes of eruption are now recognized, with even a suggestion of explosive or Strombolian-type activity.

Further chapters review the bulk composition of Io, its plumes, atmosphere, and magnetosphere. In Chapter 10 the authors discuss how Io can serve as a model for a tidally heated exoplanet, in particular planets b and c in the TRAPPIST-1 system. Future investigations by telescope and spacecraft feature in Chapter 11, written by Alfred McEwen *et al.* The latter missions include *JUICE*, scheduled to arrive in 2031.

A multi-author work such as this one needs a very detailed index, and I don't believe five pages are quite good enough. There are few names: 'Galileo' could equally be the philosopher or the space probe. 'Sulfur' is not indexed, although S_2, SO, SO_2, and sulphur ions are included. 'Volcano' and 'volcanic' are conspicuous by their absence. It would also have been convenient to have had (at the front or back) a full page (cylindrical?) reference albedo map of Io showing all the features named in the text: the maps on pages 149 and 250 only include a few names. Another issue is the high price. These drawbacks aside, this latest review of Io is full of fascinating data, richly illustrated, crammed with references, and is much to be welcomed. — RICHARD MCKIM.