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REVIEWS

Supermassive Black Holes, by Andrew King (Cambridge University Press), 2023. Pp. 308, 25 × 17·5 cm. Price £54·99/$69·99 (hardbound; ISBN 978 1 108 48805 1).

Recently, supermassive black holes have garnered significant attention, captivating both the public and scientists alike. The no-hair theorem states that any black hole can be completely described by its mass, angular momentum, and charge; nevertheless, a multitude of intricate phenomena emerge from these systems. The past decade has seen ground-breaking advances, such as the direct detection of gravitational waves from merging stellar-mass and intermediate-mass black holes as well as the imaging of black-hole shadows by the *Event Horizon Telescope*.

Looking towards the future, black-hole science holds immense promise, especially with electromagnetic facilities such as *JWST* pushing detections of supermassive black holes to higher redshifts, and next-generation gravitational-wave detectors, such as *LISA* and *IPTA*, targeting the supermassive black-hole regime. Notably, strong observational hints at a gravitational-wave background formed from the cosmic population of supermassive binary black holes detected by *IPTA* have further intensified the excitement.

Amidst this backdrop, Andrew King's book, *Supermassive Black Holes*, proves to be a timely and relevant textbook in the current research landscape. It masterfully weaves together the theories of General Relativity and fluid dynamics with the rich phenomenology of active galactic nuclei (AGN) and the co-evolution of supermassive black holes and their host galaxies. The book comprises eight chapters, where the initial four lay the essential groundwork for the cutting-edge research topics explored in the latter four.

In the first chapter, the author outlines crucial theoretical concepts and observational characteristics of supermassive black holes. Moving on, the second chapter serves as a summary of the salient features of General Relativity concerning black holes, catering to both those familiar with GR and newcomers. The third chapter focusses on astrophysical gasses, encompassing fluid dynamics in various relevant regimes, including incompressible flows, shocks, plasma theory, and magnetohydrodynamics. The author establishes connections to different astrophysical scenarios, discussing the applicability of standard approximations while cautioning against quasi-Newtonian treatments. Chapter 4 delves into accretion-disc theory, starting with Newtonian orbits and subsequently connecting them to previously discussed GR solutions. A detailed examination of the thin-disc model follows, with attention to other disc types, particularly in the super-Eddington regime (slim discs and advection-dominated accretion flows). The chapter concludes by addressing accretion-flow simulations and associated numerical pitfalls.

The second half of the book delves into frontier research topics. Chapter 5 covers various theoretical aspects of black-hole growth, including gas-transport mechanisms and chaotic accretion. It extensively discusses misaligned accretion discs, applying the same theory to circumbinary discs and their significant role in orbital shrinking and the final-parsec problem. Tidal-eruption events and the novel field of quasi-periodic eruptions are also explored, with the latter potentially providing crucial insights into low-mass black holes. Chapter 6 is a deep dive into the black-hole–galaxy scaling relations, with a focus on the AGN wind-driven scenario, supplemented by alternative explanations like deriving scaling relations from the assembly history. Observational constraints, especially from AGN in dwarf galaxies, are also analyzed. Chapter 7 reviews other forms of AGN feedback, in particular radiatively-driven winds and jets. Different jet-production mechanisms and jet precession are discussed from both observational and theoretical perspectives. The book concludes with Chapter 8, which broadly addresses 'black-hole growth' and the process of constraining different theoretical models through observations, including the AGN luminosity function, supermassive-black-hole-mass limits, and deviations from the scaling relations. Each chapter includes problem sets for further engagement.

Personally, I found the book to be a highly enjoyable read, offering a comprehensive overview of crucial theoretical concepts related to supermassive black holes. Andrew King presents the material in an accessible manner, making it particularly well-suited for graduate students embarking on their journey in this field. Additionally, advanced undergraduates seeking background reading for research projects could find this book valuable. It is also an excellent resource for individuals transitioning from a general physics background to astrophysics, as it illuminates the connections between General Relativity, fluid dynamics, and the intricate world of AGN physics. As I pass the book on to my summer student, I wholeheartedly recommend it to anyone interested in exploring the fascinating world of supermassive black holes. — Sophie Koudmani.

Simulating the Cosmos. Why the Universe Looks the Way it Does, by Romeel Davé (Reaktion), 2023. Pp. 199, 22·5 × 14·5 cm. Price £15·95 (hardbound; ISBN 978 1 78914 714 8).

Who would have thought that a book on numerical modelling could be such fun! A leading practitioner of the art, Davé demystifies the black boxes of N-body simulations, hydrodynamical modelling, and the rest in irreverent style, exemplified, perhaps, by the final sentence of Chapter 1, prior to embarking on modelling the Universe: "To do this, we're going to need computers. Big ones." The first chapter itself sprints through the development of cosmology, both observational and theoretical, from Hubble and Lemaître through the CMB and inflation to the concordance model of ΛCDM in 40 pages. While unsurprisingly light on the nuances of the history, this provides an excellent background for the later chapters on 'Putting the Universe on a Computer' and on the ever-improving simulations of large-scale structure and the formation and evolution of galaxies (including a section 'Are We There Yet?'). The easy-going style means that you are soon reading about time steps and particle-mesh codes without realizing that it's become more technical. At the end, there is even room for a discussion of whether we live in a simulation. References to academic papers are provided for those wishing to dive in deeper, but this is essentially the nearest you can get to light reading on numerical cosmology. Highly recommended — especially given the remarkable price for a hardback these days. — STEVE PHILLIPPS.

The End of Everything (Astrophysically Speaking), by Katie Mack (Penguin), 2021. Pp. 238, 19·5 × 13 cm. Price £9·99 (paperback; ISBN 978 0 141 98958 7).

Katie Mack has "[bounced] back and forth between physics and astronomy departments, studying black holes, galaxies, intergalactic gas, intricacies of the Big Bang, dark matter, and the possibility that the universe might suddenly blink out of existence" and "even dabbled in experimental particle physics for a while"; she now holds the Hawking Chair in Cosmology and Science Communication at the Perimeter Institute for Theoretical Physics in Canada and has written many popular-science pieces in various media, though this is her first book. There are many books, from popular-science books to technical monographs, about the origin of the Universe, but comparatively few about the possible ways it might end. After an introduction and summary of the history of the Universe from the Big Bang until now, she looks at five ways the Universe could end: Big Crunch, Heat Death, Big Rip, vacuum decay, and bounce.* The final chapter before the Epilogue starts with a discussion of a paper[7] in this *Magazine* by the later Astronomer Royal Martin Rees, 'The collapse of the Universe: an eschatological study'. (At that time, a Big Crunch seemed most likely — though Rees also touched on a 'conventional' Big Bounce — but today that seems to be the least likely possibility.) That is followed by a look at Dyson's view[8] assuming that the Universe will expand forever before current (and future) experiments and various ideas about where theory might be heading are discussed. The Epilogue features Rees again and other scientists talking about their personal feelings regarding the end of the Universe.

On the whole, the book does its job well, giving a popular-science-level introduction to some ways in which the Universe could end (as well as a summary of its history). Many readers might not have heard of the Big Rip or vacuum decay, and those are explained clearly and well. My main gripe is that it gets some things wrong regarding traditional observational cosmology. While it is not uncommon for confusion to arise from over-simplification, that shouldn't be a problem for a professional science communicator. The problem is not a new one: confusion related to 'the redshift–distance and velocity–distance laws'.† At the latest after the publications of Harrison's paper[9] with that title, no-one should still be confused, but many, even some professionals, are.[10] The Hubble–Lemaître law, that recession velocity is proportional to

*Tegmark [1,2] (the latter reviewed in these pages[3]) also discusses five ways in which the Universe might end: Big Chill (Heat Death), Big Crunch, Big Rip, Big Snap (can occur if the fabric of space is not infinitely stretchable), and Death Bubbles (vacuum decay; also known as the Big Slurp), but not a bouncing Universe. Of course, in some sense a bouncing Universe doesn't end, but the main reason for the difference is probably that the Big Snap has not been discussed as much as the other four, while the old idea of a bouncing or, in general, cyclic Universe (*e.g.*, ref. 4) has become more popular recently in the context of the ekpyrotic model[5] and Conformal Cyclic Cosmology[6].

†The second footnote on p. 58 provides almost a textbook example of the confusion Harrison[9] addresses.

proper distance*, is extremely simple: it is the only velocity–distance law for which a homogeneous and isotropic universe remains so. (Note that that is pure kinematics; no dynamics, much less physics, let alone General Relativity, is needed.) The dependence of (various sorts of) distance on redshift is in general complicated, and observational cosmology works by comparing an observed distance–redshift relation (the distance is hard to measure accurately; the redshift is easy) to those calculated for various combinations of the cosmological parameters. Velocities play no role. While it is true that knowing the expansion history of the Universe ($H(z)$, where H is the Hubble constant and z the redshift) allows one to determine the cosmological parameters Ω and λ (the density parameter and normalized cosmological constant, respectively) and *vice versa*, one cannot actually measure the expansion velocity at high redshift. Thus, Mack's scheme (p. 59) of determining the expansion history by measuring z and using the Hubble–Lemaître law to get the distance and then using that distance to determine the light-travel time and hence the time the light was emitted won't work: Measuring z gives us the velocity only if we already know the cosmological parameters (by using them to calculate the distance and then, *via* the Hubble–Lemaître law, to *calculate* the velocity), and similarly the light-travel time can be calculated only if the cosmological parameters are known. (Of course, in general the light-travel-time distance is not the same as the luminosity distance or angular-size distance which are the distances most commonly used in observational cosmology, though knowing the cosmological parameters allows one to calculate them all.) On p. 62, she claims that if the Universe collapses, then the Hubble–Lemaître law is valid "right up until the expansion stops completely". No. The Hubble–Lemaître law is *always* valid (at least in a Friedmann model, which is the context here). "Right now, the more distant an object, the faster it recedes [true] and therefore, the higher the redshift [not in general] (the Hubble–Lemaître law.)" She claims that we would "*perceive* distant objects as still receding long after they start turning around" [her italics]. We cannot 'perceive' velocity. We can measure redshift, but cannot (except in the limit of small redshift) convert that to a velocity without additional knowledge or assumptions. The Hubble–Lemaître law still applies, but it connects velocity with distance, not with redshift. On p. 69, she notes, correctly, that to know whether the Universe will collapse (by knowing the cosmological parameters), we must know the expansion history. True. That involves measuring distance, which is difficult. True. But the claim that galaxy velocities "can be determined with redshift measurements" at large redshift is just plain wrong. As described above, we can calculate them if we know the distance as a function of redshift, but if we know that, we don't actually need the velocities. On pp. 72–73 she again implies that not only distance measurements but also velocity measurements are part of observational cosmology. The

*Hubble himself used low-redshift data (many from Slipher and uncredited). At low redshift, one can use apparent magnitude as a proxy for distance (luminosity distance, but in the limit of low redshift all distance measures are equivalent) and redshift as a proxy for velocity, thus Hubble[11] could correctly speak of the observations supporting 'A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae', since he was working only at low redshift. What he actually observed is a correlation between apparent magnitude (for sources of presumably similar absolute magnitude) and redshift. Although there is some variation in how the terminology is (ab)used, the consensus is that the Hubble(–Lemaître) law refers to the correlation between distance and radial velocity, as in the title of Hubble's article (the velocity–distance law), although that is not what he observed. (The redshift–distance law — in general, a different law for different distances which also depends on the cosmological parameters — is neither a simple law nor named after anyone.)

latter are neither possible nor needed. Again on p. 74 (discussing supernova cosmology), she claims that one needs distance and velocity as a function of redshift; the former is sufficient. On p. 185 it is again repeated that *measurement* of the velocities of high-redshift supernovae are needed to derive the expansion history of the Universe; the reverse is true, and velocities are not needed as input into any other calculations. In any case, the redshift cannot indicate "how quickly cosmic expansion is happening at that point" without already knowing the cosmological parameters. Velocities, measured or calculated, are not used in observational cosmology at all. On p. 191, redshift drift (*e.g.*, ref. 12 and references therein) is mentioned, but confusingly cast in terms of "apparent velocity".

I have dwelt on that confusion because it demonstrates, yet again, that some who really should know better still get it wrong. Also, such popular-science books are read by many more people than those who read technical textbooks, the former sometimes providing an introduction to the latter. The reader then must understand the confusion, and the impression left is that of sloppiness. It's worth it to get it right, whatever the context. Other errors are minor: I don't think that Einstein "reluctantly" gave up the cosmological constant when he learned that the Universe is expanding; by all accounts he was more than happy to do so, whether or not he actually described it as his 'biggest blunder'[13]. The Hubble radius is sometimes confused with the event horizon (ref. 14 sets the record straight, although that should have been clear since Rindler's classic paper[15]). Entropy is not the only part of physics which cares about the arrow of time[16,17]. A universe with a (positive) cosmological constant can (but doesn't have to; it depends on the value) accelerate not only if its spatial geometry is flat, but also in the positively and negatively curved cases. A couple of things (the relationship between geometry and destiny and Hawking radiation) are presented more or less correctly, but only after repeating the common special-case version (for the former) or a completely wrong explanation (for the latter, though here the wrong version is presented explicitly to contrast it with the proper explanation).

The production is fine except for the black-and-white figures in which too-light shades of grey are very difficult to make out (perhaps black-and-white versions of colour figures?). Typos are few and annoying matters of style too many but nevertheless about average for most books I read. There are fortunately footnotes rather than end notes. There is no bibliography as such, though a few papers are mentioned by author and title in the main text. The book ends with three pages of acknowledgements and a ten-page small-print index.

Despite the goofs mentioned above (which some readers might recognize and forgive), I can nevertheless recommend the book, since otherwise it is well written and provides a popular-level introduction to a topic which is usually reserved for more technical literature (*e.g.*, refs. 1, 7, 18–20). — Phillip Helbig.

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Solar Surveyors: Observing the Sun from Space, by Peter Bond (Springer), 2022. Pp. 535, 24 × 16·5 cm. Price £29·99 (paperback; ISBN 978 3 030 98787 9).

Solar Surveyors is a very comprehensive overview of mostly space-based solar and interplanetary missions dating from the earliest rocket launches to study solar X-ray and ultraviolet emission in the years following World War II to the latest probes still operating. There is a long introductory passage giving the reader the fundamentals of solar physics, including solar radiation and the nuclear source of solar energy, as well as the history of the subject dating back to the time of Newton and Herschel. There is a well-illustrated section on ground-based observatories including the latest telescope in Hawaii with an outline of the helioseismology *GONG* network, followed by how the early rocket-borne instruments enabled solar astronomers to investigate the nature of the high-temperature solar corona and solar flares.

A discussion of interplanetary probes takes the reader on to the meat of the book, the space observatories looking at the Sun from low-Earth orbit to those viewing the Sun from interplanetary probes. Examples include the high-energy X-ray mission *RHESSI*, the two *STEREO* spacecraft and Japanese *Hinode* spacecraft, and *Solar Orbiter*, which is still about to obtain images of the polar regions of the solar corona as well as hard-X-ray images of flares.

Nearly all the references are to web sites rather than journal articles, which could be a little dangerous as web sites are liable to change with time. I did some spot checks and they seemed to be still valid. I am familiar with many of the missions listed and found at least one (to the *Coronas F* mission) where the wavelength ranges are wrong, apparently by a factor ten because of an erroneous Ångstrom-to-nanometre conversion.

Although the book is very well illustrated, some of the figures seem to have come from an imperfect reproduction of those in web sites.

The book would be very useful to those who are writing introductions to their PhD theses and perhaps the general reader who wishes to be familiar with the history of space solar physics, although the level of detail may be a little off-putting. — Ken Phillips.