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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

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held on-line

EMMA BUNCE, *President*
in the Chair

The President. Good afternoon everybody. A very warm welcome to all of you. On to the main programme. Today we're going to have two speakers and we're going to begin promptly with our first speaker, Amaury Triaud from Birmingham University, who is the Fowler 'A' Award recipient for 2020. Amaury's talk is entitled 'The ultra-cool dwarf and the seven planets'.

Professor A. Triaud. My talk is about the TRAPPIST-1 planetary system. The star name comes from an acronym for the *TRAnsiting Planets and PlanetesImals Small Telescope*, actually a pair of telescopes which are based in La Silla, Chile, and the Atlas Mountains, Morocco. The TRAPPIST-1 system orbits around a cool and faint star in the constellation of Aquarius, just north of the ecliptic. There are seven planets in the system, each with a similar mass and radius to that of the Earth. The system is very compact in that the distance between the star and the outer orbit is only 7% of an astronomical unit, with some pairs of planets only 3× the Earth–Moon distance apart. All seven planets are considered *temperate*, meaning that, under the right geological and atmospheric conditions, water in liquid form could exist on some part of the surface, although there may be none now.

This star was chosen for investigation because it has 10% of the mass and radius of the Sun and is a member of the most populous group of stars in the Galaxy. Searches for exoplanets usually involve single stars with masses similar to the Sun but these only constitute 7 or 8% of the Galactic population whilst stars with masses less than 25% of that of the Sun represent 50% of the stars in the Galaxy.

The ultimate objective is eventually to measure the chemical make-up of exoplanets' atmospheres, and for this a method called transmission spectroscopy is needed, with data taken while the planet transits its host star. The method works in the following way. An exoplanet with an atmosphere like Earth's scatters bluer wavelengths to make the planet's size appear to increase at those wavelengths since the planet's atmosphere stops some of the star's flux from reaching the observer, whilst at red wavelengths the planet would appear slightly smaller. To retrieve the chemical composition of an exoplanet's atmosphere, the apparent size of the planet is carefully measured as a function of wavelength.

Sources of opacity in the atmosphere can be attributed to specific molecules, and it may be possible to distinguish between isotopes.

A planet transiting a star as small as TRAPPIST-1 produces a signal roughly 100× stronger than for a Sun-like star. This makes detection easier, but also improves the atmospheric follow-up, since the atmospheric signal is similarly amplified. In addition, smaller host stars tend to have planets which are closer in, where the habitable zone is. Furthermore, this also means that confirmation of the planet is faster to achieve since the orbital period is shorter. Finally the closer a planet is to its star, the more probable for the planet to be seen to transit from Earth, meaning that fewer stars need to be surveyed before a detection is made. Overall, considering small stars makes the search for Earth-like planets easier, faster, and more efficient.

The *James Webb Space Telescope* will be launched, we hope, in autumn 2021. It contains instrumentation able to measure the transmission spectroscopic signals of Earth-like planets around nearby stars. However, the mission length is too short to get a sufficient number of observations for Earth-like planets orbiting Sun-like stars. Studying the atmospheres of habitable-zone Earth-sized planets will only be achievable if they orbit stars with $M \leq 0{\cdot}15\ M_{\odot}$, whose temperate planets have short orbital periods, producing many transits during the *JWST*'s mission. The *SPECULOOS* network of telescopes (*Search for Planets EClipsing Ultra-cOOl Stars*) was built specifically to monitor such low-mass stars and detect Earth-sized planets *via* the transit method. *SPECULOOS* has telescopes at Paranal (Chile), Tenerife (Canary Islands), and at San Pedro Mártir in Mexico. TRAPPIST-1 was discovered during proof-of-concept observations made with the *TRAPPIST-South* telescope, in preparation for constructing *SPECULOOS*. Thanks to additional data from several telescopes, including NASA's *Spitzer*, the planets in TRAPPIST-1 are shown to have periods ranging from 1·5 days to 19 days, but their orbital periods can fluctuate by up to several hours due to gravitational interactions. As they pass by each other the planets exchange angular momentum. The inner planet receives a similar amount of flux from its star that Mercury does from the Sun, whilst the outermost planet receives flux close to that of Ceres. The masses range from 0·4 to 1·1 M_{Earth}, which are now known to 2–3% precision, enough to infer bulk properties for the planets.

When considering observations of exoplanet transits of stars with $M < 0{\cdot}15\ M_{\odot}$, observations with *TRAPPIST* and *SPECULOOS* show only one occurrence in 50 stars observed, whilst the *Kepler* satellite found only two such systems in 107 stars observed. It seems likely that the number of Earth-sized planets orbiting low-mass stars in the Milky Way may number as much as ten times as many as Earth-sized planets orbiting Sun-like stars. *SPECULOOS* will monitor 1000 systems, and in the next five years it is hoped to discover 20 to 30 new Earth-sized planets. Observations of their bulk composition and atmospheric composition will allow us to study the diversity of Earth-like environments, and will need us to combine geophysics with astrophysics.

The President. Amaury, thank you so much, that was an absolutely wonderful presentation. Let's open for questions, over to you, Sheona.

Dr. Sheona Urquhart. We've got quite a few questions so we'll just see how many we can get through. The first one comes from Amy Grigorescu and she was wondering whether any of the TRAPPIST-1 system planets are tidally locked?

Professor Triaud. Yes indeed, we think so, this is what we expect from theory. By tidally locked we mean in the same way that the Moon always shows the same face to the Earth, so the planets are expected to show the same face to the star and have a permanent day and permanent night which would affect the climate. However, until recently it was hard to know of any way we could measure whether this was true or not, but we can thanks to collaboration with Émeline Bolmont, a professor at the University of Geneva. She actually discovered that, because of the subtle motion of the planets and the interactions between one another, it encodes the rotation of the planet as well, and if the planets rotate ever so slightly off from a tidally-synchronized state as low as one percent we will see a deviation on the time of the transits of the order a few tens of seconds in the next few years. Thus we might actually be able to measure the rotation rate, and place a limit on the rotation rate of this planet above tidal synchronization. So far it looks like they're pretty synchronized.

Dr. Urquhart. The next question is from Paul Wheat who asks "In terms of habitability, SETI, and round-trip times, have we done long surveys of every star within 40 to 50 light years?"

Professor Triaud. Not every star, that's why we have a survey; actually our survey is looking at these low-mass stars within 40 parsecs only so we are quite limited. I'm not sure I understood the 'round-trip' part of the question, could you repeat please?

Dr. Urquhart. He goes on to say that *Kepler* surveyed very distant areas so we will never complete a round-trip exchange of radio with those systems.

Professor Triaud. We haven't finished this survey so I don't know about the SETI efforts, but certainly in terms of exploration for planets we haven't. One thing to remember is that whilst for most of the systems we don't detect transiting planets, it doesn't mean planets are not there. Most of the planets don't show up — most of the systems don't transit and so after we've done a survey I think there will need to be more work to establish the presence of planets using other methods like radial velocities. On some of these ultra-cool dwarfs, I expect most stars to have a planetary system.

Dr. Urquhart. Paul Murdin asks "Do the planets exhibit a Bode's law?"

Professor Triaud. There is maybe something of that kind — it's a bit controversial to talk about it but it seems that some systems are arranged and one can understand it in such a way that each planet has a 'Hill' sphere, in other words, a radius around which they will dominate the local gravitational field and those 'Hill' spheres usually don't overlap otherwise the system would be unstable. Because of that it creates a fairly natural parallel if you pack planets, the Hill sphere is related to the radius, like the semi-major axis to a power, I can't remember exactly which actually, but so it would naturally lead to a power law. However, planetary systems do become unstable and we see several systems and it may be that the systems are born as fairly packed systems and then as time goes by, you start losing planets through gravitational interactions, collisions, and expulsion. In TRAPPIST-1 it didn't happen but in other systems it probably did, which would leave holes and make the Bode's law incomplete. They would be missing integers, so to speak.

The President. I think we need to move on to our next speaker who is Josh Nall from the Whipple Museum of the History of Science, Cambridge University, to give the RAS Diary Talk on 'Calculation and Conflict: Anniversary Reflections on the Early History of the RAS'. Over to you Josh, thank you.

Dr. J. Nall. [A contribution based on this talk can be found following this report.]

The President. Josh, that was absolutely fascinating, a really enlightening talk, so thank you very much for giving that presentation. We do have some questions so over to Sheona.

Dr. Urquhart. The first question is from Nick Kanas and he asks "What was the status of John Flamsteed's catalogue by the time of the founding of the RAS? From John Herschel's quote, it would appear that it was not seen as being especially accurate".

Dr. Nall. That's a good question. I suspect not. I think the early Fellows of the Society gave due deference to their predecessors. Obviously Flamsteed's catalogue would have been considered near the top of the tree simply because it had been produced at Greenwich and so it was one of the most complete and usable catalogues. The 'business astronomers' were particularly frustrated at the propensity for observatories not to publish and not to reduce data, and at least Flamsteed's catalogue was reduced at Greenwich. I think that there was a recognition that the advances in continental mathematical theory, particularly the work of Bessel, combined with developments in instrument-making, meant that it would be possible and should be possible to produce much more accurate and extensive catalogues, and so that was really their push. But certainly, I don't think they would have said anything rude about Flamsteed.

Dr. Urquhart. Rob Peeling asks "The criticism about the *Nautical Almanac* is interesting. H. H. Turner recounts James South reporting that the marine cartographer W. H. Smyth preferred to trust the French almanac and gave his UK version away to a foreign commander. Is there any evidence of other agreement from naval commanders of the problem, Beaufort perhaps?"

Dr. Nall. There's a wonderful anecdote associated with that. What South actually reports is that Smyth gave the British almanac to a Spanish captain as a courtesy while he was sailing in the Mediterranean because the Spanish captain had given him a European ephemeris, and the way South ends the anecdote is he says that Smyth made it back to Britain safely but there's a rumour circulating that the Spanish captain was never seen again. And he publishes this! There's a suggestion that it may be a joke but South is also implying that ships were being sunk because the British almanac was so bad. As to whether there were naval men complaining about the *Almanac* at this point I can't answer, and, in fact, that is something that I should look into because it would be very interesting to see if there were actually people coming back from voyages complaining and throwing their almanac down on the table in Greenwich and saying "this is useless".

Dr. Urquhart. I've got a question from Steve Miller, and he says "Did anything change in relations between the Astronomical Society and the Royal Society when Davy took over from Banks and started to move the 'gentleman' members out of the Royal Society?"

Dr. Nall. Yes, but I think it was reasonably slow. Davy had a hell of a time as President of the Royal Society. When he joined, it was still in a pretty parlous state because of the Banksian approach which had loaded the membership with aristocrats and club men who had little or no interest in science. I think Davy found it a bit of a nightmare, frankly, and he tried very hard to move it back towards being a serious society. Banks dies in 1820 May, and by the time Davy's trying to turn it around in the 1830s, a lot of specialist societies have already been established, such as the Geological Society, the Chemical Society, and the Astronomical Society. So this story was not unique to the Astronomical Society — lots of specialist societies had been established because the Royal Society had been judged such a useless space, and I think it takes a lot longer than Davy, frankly, to steer the ship back to respectability. As you saw, Babbage's book comes out in 1830, the quote I gave you is 1835. By the time Davy is in charge of the society it is still being talked of as completely awful in the views of these younger, modish, business-minded scientists.

The President. Thank you very much, Sheona, for helping with the questions and thanks again to the speakers for today's meeting, both wonderful presentations. All that remains is for me to give notice that the next monthly A&G Open Meeting of the society will be on Friday the 11th of December. Thank you all for joining us and we hope to see you all very soon.

CALCULATION AND CONFLICT: ANNIVERSARY REFLECTIONS ON THE EARLY HISTORY OF THE RAS

By Joshua Nall

Whipple Museum of the History of Science, Cambridge University

First, let me note how pleased I am to be able to continue the tradition of a 'diary talk' at the November Ordinary Meeting, themed around one of the significant anniversaries marked each year in the Society's pocket diary. It was, of course, a very easy job this year to select which anniversary to celebrate, and it is a great honour to be able to mark the 200th anniversary of our own Society this evening.

The obvious place to start my talk is at the Society's very first meeting, held on the 12th of January 1820 on a bitterly cold evening in central London. John Herschel recorded this modest description of the event in his diary: "Dine at the Freemason's Tavern to meet Dr Pearson and other gentlemen to consider of forming an Astronomical Society."[1] Present were fourteen men aged between twenty-four and sixty-five, and my task this evening is simple enough: to explain why these men met to form such a society at that point in time.

I want to resist the temptation to presume that forming specialist learned societies was merely a typical act of this era; rather, I want to explore the specific agendas of those founder-members. The men who established what was then called the Astronomical Society of London (ASL) were, I want to argue, a select group. This audience will, I hope, already be familiar with some of the names of these charter members, thanks in no small part to Mike Edmund's wonderful series of capsule biographies that have run in *Astronomy & Geophysics* in recent years. Here is the group's basic composition: three stockbrokers, three gentlemen of independent means, two schoolmasters, two military men, a retired merchant, an administrator retired from India, a lawyer (and, by happenstance, a 24-year-old visiting Professor from Wilna, Poland [now Vilnius]).[2]

A few things are evident from this list off the bat. These are by and large not men of the aristocracy — they are not 'grand amateurs' of leisured wealth — but are rather from the mercantile and scholastic upper middle-class. And the group is striking as much for who is *absent* as for who is present. Indeed, I want to argue here that it is from these absences that some of the founding agendas of the Society begin to reveal themselves. There are, for example, no women here — perhaps not surprising for the era but still a reminder that this was a club for gentleman practitioners. This was not a group that were in any way interested in widening access to astronomical knowledge. Consequently, popular lecturers are also absent from the meeting. We should remember that aside from the Astronomer Royal and his small cohort of assistants at Greenwich, most of the people making money from astronomy in this period were popular lecturers and writers. No instrument-makers were invited, either. Again, this might seem unsurprising to us, but we should remember what Jim Bennett has shown, namely that during the 18th Century many of the preeminent makers — men such as Graham, Ramsden, Troughton, Short, Dollond, and Nairne — were fellows of the Royal Society and saw themselves very much as active contributing partners in the astronomical enterprise.[3] Finally, and perhaps most strikingly, we must note the absence of both the Astronomer Royal, John Pond, and the President of the Royal Society, Joseph Banks.

All of these absences were very much deliberate, I want to argue, and taken together they reveal a particular ideology among the ASL's founding members. I borrow from my colleague William Ashworth the title of 'business astronomers' to describe this founding group, and follow Ashworth in suggesting that such an umbrella term captures a shared set of ideals and methods that can be linked to wider interests in the world of Cambridge mathematics and the business practices of the city of London.[4] Many of the charter members were businessmen themselves, and together they shared a joint commitment to a particular future for the discipline of astronomy built on the same ideological commitments that drove their mercantile successes.

A sense of this ideology can be gleaned from the ASL's founding address, written by John Herschel and Francis Bailey and circulated ahead of the Society's first public meeting: "Beyond the limits … of our own system, all at present is obscurity. Some vast and general views on the construction of the heavens, and the laws which may regulate the formation and motions of sidereal systems, have, it is true, been struck out; but, like the theories of the earth which have so long occupied the speculations of geologists, they remain to be supported or refuted by the slow accumulation of a mass of facts: and it is here, as in [geology], that the advantages of associated labour will appear more eminently conspicuous."[5] We see here the first inklings of what will become two abiding concerns for the Society in its first years: on the one hand an obsession with the accumulation and reduction of astronomical data; and, on the other hand, a deep scepticism towards all forms of cosmological speculation.

To understand this ideology, a good place to start is with the first President of the Society, Edward Adolphus Seymour, eleventh Duke of Somerset. Seymour, a noted amateur mathematician, had been unanimously elected to this post at the Society's first public meeting, but had almost immediately retracted his acceptance of it in a letter to the Society's ruling Committee: "The … great names which are to be found in the list of [your] members, had given ample ground for trusting that, as nothing was intended inimical, so, nothing could follow prejudicial, to the interests of an old respectable and chartered body. Its President is however of quite a different opinion, and apprehends the ruin of the Royal Society. To Sir Joseph Banks I have been long & strongly attached, not only by the ties of public regard, but those of private friendship; and my remaining in a post, which he considers as a hostile position, might be liable to unfavourable comments, & would certainly be very painful to my own feelings."[6] Seymour is quite explicit here that it was the President of the Royal Society (RS), Joseph Banks, who had scotched his appointment (a move that forced an aged William Herschel reluctantly to accept the post in Seymour's stead).

Banks's motivation for such a manoeuvre was quite clear to all involved: he vehemently opposed the establishment of an astronomical society, just as he had opposed the establishment of other 'breakaway' specialist scientific societies such as the Geological Society and the Royal Institution. This antipathy ran both ways. The business astronomers detested Banks every bit as much as Banks loathed their upstart new society. Indeed, my argument here is precisely that the ASL was born out of just this conflict; out of a frustration at the state of their science and forged very much in opposition to what they judged to be entrenched and corrupt authority figures at the highest levels of British science.

These figures were embodied, above all, by Banks himself — an aristocrat dilettante botanist and club man who, by 1820 January, had been President of the RS for more than forty years. Banks's distaste for the exact sciences was well known, and his management of the RS was notorious for its granting of insider privileges and backroom handouts. The business astronomers did not care to play by these aristocratic rules. Exemplary is the work of ASL founder-member Charles Babbage, whose 1830 bombshell, *Reflections on the Decline of Science in England and Some of its Causes*, laid bare for all to read the jobbery and mismanagement that he perceived to lie at the heart of scientific London.[7] The book was, above all, a vicious broadside against the RS and the 'Banksian regime'[8] that had dominated it for much of the previous half-century. As Babbage put it to his friend Dawson Turner: "the power [Banks] possessed was not that which is yielded to high moral character … but was almost solely given to his great wealth: The subservience and sycophancy which characterised the Royal Society during his long mismanagement of it has brought it to its present position."[9] As far as the business astronomers were concerned, then, the Banksian regime was aristocratic, monopolistic, undemocratic, secretive, based on a system of patronage, and hostile to the mathematical sciences. The ASL was founded as a deliberate act of resistance against this power structure, and with the expressed intention of steering astronomy in a different direction built on the sound methods of mercantile capitalism. "The business astronomers set out," Ashworth has argued, "to develop a trustworthy approach to the accumulation of intellectual and financial capital, through the establishment of a firm calculating base in which data were constantly monitored and reduced."[10]

Behind this political commitment to opposing Banks and his regime was also a scientific commitment to a particular model for the future of astronomical practice. Such a model was not itself *sui generis* — John Herschel himself laid out its basic characteristics regularly in his myriad publications, such as here in his popular *Preliminary Discourse on the Study of Natural Philosophy*: "A correct enumeration and description of the fixed stars in catalogues, and an exact knowledge of their position, supply the only effectual means we can have of ascertaining what changes they are liable to, and what motions, too slow to deprive them of their usual epithet, fixed, yet sufficient to produce a sensible change in the lapse of ages, may exist among them."[11] This model relied fundamentally upon the marriage of massive data collection and rigorous mathematical analysis. The problem, as the business astronomers saw it, was that — in Britain at least — suitable stellar catalogues were entirely lacking, with data either languishing unreduced or, if reduced at all, being of a poor and inconsistent standard.

The solution, as they saw it, lay in the best models of mathematical analysis then being advanced in continental Europe. At Cambridge, several of the business astronomers had been instrumental in establishing the Analytic Society, which had pushed for modernizing reform of the University's mathematics tripos, including the adoption in calculus of Leibnitzian notation in lieu of the town's traditional commitment to Newtonian fluxions. And in astronomy, the business astronomers were particularly impressed with the work of Friedrich Bessel, director of Königsberg Observatory and doyen of continental positional astronomy. Bessel's own mathematical skill had delivered greatly improved values for the astronomical constants and had established a uniform system of data reduction capable of correcting for aberration, nutation, and refraction. Speaking before the ASL in 1829, John Herschel celebrated Bessel's work as "the perfection of astronomical bookkeeping"[12], and it was the incorporation of just this Besselian paradigm into British astronomy that the early members of the Society pursued with vigour. In his magisterial 1923 history of the early Society, H. H. Turner summed up this new scientific regime pithily: "We find ample evidence in the history of the early years of the new Society that its prime motive was 'precise measurement and systematic calculation.' It might have been supposed that the more picturesque work of its first actual President, Sir William Herschel, would inspire the active members to follow him … in examining nebulae, stellar clusters and other objects of special interest. Instead of this Francis Baily led them on a campaign of meridian observation, star-corrections, and improvement of the Nautical Almanac."[13]

It is in this final phrase — "improvement of the Nautical Almanac" (*NA*) — that we find one of the most important early achievements of the business astronomers and their upstart society. As I'm sure many in this audience already know, the *NA* had first been produced in 1767 under the guidance of Astronomer Royal Nevil Maskelyne and had subsequently been published annually from Greenwich as an essential aid to finding longitude at sea by the lunar-distance method.[14] But the business astronomers judged this work to have fallen into decline after Maskelyne's death in 1811, and almost as soon as they had organized the ASL they led a full-frontal assault on it and the body that oversaw its production, the Board of Longitude (BoL). Hence we see more clearly now why Maskelyne's successor, John Pond, had not been present at the Society's founding meeting — Pond and the BoL were squarely in their sights.

As befit their modernizing, business-minded approach to science, the ASL eschewed gentlemanly codes of practice that had traditionally kept conflict and critique behind closed doors, or at the very least left disputants anonymous in the public sphere. In contrast, members of the ASL issued censorious pamphlets that they proudly signed, and which unapologetically named their targets. Exemplary is Francis Baily's 1822 pamphlet, *Remarks on the Present Defective State of the Nautical Almanac*, which charged the *NA* of having "begun to lose its character for accuracy" and suggested that the work was now a "bye-word amongst the literati of Europe." Thomas Young, who since 1818 had been secretary of the BoL and superintendent of the *NA*, took particular offence, though he kept his responses to private channels. "Mr. Baily will never rest satisfied," he wrote to the Admiralty, "until the Astronomical Society, not content with the humiliation of the Royal Society, shall succeed in dictating to the Admiralty and the British Parliament, and the House of Commons."[15]

Young was certainly right, and the ASL could count this campaign against the "defective" *NA* as one of their first great successes. Baily's attack, along with those of allied business astronomers, forced a parliamentary inquiry that ultimately led to the abolition of the BoL in 1828. Two years later, and under on-going pressure to reform the *NA*, the Admiralty approached the ASL for advice. The resulting committee of forty Fellows recommended a raft of changes, all of which were approved by the Admiralty. Pond, who had assumed the role of superintendent of the *NA* in the wake of the BoL's abolition, promptly relinquished the post, whence it passed to William Stratford, Secretary of the ASL. In the same year that the Society received its Royal Charter, 1831, it also secured control over the nation's principal almanac of astronomical data.

This control was further solidified by the appointment in 1835 of George Biddell Airy as Pond's successor as Astronomer Royal. Although Airy was not a charter member of the Society (he had been an eighteen-year-old Cambridge student in 1820 January), he was very much a business astronomer and a stalwart of the RAS. His appointment, along with concomitant reform of the *NA*, might be taken together as the crowning achievements of the Society in its first two decades.

Three lasting consequences of this ascendancy of 'business astronomy' are worth noting before I finish this evening. The first is a striking feature of the reign of Airy at Greenwich, namely the promotion of *mathematical theory* as the pre-eminent practice of the astronomical sciences. Writing to a colleague in 1832, Airy observed that: "The work of a mere observer is the most completely horse-in-a-mill work that can be conceived. The beau idéal of an observer of the highest class is a compound of a watchmaker and a banker's clerk. Most of the observers that I know are far below this standard. You will see therefore that the mere observer is a person very very far below the mere chemical experimentalist."[16] With the observer relegated to highly standardized and regulated drudge-work[17], the pinnacle of astronomical labour became the post-observation application of mathematical theory to 'raw' positional data.

Secondly, with this promotion of theory also came the diminution of the status of the instrument-maker. Contrary to their elevated status at the end of the 18th Century, the early years of the Society are marked by a decline in prestige for artisanal labour, again at the expense of the mathematical arts. As Benjamin Gompertz put it to the ASL in 1822: "instruments supply data to the theory; but it is theory which invents the instruments. … [It is] theory which points out the cause of the defects; theory which directs the practitioner to the requisite improvements."[18]

Finally, we can return to a point that has already been made this evening, which is the business astronomer's broad repudiation of the more *picturesque* approaches to their science. Such practices, as H. H. Turner noted, were precisely those which we might associate with the Society's first actual President, William Herschel, and incorporated not only the desire to discover new celestial objects but also the license to speculate and partake in cosmological theorizing. Men like Airy, in contrast, could by the middle of the century write with some pride that: "I can abandon such showy things as discovering comets and planets and can therefore do the dull meridian work surprisingly well, and this is known to and approved by the astronomical public of England but it would not do in France."[19] Airy would no doubt have credited the success of this approach in no small part to the ascendancy of the learned society to which he himself contributed so much.

Alas I do not have time this evening to continue to the next stage of this story. So I will leave you instead with one final note. The changes that I have described here — each of them considerable achievements that can be credited to the business astronomers and their young Society — were neither universal nor permanent. With more time, I could go on to discuss important challenges to the ideology of business astronomy that would emerge and in turn themselves profoundly shape the practices of astronomy after mid-century. Pre-eminent among these was of course the new domain of astrophysics. But as I have written about this new paradigm and its effects on the RAS elsewhere[20], I will leave you now with thanks for your attention this evening.

References

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(4) William J. Ashworth, 'The Calculating Eye: Baily, Herschel, Babbage and the Business of Astronomy', *British Journal for the History of Science*, **27**, 409, 1994.
(5) For the full text of this address, see: *Memoirs of the Astronomical Society of London*, **1**, 1, 1822.
(6) The letter is reproduced in full in: Turner (1923), *op. cit.*, p. 9.
(7) For more on this book and its reception, see: James A. Secord, *Visions of Science: Books and Readers at the Dawn of the Victorian Age* (University of Oxford Press), 2015, p. 52.
(8) I borrow this phrase from: David Philip Miller, 'The Revival of the Physical Sciences in Britain, 1815–1840', *Osiris*, **2**, 107, 1986.
(9) Quoted in: William J. Ashworth, 'John Herschel, George Airy, and the Roaming Eye of the State', *History of Science*, **36**, 154, 1998.
(10) Ashworth (1994), *op. cit.*, p. 416.
(11) John Herschel, *A Preliminary Discourse on the Study of Natural Philosophy* (Longman, Rees, Orme, Brown & Green), 1831, p. 276.
(12) Quoted in: Ashworth (1994), *op. cit.*, p. 429.
(13) Turner (1923), *op. cit.*, p. 25.
(14) For a rich history of this enterprise, see: Richard Dunn & Rebekah Higgitt, *Finding Longitude* (Royal Museums Greenwich), 2014.
(15) Quoted in: Ashworth (1994), *op. cit.*, p. 433.
(16) Quoted in: Simon Schaffer, 'Where Experiments End: Tabletop Trials in Victorian Astronomy', in: Jed Z. Buchwald (ed.), *Scientific Practice: Theories and Stories of Doing Physics* (University of Chicago Press), 1995, p. 257.
(17) For more on this "factory" system, see: Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context*, **2**, 115, 1988.
(18) Benjamin Gompertz, 'On the Theory of Astronomical Instruments', *Memoirs of the Astronomical Society of London*, **1**, 349, 1822.
(19) Quoted in: Ashworth (1998), *op. cit.*, p. 161.
(20) Joshua Nall, *News from Mars: Mass Media and the Forging of a New Astronomy, 1860–1910* (University of Pittsburgh Press), 2019, pp. 21–46.

ASTRONOMERS IN VICTORIAN BRISTOL (1820–1901)

By Steven Phillipps

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As a maritime city with a long history, Bristol has an equally long connection with navigation, originally by the stars. In the current article we will, however, only consider contributions to what we can call 'modern' astronomical science. To set a specific start date we choose 1820, the date of formation of the Royal Astronomical Society (originally as the Astronomical Society of London)[1]. The Society's inception also came just a few months after the birth of the future Queen Victoria, long-time patroness of the RAS[2].

There was certainly some public interest in astronomy among Bristolians in the 1820s and '30s, for instance, *via* the Bristol Institution for the Advancement of Science, Literature and the Arts, founded in 1823, and the short-lived Bristol College (1830 to 1841) where astronomy was on the science curriculum[3]. The Rev. Lant Carpenter gave lectures on astronomy for the Institution, while the peripatetic lecturer Deane Franklin Walker also presented a series of talks at Bristol Mechanics' Institute in 1830[4]. However, neither Carpenter, a Unitarian minister who ran his own acclaimed academy in Bristol, nor eminent local geologist William D. Conybeare FRS (the first to describe a plesiosaur), who was a leading light at both the Institution and the College, had more than a generalist's interest in astronomy.

Carpenter's students in the 1820s did include a future RAS fellow, though. William Tucker Radford from Exeter (born in 1810), who subsequently qualified as an MD at Trinity College Dublin, was noted as an observer of double stars after returning to Devon, and was elected an FRAS in 1865[5]. In addition, Conybeare was instrumental in having well-known mathematician and writer on science and astronomy Mary Somerville (an Honorary Fellow of the RAS) elected to an honorary membership of the Institution in 1835 (though she lived in London and Italy)[3].

One of the students who attended the College, before matriculating at Cambridge in 1837, was the Irish-born George Gabriel (later Sir George) Stokes. He became Lucasian professor of mathematics in Cambridge in 1849 and was the president of the Royal Society from 1885 to 1890. Though not an astronomer *per se* — he was never an FRAS — his work in fluid dynamics and polarization of light were key contributions[6]. He was on the Board of Visitors of the Royal Observatory at Greenwich and also married the daughter of Irish 'grand amateur' the Rev. Thomas Romney Robinson FRS, director of the Armagh Observatory.

If we exclude the Cornish engineer and politician Davies Gilbert FRS, president of the Royal Society from 1827 to 1830, who was an original member of the RAS in February 1820, but had only lived briefly in Bristol while at Benjamin Donne's Mathematical Academy, prior to going up to Oxford in 1786[7], the first Bristolian FRAS appears to be one William West. He first appears in the membership list in *MemRAS* in 1838[2], with his address given as 'Observatory, Clifton'. The observatory, close to the famous Clifton Suspension Bridge, is still in existence as a tourist attraction and event venue. West, an oil painter and watercolourist, had acquired it as a studio in 1826 (it was then a derelict windmill) and installed a number of telescopes, primarily for himself and fellow artists of the Bristol School to view the surrounding landscape. He also built a camera obscura which he used to produce 'photogenic drawings' based on the work of pioneer photographer, and fellow member of the RAS, William Fox Talbot. Around 1835 he extended the buildings, adding an astronomical telescope in a dome[8].

The next person to appear in the publications of the RAS with a link to Bristol is Thomas Gamplen Bunt. He appears in *Memoirs of the RAS* in 1842[9] when he is recorded as having presented to the Society "The New Planetarium for accurately finding the true and apparent places of the planets on any day during the present century". (*The Athenaeum* magazine in 1832 had carried an advertisement for his "New Planetarium, with instructions for its use", describing it as "a beautifully engraved diagram of the planetary orbits … highly useful in teaching the elements of popular and practical astronomy".) Born in Taunton in 1795, he was a land surveyor in Clifton and a member of the British Association for the Advancement of Science. The sixth meeting of the BAAS was held in Bristol in 1836 August and amongst a distinguished list of 'officers of sectional committees' (including the likes of the Rev. William Whewell and Sir William Hamilton), Bunt was recorded as a secretary of the Mechanical Section (of which M. I. Brunel, father of I. K., was vice-president and Davies Gilbert president)[10]. Bunt was also responsible for the Bristol tide tables from 1836 and devised a new type of tide gauge to use in the River Avon, some of his work (in collaboration with Whewell) appearing in the *Philosophical Transactions of the Royal Society*.

In 1849, *Monthly Notices* reported[11] that, at the November RAS meeting, "The Astronomer Royal exhibited an instrument for performing arithmetical multiplications and divisions, constructed under the direction of William Bell, Esq., Coronation Road, Bristol". The Astronomer Royal (G. B. Airy, also RAS President) commented that, despite its advantages, in his opinion it was "too expensive and too cumbrous to be extensively used". Bell was a Scottish civil engineer[12], born in Leith in 1818, who lived in Bedminster. He had worked on the Bristol and Gloucester Railway and in 1846 became Isambard Kingdom Brunel's Resident Engineer on the Cumberland Basin Docks project in Bristol. He also worked for Brunel on experiments connected with the *Great Eastern* steamship prior to its launch. Brunel himself was elected an FRAS in 1852[13], but despite his iconic connections with the city never actually lived in Bristol. Bell contributed chapters to *The Life of Isambard Kingdom Brunel, Civil Engineer* published by Isambard Brunel Jr. in 1870.

Neither Bunt nor Bell were ever Fellows of the RAS. The next such with a Bristol address appears to be William Corbett Burder of Clifton, who was elected a Fellow in 1860 March. His RAS obituary[14] credits him with the naked-eye discovery of two comets, in 1854 and 1861. The latter was reported in his lone contribution to *MN*[15]. In 1863 he presented a copy of his *Meteorology of Clifton* to the Society. Son of a clergyman and grandson of George Burder, a noted non-conformist minister and theologian, W. C. Burder was born in Stroud in 1822 but moved to Bristol when he was apprenticed to an architect there, and was subsequently an architectural engraver. He was also a co-author of *The Architectural Antiquities of Bristol and its Neighbourhood*, for which he engraved the plates.

His brother George Forster Burder was not an FRAS, but his observations (sent to *The Times*) were used in an *MN* paper[16] by Alexander Herschel on the 'Radiant Point of the November Meteors, 1866'. He also later provided observations of meteors for papers by fellow Bristolian W. F. Denning (see below). He was principally interested in atmospheric phenomena, publishing several papers in *Nature* on topics such as aurorae, red sunsets, and the twinkling of stars. His contributions to the Bristol Naturalists' Society, of which he was a founder member, and later president, included 'Peculiar Phenomena during the Eclipse of the Moon on Oct. 4th, 1884' and, in 1888, 'The illumination of the eclipsed moon'. Like his brother, he had a major interest in meteorology, being a Fellow of the Royal Meteorological Society and supplying a succession of articles, often on rainfall, to the Proceedings of the Bristol Naturalists' Society. (One of his other papers for this society celebrated 'The Tercentenary of the Potato'. The even more intriguingly titled 'Aliens at Kingsdown', contributed by a fellow naturalist, turns out to have been about non-indigenous plants.) G. F. Burder was born in 1826 in Stroud and trained at University College London and King's College Aberdeen, becoming a Fellow of the Royal College of Physicians in 1875. He had a practice in Clifton and was consulting physician to the Royal Bristol Hospital, also lecturing at Bristol Medical School[17].

The next Bristol FRAS, again living in Clifton, was the Reverend Jacob Morton, elected in 1862 but making no further mark on the scientific literature. The son of a lead miner, he was born in 1818 in the Derbyshire village of Bradwell, a centre of nonconformism, and became a Wesleyan minster[18]. Notably itinerant, he had been married in Wells in Somerset in 1845, lived in Ealing in 1851, was in Yorkshire after Bristol (writing a biography of his brother John, another Wesleyan preacher), and died in Exeter in 1873. (Another brother, Thomas, had a rather different career, as a soldier, serving in Afghanistan and the Crimea.)

In 1868 we find the first recorded contribution from a then 19-year-old William Frederick Denning, who went on to become undoubtedly the most well-known of Bristol amateur astronomers. His earliest note appeared in correspondence to the *Astronomical Register* and concerned the visibility of Jupiter's satellites when Jupiter was close to the Sun[19]. Born near Radstock in Somerset in 1848, his family moved to Bristol when he was eight and he remained there for the rest of his life. One of nine children of an accountant, Denning's occupation outside astronomy is unclear[20]. He also sometimes listed himself as an accountant, but probably supported himself mainly *via* journalistic activities; he wrote astronomy articles for newspapers, *Boys Own Magazine*, and the *Encyclopedia Britannica*.

There was no astronomical society in Bristol at this time (nor would there be for another 70 years), the main scientific society in the city being, as noted above, the Bristol Naturalists' Society, founded by the local geologist William Sanders FRS in 1862. Denning started his own (national) Observing Astronomical Society in 1869[21], which proved short lived, and he later became a stalwart member of the British Astronomical Association after it formed in 1890. He also joined the Liverpool Astronomical Society, probably the main provincial society of the day. He had become an RAS Fellow (at the second attempt) in 1877. In the same year, in only its second issue, he made the first of "not less than five hundred" contributions to *The Observatory*, over a span of 54 years[22].

In total he published 1179 contributions to scientific journals, including some in *Nature* and many in *Monthly Notices*[20]. He also published in overseas journals such as *Astronomische Nachrichten*, *L'Astronomie*, and the (US) *Sidereal Messenger*, and they in turn frequently discussed his work. Many of his contributions were observations of Jupiter, but even more were on meteors; he was director of the BAA's meteor and comet sections in the 1890s. Observing from Ashley Down with a 10-inch reflector, he discovered five comets, including the periodic comet 72P/Denning–Fujikawa in 1881, as well as Nova Cygni 1920. His 1894 comet was the last discovered from the UK until the 1950s. He won the Valz Prize of the French Academy of Sciences in 1895 and the Gold Medal of the RAS in 1898. He was awarded the degree of Master of Science, *honoris causa*, by the University of Bristol in 1927. He has a lunar crater, a Martian crater, and an asteroid all named after him. He wrote a number of books for other amateurs, starting with *Astronomical Phenomena in 1872*. He is also name-checked in a rather more famous book. In H.G. Wells' description of the arrival of the first Martian cylinder in *War of the Worlds* (1898), we read that "Denning, our greatest authority on meteorites, stated that the height of its first appearance was about 90 or 100 miles". A keen cricketer in his younger days, according to his obituary in *The Observatory* (written by the Rev. T. E. R. Phillips), the legendary W. G. Grace once invited him to keep wicket for Gloucestershire[23].

In terms of RAS fellowship, Denning was preceded by David Vines, Esq., Kingswood, Bristol, who was elected in 1868[24]. He was born in 1809 in Wiltshire and was a schoolmaster at 'Ashley House School for Young Gentlemen' (where he also lodged). He also subscribed to the *Astronomical Register*, but no records of his particular astronomical interests are evident.

Another Bristolian joining the RAS in 1868, albeit from a much greater distance, was Edward John White. He was born in Bristol in 1831 and was a pupil at Queen Elizabeth Hospital in the city. He trained as a mechanical engineer before heading for the Australian goldfields in 1853. Said to have studied astronomy from an early age (presumably while still in Bristol), he was soon offered a position as Chief Assistant at Melbourne Observatory. He was responsible for the *First Melbourne General Catalogue of 1227 Stars* and had charge of the Venus-transit observations in Tasmania in 1882[25].

In the *Astronomical Register* for 1869, Denning noted the plans he was making, with other amateurs, to investigate the existence of the supposed intra-Mercurial planet Vulcan from its transits across the Sun[26]. One of his colleagues in the enterprise was a Mr. Chas. Hill of Bristol who had an 8½-inch reflector. He was also noted to have observed "Winnecke's periodical comet"[27]. It is likely that this was the Charles Hill (born in 1831) who was the 'son' in Charles Hill & Sons, a major shipbuilding firm in Bristol, and who lived at the time at Henbury Hill.

A soon-to-be-well-known Bristol name, Silvanus Phillips Thompson BA (London), joined the RAS in 1875. His address was given as St Mary's, York (where he had been born into a Quaker family in 1851). Already trained as a teacher, he also studied chemistry and physics at the Royal College of Mines in South Kensington, and was appointed to a physics lectureship in the newly founded University College Bristol in 1876[28]. He was elected to the chair in experimental physics in 1878, his counterpart in chemistry being William Ramsey who later isolated helium (previously known only from its spectrum in the Sun) and won the Nobel Prize. Thompson lived in Clifton but in 1885 moved on to be Principal and Professor of Applied Physics and Electrical Engineering at Finsbury Technical College. He was elected a Fellow of the Royal Society in 1891. Though mainly known for his work on electricity, he also researched in optics which may have linked to his membership of the RAS. Amongst his various books, alongside the classic *Elementary Lessons in Electricity and Magnetism* published while in Bristol, was the first English translation of Christiaan Huygens' treatise on light, *De La Lumier*.

W. E. Metford of Redland in Bristol appears in the *Astronomical Register* in 1876[29] with a description of 'Electric Lighting of Telescope Circles, *etc.*' for his 4½-inch telescope with "the aid of a Geissler tube and Ruhmkorff coil". William Ellis Metford (born in Taunton in 1824) was an engineer who first worked on I. K. Brunel's Bristol and Exeter Railway. He later obtained an appointment on the East India Railway but arrived just as the Indian Mutiny broke out. A keen shot, subsequently he worked in the armaments business, developing the Lee–Metford and Martini–Metford service rifles[30].

The next Bristolian RAS Fellow was the Rev. Philip Rowling Sleeman of

Clifton, elected in 1878[31]. He was born in Bristol in 1841 (his father, of the same name, was a GP there) and became curate of St. Paul's Church in Bristol, later recording himself as a 'clerk in holy orders'. He does not have an RAS obituary and details of his astronomical interests are unknown.

Alfred John Parkman Shepherd also became a Fellow in 1878, while at Oxford. The son of a bookseller and stationer, he was born in Clifton in 1855 and went to school in Bristol, presumably already having astronomical interests while living there as he joined the RAS when still only 22. After being ordained in 1878, he was Chaplain to the Bishop of Lahore and later spent many years as a rector in Berkshire, also serving as honorary Canon of Christ Church Cathedral in Oxford[32].

Frederick Haller Stevens BA was another to become a Fellow in 1878. Born in Birkenhead in 1853, he was a mathematics master at Clifton College from 1876 and a member of the Mathematical Association. He was part of the 'Engineering side' at the college and was in charge of the 'Woolwich Department' for boys who aimed to join the army *via* The Royal Military Academy, Woolwich (44 Old Cliftonians died serving in the army in the upcoming South African (Boer) War)[33]. Also an author, Stevens' main literary offerings were several variants of textbooks on Euclid's Elements and *Lessons in Experimental and Practical Geometry*. His time at Clifton overlapped that of Herbert Hall Turner, future Savilian Professor of Astronomy in Oxford and RAS President, who was a pupil at Clifton from 1874 to 1879, though it is not clear whether the latter was interested in astronomy while at school[34]. (Stevens would not have taught Turner's contemporary Douglas Haig, the future Field Marshal Earl Haig, either, as despite his future career Haig entered the 'Classical side'[33].)

A subsequent headmaster at Clifton also had astronomical interests. Rev. James Maurice Wilson was recorded in *MNRAS*[35] as leaving his post at the Temple Observatory at Rugby to take up the Clifton headship in 1879. As well as his responsibility for the Temple Observatory, where he had observed double stars, he was also maths and science master at Rugby School. (Frederick Temple was an earlier headmaster of the school.) Born on the Isle of Man in 1836, Wilson had attended Sedburgh School (in what is now Cumbria) before entering St John's College in Cambridge, earning the ultimate accolade of Senior Wrangler in 1859. An important player in increased science teaching in public schools, he wrote a textbook *Elementary Geometry* in 1868, at a time when normally only 'Euclid's Elements' was utilized (see above entry for F. H. Stevens). He also co-wrote (with Edward Crossley and Joseph Gledhill) a *Handbook of Double Stars* the year he moved to Clifton. He later became a Church of England vicar in Rochdale, subsequently Archdeacon of Manchester, a noted theologian, and a strong advocate for Darwin's theory of evolution[36]. However, he retained an interest in astronomy as a member of the North West branch of the BAA. He was Canon of Worcester Cathedral until 1926 and lived to be 94[37].

A third fellow with a Bristol connection elected in 1878 was John Frederic Main MA, DSc. He was then professor of mathematics, applied mechanics, and engineering at University College Bristol, where he was responsible for the creation of the School of Engineering. Though from a Hampshire family, he had been born in St. Thomas, Jamaica, in 1854. (He appears not to be related to the two Rev. Mains in the RAS around that time; Robert who was RAS President in 1859–1861, and his brother Thomas, another early Fellow.) Tenth Wrangler at Cambridge in 1876, J. F. Main wrote a number of book reviews for *Nature* and, after relocating to Davos for his health, sent a letter about meteors to *Nature* from Wiesen in Switzerland in 1885. In 1887, in *Proceedings of the Royal Society*, he had a 'Note on Some Experiments on the Viscosity of Ice', which used a device built for him by an engineer in Zurich. He subsequently moved to Denver, Colorado, and became co-director of a banking and investment company but died at the age of only 37[38].

The year 1882 saw the election as an RAS Fellow of surgeon William Barrett Roué MB, MS, of Clifton, Bristol. He was born in Bristol in 1849 and was a GP and consulting physician at Bristol Royal Hospital for Sick Children and Women, though he had trained in Durham[39]. In 1881 he had sent a communication to *The Observatory* announcing that "On Monday … (as I was returning from observing the spot on Jupiter in company with my friend Mr. W.F. Denning FRAS, of this town) I saw a splendid meteor"[40].

Also in 1882, Arthur Mason Worthington, of Durdham Down, Bristol, communicated an observation of an auroral beam to *Nature*[41]. Born in Manchester in 1852 and educated at Oxford, he was an assistant master of physics at Clifton College from 1880 and had his own telescope erected close to the College. He had joined the RAS in 1877. While at Clifton, he wrote an *Elementary Course in Practical Physics*. He subsequently became headmaster and professor of physics at the Royal Naval Engineering College in Devonport and then the Royal Naval College at Greenwich. An authority on the properties of liquids, as summarized in his book *The Splash of a Drop,* he was elected an FRS in 1893[42].

Bristol's next Fellow, in 1884, was Samuel Palmer Chapman of Clifton[43]. Born in Lincolnshire in 1809 — so he was 74 when he became an FRAS — he recorded himself as a 'retired artist' in 1881 when he lived in Horfield in Bristol. In the 1860s and 1870s he was a 'photographic artist' working with his son, also a photographer, in South Wales. In addition he published a book of poetry, *Stolen Minutes with the Muses*, which was discussed by Dylan Thomas. When he was younger, though, he had run a grocery in Lincoln.

Thomas Cunningham Porter BA of Redland in Bristol joined the RAS in 1885. He was born in Bristol in 1860 and attended Bristol Grammar School before going up to Oxford, reading mathematics and natural science. He became a master at Eton (and a Reverend) and in 1900 was co-founder of the Public Schools Science Masters' Association[44]. (At Eton, he was apparently reputed among the boys to have raised a cat from the dead with a galvanic battery.) He had numerous papers in *Nature*, particularly on Röntgen rays and optics, patenting a stereoscopic projection system. His one published contribution to *MN* was 'Observations taken at Vadso during the total Eclipse of the Sun, 1896 August 9, by passengers of the S.S. Neptun (Norwegian). (Drawn up and communicated by T.C. Porter, Eton College.)'. These were observations of the general conditions, as the Sun was obscured by cloud, a co-observer of Porter's noting that "The reindeer which was standing grazing when the eclipse began, lay down as it became darker", probably the only reported astronomical observation by a reindeer[45]. Porter reported on the 1905 eclipse in Algeria in *Proceedings of the Royal Society*. His brother-in-law was Field-Marshal Lord Allenby.

Porter was followed as an RAS fellow by John Harvey Jones of Montpelier, Bristol, who was proposed by Denning in 1888. Born near Bath in 1859, he subsequently moved to Bristol to assist his father in his business manufacturing organs and other musical instruments. He was also an accomplished musician in his own right, being the organist at St. Nathaniel's Church in Bristol. He was interested in astronomy from an early age and possessed a number of telescopes, eventually an 8½-inch which he used mainly to sketch the Moon and planets. He was a founder member of the BAA and a member of their lunar section. He also supplied regular weather reports to the Meteorological Office, and to local newspapers, but died when he was only 37[46].

Moving on to 1890, we have a notable Bristolian becoming a Fellow of the RAS, though it is unclear whether he had his astronomical interests while still living in the city. William Friese-Green (then just William Edward Green) was born in Bristol in 1855, the son of a smith, and following attendance at Queen Elizabeth Hospital school was apprenticed to a local photographer before opening his own studios[47]. However, his pioneering experiments on motion pictures came largely after relocating to London in 1885. His address on joining the RAS was given as 'Photographer, 92 Piccadilly' and he was proposed by James Glaisher FRS, formerly of the Royal Observatory, the president of the Royal Photographic Society. Working with his son Claude, Friese-Green also later invented processes for making moving pictures in colour, but his inventiveness exceeded his business acumen and he was declared bankrupt three times.

Similarly, it is not certain how much interest another FRAS elected in 1890, Henry William Lloyd Tanner, had in astronomy while he was a pupil at Bristol Grammar School. Born in Kent in 1851, he went up to Oxford in 1869 as Natural Science Scholar. After other positions, including teaching at his old school, in 1883 he was appointed Professor of Mathematics and Astronomy at the newly founded University College of South Wales and Monmouthshire in Cardiff, despite objections based on his links to the National Secularist Society "whose influence on students might be anti-religious". Primarily a pure mathematician, publishing largely in the *Proceedings of the London Mathematical Society*, though he contributed one paper to *MN* on meteors, he was elected an FRS in 1899[48].

Henry James Pollard of Totterdown, Bristol, joined the BAA in 1891. Some of his meteor observations were included in the *Memoirs of the BAA*[49] and he also contributed on the same topic to *The English Mechanic*, the most popular weekly science magazine of its day, aimed at all classes of readers (it cost just 2d). Pollard is a clear exception to the usual gentleman amateur astronomers, Totterdown being an area of terraced housing built largely to accommodate railway workers, socially very distant from the villas of Clifton. Locally born in 1860, one of eight children of a shipwright, he was employed as a blacksmith at a ship builders in Bristol before working on railway locomotives.

Edward Tremlett Carter also became an FRAS in 1891. Although he had recently moved away from the city, he was brought up in Bristol (he was actually born in Calcutta in 1866) and educated at the Merchant Venturers' College and then at University College Bristol, where he studied physics under Silvanus Thompson (see above). After working as a college demonstrator he moved to the School of Electrical Engineering and Submarine Telegraphy in London (under Lant Carpenter, grandson of the one noted above). He was a member of the Institution of Electrical Engineers and of the Physical Society of London and spent the rest of his career as an editor for *The Electrician*. He wrote *Motive Power and Gearing for Electrical Machinery* among other technical works[50] as well as the science-fiction novel *People of the Moon*. He was particularly interested in astrophysics and the evolution of the Universe but had a delicate constitution and died at the age of only 37.

In 1893 Rev. Edwin Gorsuch Gange, a Baptist minister from Cotham Park in Bristol, was elected as an FRAS, again having been proposed by Denning[51].

There is no evidence of his astronomical interests, though he was also in the BAA. Born in 1844 in London (though his father was from Bristol), he moved to Bristol in 1870 and was subsequently pastor of Broadmead Chapel for 25 years and President of the Baptist Union (though on election to the RAS his address was given as Hampstead). His son Stanley was Liberal MP for Bristol North and Sheriff of Bristol.

Arthur Charles Lisle Dowding of Eastville, Bristol, was elected to the BAA in 1893[52]. Born in Clifton in 1864, he was a clerk to a merchant in the city. He later gave up this trade and became a novelist, under the pseudonym Lewis Ramsden, writing amongst others the lost-island-type fantasy *Temple of Fire*[53]. He moved to Worcestershire in the 1900s and no record of his astronomical work in Bristol is evident.

The next RAS Fellow from Bristol, elected in 1894, was Rev. Samuel Robert Browne MA, LLD "Mathematical Master in Bristol Grammar School", who apparently at the time lived in a house called Camelot in Clifton[54]. He was proposed by F. H. Stevens (see above). He was born in 1854 in Bolsover, Derbyshire (where his mother was a school mistress), and previously taught in a school in Marylebone. He was later recorded as a Church of England clergyman.

The year 1894 also saw a J. Ryan of University College Bristol contribute a paper to *Nature* on 'The Aurora of March 30', as observed from Bristol[55]. Unfortunately it has not been possible to place him securely, but he was clearly familiar with the constellations, noting that a ray of the aurora spread between Ursa Major and Auriga. He may possibly be the Mr J. Ryan of Kensal Green who sent a meteor observation to the ubiquitous Denning in 1905. (The 1891 census has a John Ryan, born Newport, Monmouthshire, in 1861, as a professor of physics and engineering, but living in Lambeth, so he would fit the bill if he moved briefly to Bristol.)

In *Popular Astronomy* (the successor in the USA to the *Sidereal Messenger*) in 1897, in a 'General Note' headed 'Fireball'[56], Denning reports that he "received several oral descriptions of the fireball from residents in Bristol and some correspondents in this part of England have sent me their records". However, he does not give their identities.

In December 1897, Samuel Cooke MA was proposed as an RAS Fellow by no less a personage than the Society's President Sir R. S. Ball LLD, FRS, Lowndean Professor in Cambridge, and was duly elected the following February. Cooke was stated to be the Principal of the College of Science in Poona, India, but his address was given as Clifton, Bristol. He was born in Waterford in 1844 and educated at Trinity College Dublin. On graduating in 1868 he took up a post as professor of chemistry and geology at what was then the Civil Engineering College in Poona where his father Theodore was Principal, succeeding his father when the latter retired in 1893. He wrote a number of textbooks including *First Principles of Chemistry* and *First Principles of Astronomy*. Apart from this book, no astronomical work is evident, in Bristol or elsewhere, even though there was an observatory in Poona. (When British astronomers travelled to the 1898 solar eclipse visible near Poona, Cooke does not appear to have been involved in the organization, which was in the hands of Professor Kvasji Dadabhai Naegamvala, an FRAS since 1885, curator of the Maharaja of Bhavnagar Observatory from when it opened in 1888.) Cooke, also a member of the Royal Historical Society and a fellow of the Geological Society and the Institute of Chemistry, died in Clifton only a year after joining the RAS[57]. His son, also Samuel, was an officer in the Central India Horse, rising to Lieutenant Colonel.

It is not clear when Frank Sargent first developed his interest in astronomy, but given that he was born there in 1871 one may reasonably surmise that it was in Victorian Bristol. Living in the Easton area, he originally assisted his father, a boot manufacturer, before working as a cycle builder. By 1911 he was a scientific instrument maker at Bristol University. He had joined the BAA in 1910 and was elected an FRAS in 1914. In 1916 he submitted a report from his own observatory to *MN*[58] noting the acquisition of a 5-inch Cooke refractor (erected "due to the kindly interest and munificence of certain gentlemen who are fellows of the RAS"), which he used, along with a 10½-inch reflector, to make observations of Jupiter. In 1919 he became the professional Observer at Durham University Observatory, working primarily on double stars[59].

Edward Fawcett White must certainly have had interests in astronomy prior to the end of the period covered in this article, as he was proposed as an RAS Fellow in 1901 December. Born in Plymouth in 1869, he attended school in Bristol before becoming assistant to his father as instructor in navigation at the Naval School there, taking charge after his father retired. He was subsequently appointed lecturer in navigation and nautical astronomy at the Merchant Venturers' Technical College[60]. His younger brother, Captain Eldred Weston White, then living in Southville, Bristol, joined the RAS in 1908[61]. The latter had obtained his *Certificate of Competence as Master of a Foreign-going Ship* in Bristol in 1899.

Agnes Fry lived at Failand House, just outside Bristol, a Georgian manor acquired by her father the Right Honourable Sir Edward Fry FRS, of the famous Fry's chocolate company in Bristol, who was a Privy Councillor and Lord Justice of the Appeal Court. Born in 1869, she developed wide scientific interests, particularly astronomy and botany (contributing a paper to *Nature* on tree boughs). Agnes observed a bright meteor in 1899[62] (her twin sister Isabel had reported on one in 1887, when the family lived in Highgate[63]) and subsequently joined the BAA in 1901. She was elected an FRAS in 1919. She wrote a number of books including *Stars and Constellations: A Little Guide to the Sky* and translated a work on Giordano Bruno from German. She also collaborated with her father in his work on mosses.

Strictly, Irene Elizabeth Toye Warner became well known after the end of our stated era, but she was born in Kingsdown, Bristol, in 1882 so may have been active in astronomy by 1901, by which time her family lived in Horfield Common. By the early years of the new century, she was well known for her astronomical writing, including poems on astronomical themes. She joined the BAA in 1907, the Astronomical Society of Wales in 1910, and was one of the first group of women elected as Fellows of the RAS in 1916 January[64]. She had wide literary and historical range in her writing, for instance *Halley's Comet and Historical Events* and studies of the constellations as seen by other cultures. She also had an interest in spiritualism and occult magic. She provided meteor observations to her local contemporary William Denning, whose other correspondents included a W. Warner and Mrs Annie Warner, almost certainly Irene's parents[65]. Her father Wiclif Warner, born in Hertfordshire in 1856, had been an architect and surveyor and by 1901 was "living on own means". Annie Amelia Warner, née Carroll, was born in Bristol in 1861, the daughter of an accountant, and attended a boarding school in Westbury-on-Trym.

In summary, it appears that for a major, wealthy, mercantile city, Bristol was surprisingly short on active Victorian astronomers. There are certainly no 'grand amateurs' and even the category of their less-wealthy counterparts is sparsely filled, as few maintained regular observing programmes — Denning being the honourable exception. There are several 'professionals', in as much as they earned a living as science professors, engineers, or school masters, but apart from Wilson, E. J. White, and Sargent they were not specifically astronomers, and even these were paid for their astronomy only before or after living in Bristol. Most of the others, often clergymen plus the odd doctor or architect, are probably best described as what Allan Chapman refers to as 'leisured enthusiasts'[66], a few of them like the Burders making significant observations but many evidently settling for reading about astronomy or attending meetings. Aside from Denning, and despite having to earn a normal living, the most assiduous observer in Bristol was probably the musical instrument maker J. H. Jones, while we have one working-class man, the blacksmith Henry Pollard. Finally, at the end of the Victorian era, we find the first two Bristol women involved in astronomy, the well-off Irene Warner and the decidedly wealthy Agnes Fry, both of whom could be considered primarily as writers.

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CAN'T GET THERE FROM HERE? CURIOUS LOGIC IN THE FAMOUS PAPER BY EINSTEIN AND DE SITTER

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The Einstein–de Sitter cosmological model, a spatially flat Friedmann–Robertson–Walker (FRW) cosmological model containing ordinary matter ('dust') but no radiation or cosmological constant, has been studied extensively, both because of its mathematical simplicity and, partially related to that, because it was often used as a fiducial model. It is thus interesting that Einstein and de Sitter performed their main calculation, that of the density based on the Hubble constant, in a very roundabout and confusing way. After providing some historical background, I describe their calculation and explain why their method is technically correct even though it is misleading.

Introduction

In one of his lectures at the 1993 Saas-Fee course 'The Deep Universe', Allan Sandage[1] recommended that those attending* read the cosmological literature of the 1920s and 1930s. While unfamiliar notation (not to mention unfamiliar languages) might put off some modern readers, it is a rewarding exercise, and it is possible to read it all in a reasonable time (until about 1940, Feynman read even the entire *Physical Review*). The history of the field is perhaps more important in cosmology than elsewhere, so that in itself is a reason to study the literature, but sometimes curiosities are also found; one of those is the topic of this paper.

The Einstein–de Sitter cosmological model

The Einstein–de Sitter model[2] is a mathematically simple cosmological model; the scale factor R is proportional to time as $t^{2/3}$. The age of the Universe is 2/3 the Hubble time ($R/\dot{R}$, the inverse of the Hubble constant). The density in kg per m^3 is given by $1/(6\pi G t^2)$ where G is the gravitational constant and t is the age of the Universe in seconds. As such, it has often been used as a fiducial model for back-of-the-envelope calculations, and for a time it was the 'standard model' of the Universe, due to several factors: no curvature had been detected (and still hasn't), dislike of the cosmological constant by many, belief that inflation produces a Universe very close to flat, cosmological parameters then not ruled out by observations, and so on. No doubt its mathematical simplicity also contributed to its popularity, both for aesthetic and practical reasons. See ref. 3 for more on the historical importance of the Einstein–de Sitter model.

One can take Hubble's value[4] of 500 km/s/Mpc as a typical estimate of the Hubble constant at the time, which in the Einstein–de Sitter model corresponds to an age of about 1·3 billion years and a density of $\approx 4{\cdot}7 \times 10^{-25}$ kg/m^3 ($\approx 4{\cdot}7 \times 10^{-28}$ g/cm^3).

The short paper by Einstein and de Sitter

Despite some claims to the contrary (*e.g.*, ref. 5), the goal of their two-page paper[2] is straightforward[3]: since there was no observational determination of the value or even the sign of the curvature†, and since the cosmological constant is not necessary in an expanding universe, one can construct a simple model which nevertheless is compatible with the observational data. Now known as the Einstein–de Sitter model, such an FRW universe is spatially flat, has no cosmological constant, and otherwise contains only homogeneously distributed matter ('dust'), *i.e.*, no pressure or radiation. At least with regard to the lack of curvature, the simplicity was clearly meant to be provisional, as the last sentence indicates: "The curvature is, however, essentially determinable, and an increase in the precision of the data derived from observations will enable us in the future to fix its sign and to determine its value." It is thus in line with Einstein's philosophy to make things as simple as possible but not simpler‡. Interestingly, Einstein and de Sitter each did not think that the paper was very important, but each believed that the other did.[7,8]

*The majority were much younger than he was; Sandage pointed out that when he had started out, computers were female and worked in the cellar.

†That is still true today.

‡An aphorism along those lines is often attributed to Einstein, but, though it is probable that he said something similar, and is certainly a valid characterization of his thought, there is no direct written evidence for such a phrase[6].

Historical background

Although Friedmann[9,10] had explored the full range of FRW models, discussion often concentrated on fiducial models, no doubt due at least in part to the difficulty of calculations in the general case and because observations were not good enough to rule out all simple models. Early examples were the static Einstein universe[11] and the de Sitter universe[12,13], dubbed 'solution A' and 'solution B' by de Sitter[14]. The discovery of the expansion of the Universe ruled out the former*, while the latter, containing no matter, was clearly at best an approximation. Lemaître[17] presented a model which fitted all the data (and still does, with respect to its general characteristics if not the values of the parameters), his famous *Univers homogène de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extra-galactiques*†, though with positive curvature and a positive cosmological constant, calculations were not straightforward. After he had dropped the cosmological constant because he deemed it unnecessary in an expanding universe, Einstein preferred positive-curvature (and hence spatially closed and thus finite) cosmological models (*e.g.*, ref. 20). Thus, except for de Sitter's obviously incorrect model, preference had been for models with positive curvature. The Einstein–de Sitter model departs from that, and also drops the cosmological constant, an unusual move at the time: Eddington (*e.g.*, ref. 21) and Lemaître (*e.g.*, refs. 17,18,22–26) took the cosmological constant essentially as a given; Eddington[27] even wrote "I would as soon think of reverting to Newtonian theory as of dropping the cosmical constant."

Their calculation

I quote (apart from their footnotes) the portion of their paper containing equations in full:

"If we suppose the curvature to be zero, the line-element is

$$ds^2 = -R^2\,(dx^2 + dy^2 + dz^2) + c^2dt^2, \tag{1}$$

where R is a function of t only, and c is the velocity of light. If, for the sake of simplicity, we neglect the pressure p, the field equations without λ lead to two differential equations, of which we need only one, which in the case of zero curvature reduces to:

$$\frac{1}{R^2}\left(\frac{dR}{cdt}\right)^2 = \frac{1}{3}\kappa\rho. \tag{2}$$

The observations give the coefficient of expansion and the mean density:

$$\frac{1}{R^2}\frac{dr}{cdt} = h = \frac{1}{R_B}; \quad \rho = \frac{2}{\kappa R_A^2}. \qquad [2']$$

Therefore we have, from (2), the theoretical relation

* Einstein himself seems to have been more convinced by the instability argument (*e.g.*, ref. 15) than by observations when he gave up his static model[16].

†A translation of the paper was published as 'A Homogeneous Universe of Constant Mass and Increasing Radius accounting for the Radial Velocity of Extra-galactic Nebulæ'[18] which, interestingly, left out the calculation of what is now known as the Hubble constant[19].

$$h^2 = \frac{1}{3}\kappa\rho\,. \tag{3}$$

or

$$\frac{R_A^2}{R_B^2} = \frac{2}{3}. \tag{3'}$$

Taking for the coefficient of expansion

$$h = 500\text{km./sec. per } 10^6 \text{ parsecs}, \tag{4}$$

or

$$R_B = 2 \times 10^{27}\text{cm.},$$

we find

$$R_A = 1{\cdot}63 \times 10^{27}\text{cm.},$$

or

$$\rho = 4 \times 10^{-28} \text{ gr. cm.}^{-3}, \tag{5}$$

which happens to coincide exactly with the upper limit for the density adopted by one of us."

It doesn't actually "coincide exactly": for a density of 4×10^{-28} g/cm^3 the Hubble constant in the Einstein–de Sitter universe is ≈ 465 (and the age about 1·4 billion years). However, considering the low accuracy and precision of the three quantities — the average density of the Universe, its age, and the Hubble constant — it is a strong indication that our Universe is at least approximately described by the Einstein–de Sitter model.

Apparently they assumed that their readers would be familiar with their notation: R is the scale factor (usually taken to be the radius of curvature of the universe or, in the flat-space case, c/H_0), $\kappa = (8\pi G\rho)/(c^2)$, R_B and R_A refer to the solutions A and B mentioned above, h is the Hubble constant (usually written H today; as with other parameters, a subscript 0 refers to the value at present), and ρ is the matter density. It is clear from equations (2), [2′], and (3) that h has the dimension of inverse length (*i.e.*, the Hubble constant divided by the speed of light) while in equation (4) it has the usual unit of inverse time.

As stated in the title, their point is "the relation between the expansion and the mean density of the universe". That could have been calculated directly from equation (3), making their point that those two observational quantities result in a valid equation, thus providing some observational evidence that their model might be at least a rough approximation. But that is not what they did.

Rather, they introduced $h = 1/R_B$, which is essentially the recirocal of the Hubble length, often adopted as the scale factor for spatially flat universes, where the infinite radius of curvature would not be useful. However, 'B' suggests 'solution B', the de Sitter universe, in which the Hubble length is not only constant in time, but is also the distance to the event horizon (in general, neither is the case). Even more strange is the introduction of R_A, the radius of curvature of the static Einstein universe, which is very different from the Einstein–de Sitter universe; the former is static, has positive spatial curvature and thus finite, and a positive cosmological constant, while the latter is expanding, spatially flat and thus infinite, and has no cosmological constant.

The relation $\rho = 2/(\kappa R_A^2)$ holds for the static Einstein universe, but doesn't hold in general. (Expressed differently, in the Einstein universe, $R^{-2} = \lambda = (4\pi G\rho)/c^2$. Note that here, λ has the dimension of inverse squared length; one also sees inverse squared time, but the former follows the notation in the Einstein & de Sitter[2] paper. Also, their λ is usually written Λ today, while $\lambda = \Lambda/(3H^2)$.) There seems to be no reason to introduce R_A, as the quantity has no special meaning in general. Using the definitions above, essentially $R_A^2 = 2/(\kappa\rho)$ and $R_B^2 = 3/(\kappa\rho)$, they trivially calculated the quantity $R_A^2/R_B^2 = 2/3$.* The measured value of h (equation (4)) is then used to find R_B, then the ratio used to find R_A, then the definition of R_A is used to find ρ (which could have been calculated directly from equation (3)).

Note that the actual definition of R_A cancels out. They could just as easily have used $R_A^2 = 24324{\cdot}37793/(\kappa\rho)$, performed an analogous calculation, and achieved the same result. Again, they could have calculated the density ρ directly from equation (3). Why they didn't, I don't know.

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*Note that in the de Sitter universe, $R_B^2 = 3c^2/\lambda$; in the static Einstein universe, $R_A^2 = 2c^2/\lambda$. Thus, the ratio between those two is 2/3 as well.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 4: THE EVOLVED G-TYPE SYSTEM AN CAMELOPARDALIS

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AN Cam is a little-studied eclipsing binary containing somewhat evolved components in an orbit with a period of $21^{d}\cdot0$ and an eccentricity of 0·47. A spectroscopic orbit based on photoelectric radial velocities was published in 1977. AN Cam has been observed using the *TESS* satellite in three sectors; the data were obtained in long-cadence mode and cover nine eclipses. By modelling these data and published radial velocities we obtain masses of 1·380 ± 0·021 $M_{\odot}$ and 1·402 ± 0·025 $M_{\odot}$, and radii of 2·159 ± 0·012 $R_{\odot}$ and 2·646 ± 0·014 $R_{\odot}$. We also derive a precise orbital ephemeris from these data and recent times of minimum light, but find that the older times of minimum light cannot be fitted assuming a constant orbital period. This could be caused by astrophysical or instrumental effects; forthcoming *TESS* observations will help the investigation of this issue. We use the *Gaia* EDR3 parallax and optical/infrared apparent magnitudes to measure effective temperatures of 6050 ± 150 K and 5750 ± 150 K: the primary star is hotter but smaller and less massive than its companion. A comparison with theoretical models indicates that the system has an approximately solar chemical composition and an age of 3·3 Gyr. Despite the similarity of their masses, the two stars are in different evolutionary states: the primary is near the end of its main-sequence lifetime and the secondary is now a subgiant. AN Cam is a promising candidate for constraining the strength of convective core overshooting in 1·4-$M_{\odot}$ stars.

Introduction

Although the current generation of theoretical stellar models[1–4] provides a sophisticated and, in many cases, impressively accurate description of the behaviour of stars, there remain multiple effects which are still not properly understood. These include rotation in high-mass stars[5–7], convective-core overshooting[8,9], mixing length[10], opacities[11–13], and the influence of magnetic activity in low-mass stars[14–16]. Additional constraints on these phenomena are needed *via* empirical determinations of the basic physical properties of stars. Those that have completed their main-sequence lifetime and are experiencing the faster evolutionary states that follow are most valuable because the predictions of theoretical models are more sensitive to the physics included in the models.

One of the primary sources of such empirical measurements is eclipsing binary stars[17,18], as their physical properties can be determined using only photometry, spectroscopy, and geometry. Detached eclipsing binaries (dEBs) are the most valuable because the two components can be assumed to have evolved as single stars, and thus allow the measurements of the properties of two stars of different mass but the same age and initial chemical composition. dEBs have been used, among other things, to calibrate empirical mass–radius–temperature–age relations[18–21], investigate the treatment of mixing-length and core overshooting in theoretical models[22–25], and study stellar chemical evolution[26–28].

AN Camelopardalis

In this work we present an analysis of AN Cam (Table I), a dEB containing two stars with masses near 1·4 $M_{\odot}$ but with significantly different radii and effective temperature ($T_{\rm eff}$) values. AN Cam has an eccentric orbit with a relatively long period of $21^{\rm d}\cdot00$, meaning that tidal effects are weak and thus the two stars have evolved in isolation since their formation. The current analysis is part of our efforts to extend the number of objects in *DEBCat** (the *Detached Eclipsing Binary Catalogue*), a compilation of dEBs with masses and radii measured to precisions of 2% or better[33]; see Southworth[34–36] for further discussion.

Very few studies of AN Cam have been published. Its eclipsing nature was discovered by Strohmeier & Knigge[37] and times of mid-eclipse have been obtained by several authors since then[38–43]. The only other publication of note is that of Imbert[44], who presented a double-lined spectroscopic orbit for the system based on a total of 73 radial velocity (RV) measurements. These were obtained using the *Coravel* spectrometer at l'Observatoire de Haute-Provence[4], in which a physical mask was used to observe directly the cross-correlation functions and thus the RVs of the stars[46]. These RVs will be used below as they are crucial to the measurement of the masses and radii of the stars in the AN Cam system.

TABLE I

Basic information on AN Cam

Property	*Value*	*Reference*
Henry Draper designation	HD 24906	29
Tycho designation	TYC 4514-8-1	30
Gaia EDR3 designation	551506893532348544	31
Gaia parallax	3·208 ± 0·015 mas	31
B magnitude	10.30 ± 0·024	30
V magnitude	9·69 ± 0·03	30
J magnitude	8·396 ± 0·024	32
H magnitude	8·098 ± 0·021	32
K_s magnitude	8·041 ± 0·019	32
Spectral type	F8	29

Observational material

The light-curve studied in this work comes from the NASA *TESS* satellite[47]. AN Cam was observed three times: in Sector 19 (2019/11/27 to 2019/12/24), Sector 25 (2020/05/13 to 2020/06/08), and Sector 26 (2020/06/08 to 2020/11/04). In contrast to previous papers of this series, the target was not selected for short-cadence observations. Its light-curve was therefore extracted from the

* https://www.astro.keele.ac.uk/jkt/debcat/

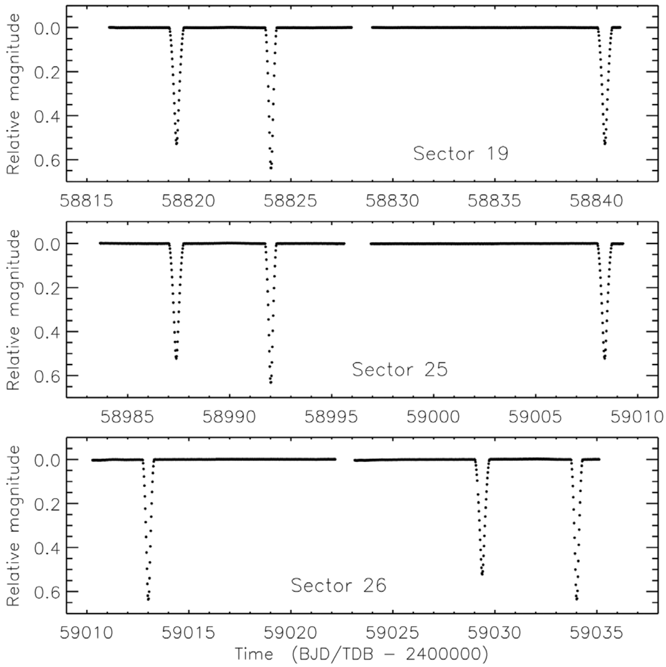

FIG. 1

TESS full-frame-image photometry of AN Cam. The three plots show the data from sectors 19, 25, and 26, respectively.

full-frame images using the LIGHTKURVE package[48]. AN Cam is also planned to be observed in Sectors 52 and 53 (2022 May–July), so future observations of a similar quality will become available (assuming *TESS* remains operational).

The end result of this process was a light-curve containing 3463 data points with a sampling rate of 1800 s (see Fig. 1). As the dEB is well-detached and shows negligible proximity effects, the data outside eclipse contain no useful information. We therefore trimmed all observations more than 1·5 eclipse durations from the midpoint of an eclipse, thus retaining 803 data points for subsequent analysis.

Light-curve analysis

We adopt the standard definition that the primary star is the one eclipsed at primary eclipse (at phase 0), and primary eclipse is deeper than secondary eclipse. It will be shown below that in the case of AN Cam this means the primary star is hotter than the secondary, but is smaller, less massive, and less bright. We refer to the primary as star A and the secondary as star B.

AN Cam has a relatively long orbital period so the stars are approximately spherical. We therefore elected to model the *TESS* data using version 41 of the JKTEBOP* code[49,50]. JKTEBOP is fast and flexible, and has been found to be in good agreement with other codes for well-detached EBs[51].

The radii of the stars are parameterized in JKTEBOP as the sum and ratio of the fractional radii ($r_A + r_B$ and $k = r_A/r_B$, where $r_A = R_A/a$ and $r_B = R_B/a$ are the fractional radii, R_A and R_B are the true radii of the stars, and a is the semi-major axis of the relative orbit) and both quantities were fitted. AN Cam has an eccentric orbit, as can be seen from the fact that the secondary eclipse is not at phase 0·5 and is not the same duration as primary eclipse. This was accounted for by fitting for the quantities $e\cos\omega$ and $e\sin\omega$ where e is the orbital eccentricity and ω is the argument of periastron. Other fitted parameters were the orbital inclination i, the central surface-brightness ratio J, the orbital period P, and a reference time of primary mid-eclipse T_0. Attempts to fit for third light yielded negative values for this quantity, so we fixed its value at zero.

Limb darkening was included in the model using the quadratic law[52] with coefficients for the *TESS* passband from Claret[53]. The two stars have similar surface gravities and $T_{\rm eff}$ values so we assumed the same coefficients for each star. We fitted for the linear coefficient but fixed the quadratic coefficient; the two coefficients are strongly correlated[54,55] so this does not introduce a significant dependence on theoretical models of stellar atmospheres.

A first fit to the *TESS* light-curve was obtained by including a first-order polynomial for each eclipse to normalize it to zero differential magnitude. The relatively long duration of individual data points could lead to smearing of the eclipse shapes even at this orbital period, so the theoretical light-curve was numerically integrated by averaging the model for each data point[20]. Each average was calculated from five samples evenly covering 1800s. The secondary eclipse occurs at phase 0·7794.

The best fit was found to be a good match to the *TESS* data, but with significant deviations during eclipse as large as 5 mmag (see Fig. 2). These could plausibly be explained by the presence of a third light that changes over the course of the observations — possible given that the *TESS* data of AN Cam are from two different cameras — or by surface inhomogeneities (starspots) that evolve over time. Closer inspection of the residuals of the fit (see Fig. 3) shows that the residuals change with the orbit and are not just miniature versions of the eclipses, so are consistent with spot activity but not with an erroneous third-light value. The residuals are seen in both primary and secondary eclipse, which means that spots are present on both stars. No evidence for periodicity due to spot rotation is found in the *TESS* observations, implying either a slow rotation or a complex spot distribution on the components' surfaces. A colleague suggested the possibility of apsidal motion, but this effect is expected to be too weak to affect our analysis because of the relatively long orbital period, small fractional radii (even at periastron), and the fact that the stars are moderately evolved so are quite centrally condensed.

Once the *TESS* data were adequately modelled, we added in the RVs from Imbert[44]. These comprise 33 measurements for star A and 40 for the brighter star B. The velocity amplitudes and systemic velocities of the two stars were included as fitted parameters. The fitted spectroscopic orbit is shown in Fig. 4. We also included some published times of minimum light to further constrain the orbital ephemeris of the system; these will be discussed below. The final results are shown in Table II.

* http://www.astro.keele.ac.uk/jkt/codes/jktebop.html

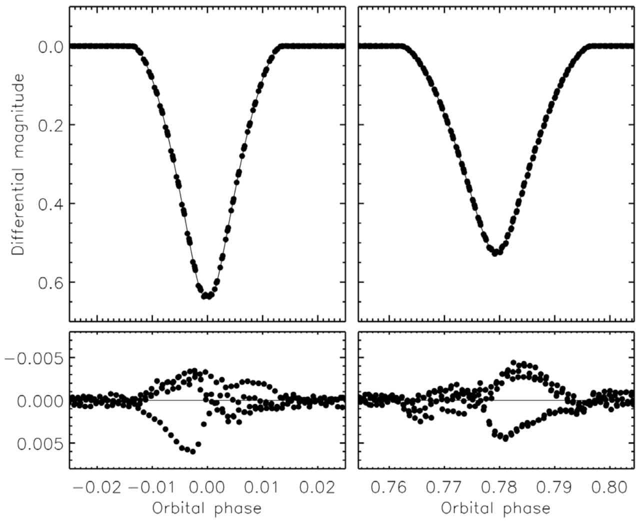

FIG. 2

The *TESS* light curve of AN Cam (filled circles) around the primary (left) and secondary (right) eclipses. The JKTEBOP best fit is shown using a solid line. The lower panels show the residuals of the fit on a larger scale.

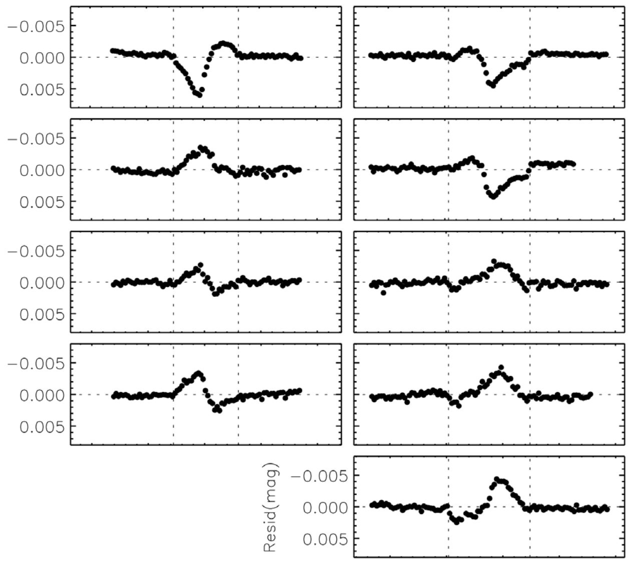

FIG. 3

Residuals of the best fit to the *TESS* data around each eclipse (filled circles). The primary eclipses are shown in the left panels and the secondary eclipses in the right panels. Each panel covers a time interval of $2^{d}\cdot4$ centred on a time of mid-eclipse. The horizontal dashed lines indicate a residual of zero and the vertical dashed lines show the start and end points of the eclipses.

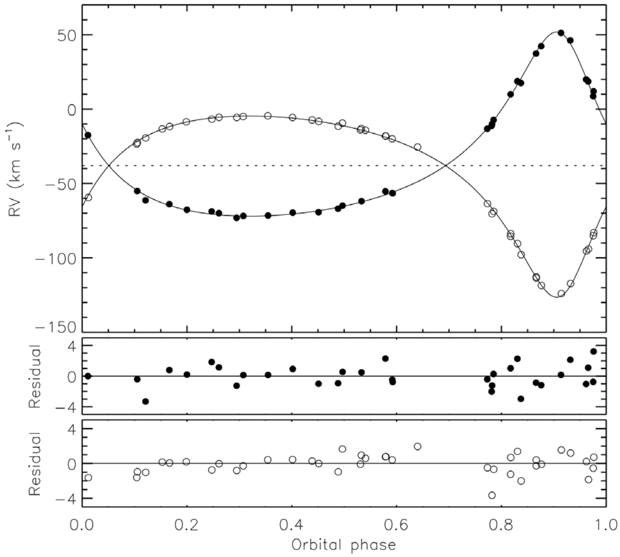

FIG. 4

Spectroscopic orbit of AN Cam using the RVs from Imbert[44]. RVs of the primary and secondary stars are shown with filled and open circles, respectively. The best fits from JKTEBOP are shown using solid lines and the systemic velocity is indicated with a dotted line. The lower panels show the residuals of the fit.

TABLE II

Best JKTEBOP fit to the TESS light curve of AN Cam. The RVs from Imbert[44] and four times of minimum light (Table III) were included in the fit. The uncertainties are 1σ. The same limb-darkening coefficients were used for both stars. The uncertainties in the systemic velocities do not include any transformation onto a standard system.

Parameter	*Value*
Fitted parameters:	
Primary-eclipse time (BJD/TDB)	2458992·01472 ± 0·00095
Orbital period (d)	20·998420 ± 0·000012
Orbital inclination (°)	89·213 ± 0·013
Sum of the fractional radii	0·10665 ± 0·00010
Ratio of the radii	1·2256 ± 0·0015
Central surface brightness ratio	0·8368 ± 0·0008
Linear limb-darkening coefficient	0·190 ± 0·011
Quadratic limb-darkening coefficient	0·22 (fixed)
$e \cos \omega$	0·45176 ± 0·00009
$e \sin \omega$	0·1208 ± 0·0009
Velocity amplitude of star A (km s^{-1})	61·89 ± 0·52
Velocity amplitude of star B (km s^{-1})	60·89 ± 0·38
Systemic velocity of star A (km s^{-1})	−38·04 ± 0·28
Systemic velocity of star B (km s^{-1})	−38·05 ± 0·16
Derived parameters:	
Fractional radius of star A	0·047920 ± 0·000077
Fractional radius of star B	0·058739 ± 0·000032
Orbital eccentricity	0·4676 ± 0·0002
Argument of periastron (°)	14·97 ± 0·11
Light ratio	1·2570 ± 0·0041

Error analysis

The systematic trends in the residuals visible in Fig. 3 are concerning from the viewpoint of error analysis, as they break the standard assumption that the data points are *iid* (independent and identically distributed). The uncertainties in the fitted and derived parameters were therefore obtained in three different ways, and the largest of the three options was retained for each parameter.

The first method used for estimating the uncertainties was the Monte Carlo algorithm implemented in JKTEBOP[56], which assumes *iid* data points but does account for correlations between parameters. The second method was the residual-permutation algorithm in JKTEBOP[55], which cyclically permutes the residuals through the data and then refits, so can capture the effects of correlated noise on the determinacy of the solution. The third method was to perform a fit to each of the three sectors of *TESS* data separately and deduce uncertainties from the scatter of the three parameter values that resulted.

In the case of AN Cam we found that the Monte-Carlo error bars were the largest for most of the fitted and derived parameters. The residual-permutation error bars were largest for the surface-brightness ratio and the velocity amplitudes. The separate-fit error bars were greatest for the ratio of the radii, the fractional radius of star A, and the light ratio of the stars. The parameters reported in Table II are from the joint fit to the full data, and the error bars are the largest of the three options for each parameter. The future observations from *TESS* should allow both the precision and accuracy of the measured parameters to be improved.

Orbital ephemeris

The *TESS* data provide a good measurement of the orbital period of AN Cam, because they cover a time interval of 216^d and the eclipses are sharp and deep. However, the RVs were obtained 40 years prior so we sought additional constraints on the orbital ephemeris of the system. We found a total of nine times of mid-eclipse from seven sources in the literature, of which three times had an associated uncertainty.

On adding these into the JKTEBOP solution we found that the fit to the *TESS* data was severely compromised, and that most of the eclipse times deviated from the best-fitting linear ephemeris by many times their uncertainties. After extensive but inconclusive investigations we resolved to include only the four most recent eclipse times and to apply a uniform uncertainty of $0^d \cdot 01$ to them. Our justifications for this approach are: (*i*) that the earlier eclipse times differ by at least $0^d \cdot 02$ and as much as $0^d \cdot 26$, and it is best to reject them *en masse* than to pick those which happen to provide a better agreement*; and (*ii*) the extremely small quoted uncertainty in one of the remaining eclipse times is hard to justify for this system and is not supported by such a level of agreement with the fitted ephemeris.

This is clearly an unsatisfactory situation, and the prospective future observations from *TESS* in Sectors 52 and 53 will help improve it. We rest our own analysis primarily on the *TESS* data, which are incomparably better than any previous light-curves of AN Cam, and on the good agreement found with the RVs from Imbert[44]. Although the large residuals in the earlier data hint at orbital-period changes or apsidal motion in this system, it is more plausible that they are compromised by the difficulty of measuring precise timings in eclipses much longer than a typical observing night (13·8 hr for the primary eclipse and

* It is worth remembering Merrill's theorem: "once discrepant measurements are rejected the remainder will be found to agree well."

17·3 hr for the secondary), deformation of the eclipse shapes by spot activity, and/or clock errors in the equipment used.

Inclusion of the four most recent eclipse times significantly improves the measurement of the orbital ephemeris for AN Cam, and has a negligible effect on the other parameters of the JKTEBOP fit. The eclipse times and fits are given in Table III.

TABLE III

Times of published mid-eclipse for AN Cam and their residuals versus the best fit reported in the current work. The orbital cycle is an integer for primary eclipses and a half-integer for secondary eclipses.

Orbital cycle	*Eclipse time (BJD)*	*Published uncertainty (d)*	*Adopted uncertainty (d)*	*Fitted time (BJD)*	*Source*
−1571	2426003·47			26003·4969	37
−665·5	2445023·32			45023·4328	38
−634.5	2445674·23			45674·3839	38
−355·5	2451532·683			51532·9430	43
−355	2451537·605			51537·5756	43
−192·5	2454955·6932		0·01	54955·6855	39
−162	2455590·2891	0·0079	0·01	55590·2707	40
−160·5	2455627·6431	0·0065	0·01	55627·6349	41
−100·5	2456887·5481	0·0001	0·01	56887·5401	42

Physical properties of AN Cam

Although JKTEBOP provided the masses and radii of the components of AN Cam measured from the *TESS* light-curve and Imbert[44] RVs, we used the JKTABSDIM code[57] to calculate the physical properties of the system in order to include quantities such as T_{eff}, luminosity, and distance. The results were in good agreement with those from JKTEBOP, but the uncertainties were greater in some cases due to the adoption of the largest of three alternative error estimates for each measured parameter (see above). The precision to which the radii are measured is limited by the RV observations, which set the scale of the system, and not by the *TESS* light-curve.

The two important quantities unavailable from the preceding analysis are the T_{eff} values of the stars. These could be constrained from the distance (311·7 ± 1·4 pc based on the parallax from *Gaia* EDR3[31]), the *BV* and *JHK* apparent magnitudes (Table I), and the light ratio in the *TESS* passband (Table II) of the system. We first obtained a value of $E_{B-V} = 0{\cdot}06 \pm 0{\cdot}04$ for the interstellar reddening of the system* from Lallement *et al.*[59,60]. We then determined the ratio of the T_{eff} values of the stars using theoretical spectra from the ATLAS9 model atmospheres[61], the light ratio in the *TESS* passband, and the *TESS* passband-response function[47]. The T_{eff} values of the stars were then iteratively determined using JKTABSDIM and the bolometric corrections from Girardi *et al.*[62] in order to match the distance to the system known from the *Gaia* parallax. We determined conservative uncertainties based on the maximum possible perturbation that could be applied to the T_{eff} values and still match the *Gaia* parallax whilst retaining a consistent distance between the different optical–infrared passbands for which apparent magnitudes are available. The final results are given in Table IV. The

*https://stilism.obspm.fr

TABLE IV

Physical properties of AN Cam. Units superscripted with an 'N' are defined by IAU 2015 Resolution B3[58].

Parameter	*Star A*	*Star B*
Mass ratio	1·016 ± 0·011	
Semi-major axis of relative orbit ($R^{N}_{\odot}$)	45·05 ± 0·24	
Mass ($M^{N}_{\odot}$)	1·380 ± 0·021	1·402 ± 0·025
Radius ($R^{N}_{\odot}$)	2·159 ± 0·012	2·646 ± 0·014
Surface gravity (log[cgs])	3·9095 ± 0·0030	3·7400 ± 0·0037
Density ($\rho_{\odot}$)	0·1371 ± 0·0010	0·0757 ± 0·0004
Synchronous rotational velocity (km s^{-1})	5·201 ± 0·029	6·376 ± 0·034
Effective temperature (K)	6050 ± 150	5750 ± 150
Luminosity log($L/L^{N}_{\odot}$)	0·750 ± 0·043	0·839 ± 0·046
M_{bol} (mag)	2·86 ± 0·11	2·64 ± 0·11

T_{eff} values imply a spectral type of F9 V + G2 IV for the system, using the calibration of Pecaut & Mamajek[63]. The atmospheric properties of the system could be measured better by a detailed analysis of high-resolution spectra of the dEB.

The evolutionary status of AN Cam

We have made a first preliminary comparison between the physical properties of the AN Cam system and the predictions of theoretical stellar models. A detailed analysis should be performed once precise spectroscopic T_{eff} and chemical-abundance measurements are available. We chose to use the PARSEC models[1] for the current analysis, and restricted our comparison to chemical compositions near solar.

Fig. 5 shows a Hertzsprung–Russell diagram with the components of AN Cam and the predictions for a subset of the available PARSEC models. It can be seen that the evolutionary tracks for 1·4 $M_{\odot}$ agree with the measured T_{eff} values and luminosities of the stars, and for both of the metal abundances shown ($Z = 0{\cdot}017$ and $Z = 0{\cdot}020$). To infer the age of the system we plotted the observed and theoretical data in mass–radius and mass–T_{eff} diagrams (not shown). A good agreement was found for an age of 3210 Myr (for $Z = 0{\cdot}017$) or 3380 Myr ($Z = 0{\cdot}020$). The formal uncertainty in these ages is only ±10 Myr, which is dwarfed by the systematic errors in the theoretical models (see Paper 1[34]). Fig. 5 shows that the two components of the dEB are in different evolutionary states, with star A being near the terminal-age main sequence and star B having already passed this to become a subgiant. The system is comparable to the AI Phe[64,65,51] and V501 Her[66] systems, but with the advantage that the masses of the stars are more similar despite the different evolutionary states*. These systems, together with others such as RT CrB[67] and CF Tau[68] where both components have left the main sequence, are important tests of the treatment of convective mixing in theoretical stellar models[69].

Summary

AN Cam has been known to be an eclipsing binary for over 60 yr[37] and a high-quality spectroscopic orbit exists[44], but it previously lacked a detailed photometric analysis. The light-curve obtained by the *TESS* satellite has allowed

*The masses of the two components differ by 1·6% for AN Cam, 4·1% for AI Phe, and 4·6% for V501 Her.

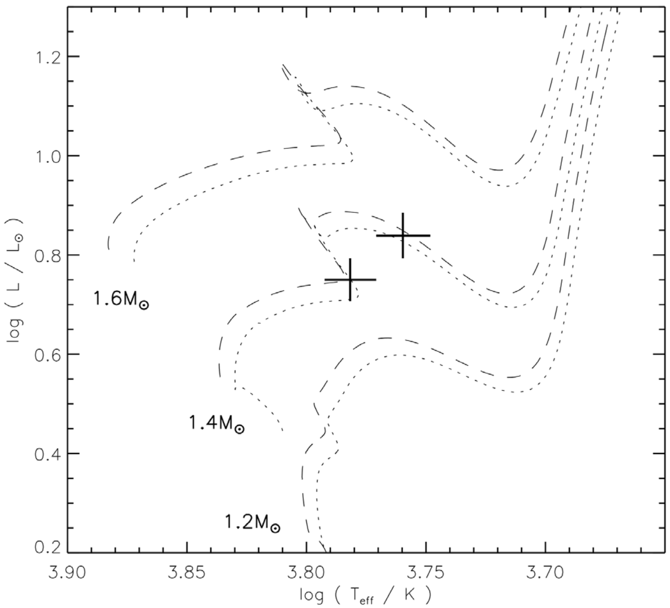

FIG. 5

Hertzsprung–Russell diagram showing the components of AN Cam (solid crosses) and selected predictions from the PARSEC models[1] (broken lines) beginning at the zero-age main sequence. Models for 1·2, 1·4, and 1·6 $M_{\odot}$ are shown (labelled). In each case the dashed line is for a metal abundance of $Z = 0{\cdot}017$ and the dotted line is for $Z = 0{\cdot}020$.

this gap to be filled. We modelled the *TESS* data simultaneously with the RVs from Imbert[44] and determined the masses to precisions of 1·5% and 1·8%, for star A and star B, respectively, and the radii to precisions of 0·5% for both stars. Published times of minimum light are mutually contradictory, suggesting the possibility of orbital-period variations in the system or instrumental difficulties with the measurement of the times of midpoint of such long eclipses. The $T_{\rm eff}$ values of the stars were deduced from their light ratio in the *TESS* passband, the *Gaia* EDR3 parallax, and apparent magnitudes of the system. Both components show evidence for spot activity.

AN Cam was found to contain two stars of very similar mass (1·38 $M_{\odot}$ and 1·40 $M_{\odot}$) but nevertheless quite different radii (2·16 $R_{\odot}$ and 2·65 $R_{\odot}$), bound in a $21^{\rm d}{\cdot}0$ period orbit with significant eccentricity ($e = 0{\cdot}47$). These properties are consistent with an age of 3·3 Gyr, an approximately solar chemical composition, and differing evolutionary states for the two stars (main sequence for star A and subgiant for star B). These properties mean AN Cam has the potential to allow a discriminating test of stellar-evolutionary models.

AN Cam will be observed by *TESS* again, in mid-2022. A detailed spectroscopic analysis would be valuable for improving the precision of the mass measurements, and for determining precise $T_{\rm eff}$ values and photospheric chemical abundances. A combined analysis of this and other subgiants in dEBs may then allow strong constraints to be placed on the strength of convective-core overshooting implemented in the current generation of theoretical stellar evolutionary models.

Acknowledgements

We are grateful to Zac Jennings for extracting the *TESS* light-curve of AN Cam, and to Dariusz Graczyk for helpful comments. This paper includes data collected by the *TESS* mission. Funding for the *TESS* mission is provided by the NASA's Science Mission Directorate. This research made use of LIGHTKURVE, a Python package for *Kepler* and *TESS* data analysis[48]. This work has made use of data from the European Space Agency (ESA) mission *Gaia*, processed by the *Gaia* Data Processing and Analysis Consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arXiv scientific-paper preprint service operated by Cornell University.

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CORRESPONDENCE

To the Editors of 'The Observatory'

The Elephant in the Open-Access Room

Open-access (meaning freely available for anyone to read on the internet) journals are becoming more and more common, with some funding agencies requiring that research financed by them be reported in open-access journals, in the case of public money, often justified by the claim that taxpayers have a right to see what their taxes have financed. While few think that open-access journals themselves are a bad idea, there are nevertheless some negative aspects associated with them. I briefly mention a few which are relatively well known then one which I haven't noticed being discussed very much.

There can be no doubt that the internet has changed the face of academic publishing, and that many aspects of that are good. For example, even without access to a subscription, enough literature is available on the internet to fulfil the needs of many researchers, for example, making it possible to work from home. (That, of course, has advantages as well as disadvantages, but shouldn't be underestimated in times such as the present when many are involuntarily working from home.) Printed journals are becoming less common; not only are many new journals on-line-only, but also some long-established journals have stopped producing paper editions, such as the *Astrophysical Journal* and, recently, even *Monthly Notices of the Royal Astronomical Society*. Much discussion has focussed on subscriptions or other ways of paying for journals: on-line publishing is cheap, compared to printing, and much of the work (*e.g.*, refereeing, not to mention writing the articles) is done at no cost to the journal (in the case of page charges or open-access fees, the authors even pay for their paper to be published). There can be no doubt that the profit margins of many journals have increased enormously; their costs have dropped, yet subscription prices continue to rise. That and dubious business practices such as requiring libraries to subscribe to bundles of journals when they don't want most of them have even led to boycotts of certain publishers.

All the same, the costs of otherwise similar journals vary enormously; a problem with some open-access advocates is characterizing all journals where the author and/or reader, directly or indirectly, pay for access as equally evil. In some cases, the author is allowed to distribute freely (something equivalent to) the final version, but lack of visibility can be a problem (and arXiv isn't always a solution).

Another trend is the move from subscription-based payment to open-access fees. While some journals have long had page charges (often in addition to subscriptions), increasingly costs are covered by open-access fees, often well over £1000 per article. Some subscription-based journals offer that as an option in order to make the article available to those without a subscription, while other journals are financed essentially entirely by such article-processing fees (making essentially all articles open access*). There are several problems with such a business model. First, there is an obvious conflict of interest: assuming that the incremental costs per article are small, which is certainly true for on-line-only journals, the more articles published, the higher the profit. There are examples of journals published by otherwise more-or-less-respectable publishers which have very little, if any, quality control. Second, it puts those who don't have the funds at a disadvantage. Even if waivers are offered, they might not always be applicable in a particular case, and in any case the author is forced to petition for such a waiver to be applied. Third, in cases where such fees are covered by an institute or other body with limited resources, unhealthy competition among colleagues can arise. Fourth, a journal which can finance itself *via* subscriptions can be assumed to have some measure of quality, and hence the author can expect some reasonable measure of visibility. If authors are paying to have their article published, rather than a subscription being paid so that high-quality articles can be accessed, there is less motivation for quality control (that is a variant of the first point). (I'm leaving out for now the entire industry of fake journals — and there are even fake conferences, often organized by the same people — which claim to be serious academic journals, often with titles similar to respected journals, and often boast famous people on their editorial boards, without the knowledge of those people. They are often

*Note that some of those journals solicit review articles from well-known researchers and waive the publication fees. Such articles, being review articles, are often highly cited, especially if they are freely available. (Interestingly, almost all journals where the author pays for publication allow distribution elsewhere, although there is no reason why that must be the case, and thus such articles are often highly visible on arXiv.) As a result, the journals obtain a non-negligible impact factor, which lures some to submit their articles to such journals. It is well known that the impact factor is highly skewed, especially in the case of high-impact-factor journals: most citations come from a few high-profile articles. Nevertheless, some authors — or their employers and/or funding agencies — are deluded enough that an article with no citations in a high-impact-factor journal counts for something, even if it is not far removed from vanity publishing.

termed 'predatory journals', but I have little sympathy with authors who don't even know which journals in their own field are considered respectable. More serious are cases where publication lists inflated by such journals are taken uncritically as evidence of academic accomplishment by hiring committees, not all members of which are experts on the field in question. Even one publication in such a journal should disqualify any candidate.)

SCOAP3 and Plan S, by enabling or requiring open-access publication, seem to have spawned, or at least contributed to the rise of, open-access journals, often of dubious quality. By transferring the fee from the authors, their institutions, libraries, or universities to higher-level organizations, the actual costs are not as visible to authors. Probably for that reason, many publishers have simply transferred the rightly criticized inflated publication costs from subscriptions and/or page charges to fees paid at the national level or even higher, making it even more difficult to avoid such overpriced journals.

One aspect of this trend which I haven't noticed being discussed much is the question of what happens to the on-line content of journals if arXiv-overlay journals or some other models which bypass traditional publishers are so successful that traditional journals are driven out of business. While some traditional journals, such as *MNRAS*, leave copyright with the author (and of course *MNRAS* is owned by the RAS and not, as are many journals, by a commercial publisher, though production is outsourced to a commercial publisher), and others, such as *Astronomy & Astrophysics*, are copyrighted by a non-profit organization (in that case ESO), the copyright to articles in many journals is owned by the publisher. If such journals, or even their publishers, are driven out of business, they almost certainly won't be willing to donate the content they own to some open-access initiative. In the case of journals which are on-line-only, there are no official paper copies. Certainly not everything is on arXiv (and of what is there, the final version isn't always on arXiv or if so that might not be known). Older articles are available *via* the NASA Astrophysics Data System Bibliographic Services, but in the case of newer articles, ADS often has only links to on-line journals. Even if someone were able to make a 'virtual journal' by organizing existing electronic versions of articles, it probably couldn't be made available, at least not until after a long time, because it would violate copyright. On the other hand, the scientific community cannot be expected to continue to pay inflated prices to publishers in order that the long-term storage of articles is secured, even less so for on-line-only journals (many of which also have prices which are much too high). Even if a solution could be implemented for all new papers, the problem of papers from recent history (the last couple of decades, say) would remain.

Such events have already happened[1]. While no major journals have yet been affected, it nevertheless seems to be something to worry about. There is perhaps a Catch-22 involved: if reasonably priced on-line-only journals are not successful, the established journals can continue to charge inflated costs. If they are, then traditional journals might disappear, and perhaps even the publishers be driven to bankruptcy, which almost certainly would lead to much less availability, and perhaps even to the complete loss of some articles. It is not that no-one has thought about the problem (see, *e.g.*, many entries at ref. 2), but rather that the scientific community as a whole has not implemented a viable solution.

I realize the irony of providing on-line-only references; future historians reading this article can check whether they are still accessible.

Yours faithfully,
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Don't Mention the War!

Leonard Matula notes in his review[1] of *The Birth of Modern Astronomy* that "many other writers have failed" to credit Fritz Zwicky with "predicting dark matter and neutron stars". While that might be the case, not uncommon is the claim that Zwicky was the *first* to suggest dark matter. Coincidentally, in my article in the same issue[2] I went to some length to point out many who had, in various contexts, suggested dark matter before Zwicky. There is also still no Nobel Prize for astronomy, though several astronomers have been awarded the physics prize; that to Bethe in 1967 was arguably the first for work connected to astronomy, though Bethe was not an astronomer; the first to actual astronomers was that to Ryle and Hewish in 1974. (Five of the last six winners have been astronomers, and the sixth, Penrose, has done work closely connected with astrophysics. In this century, six physics prizes have been awarded to seventeen people for work in astrophysics — compared to four prizes to seven people in the (five times longer) previous one.)

My main comment, though, concerns Wernher von Braun, on whom Matula spends about a quarter of his review. It's nice to see a more realistic picture painted of him; too often one-line comments, such as that which Matula criticizes, can create a false impression[3], even if that is not the intent of the author. Interestingly, I actually knew Wernher von Braun somewhat, as my mother had worked for several years as secretary to Ed(win) Riddick before I was born; the American Riddick was von Braun's public-relations/political deputy while the German Eberhard Rees was his R&D deputy (and later, succeeding von Braun, director of the Marshall Space Flight Center in Huntsville, Alabama — which is also where I was born). Although she had stopped working when I was born, she occasionally went back to visit, sometimes taking me with her. I have a distinct memory of standing in von Braun's office and drawing a rocket on a blackboard. (We moved from Alabama to Texas in early 1969, when I was just over four years old, after having spent a few months at Cape Canaveral, watching the launches of *Apollo 7* and *8* from the beach, so I was probably three or four at the time. My father had also worked, indirectly, for NASA — as did many at that time — doing static testing of the Saturn IB rocket, which was built by the Chrysler Corporation (known mainly for automobiles).)

I don't know whether my parents' involvement with NASA had anything to do with my interest in spaceflight (which later shifted more to astronomy then more to cosmology), but after that interest had developed, my mother was an invaluable inside resource, having met all of the original seven (and many of the later) astronauts as well as various politicians and heads of state — both domestic and foreign — who visited Huntsville during the space race. She had fond memories of Dr. von Braun (as she always called him) and those jibe more with Matula's account than the 'just another Nazi' image. As Matula notes, for those who haven't experienced it, it is difficult to imagine what life in a dictatorship is really like. My real concern, however, is not with von Braun but with memories and history in general. Access to written history (which, as Churchill was not the first to note, is written by the victors) is now easier than ever, while all of those old enough to remember World War II will probably be dead within the next twenty years. How will future historians decide which of conflicting accounts is closer to the truth? Also by coincidence, today in French class we discussed whether too much information can lead to loss of information (*trop d'information tue l'information*). The title of this piece is a reference to a line spoken by Basil Fawlty, played by John Cleese, in the television comedy series *Fawlty Towers*. How many young astronomers writing code in the PYTHON programming language today realize that the name is a reference to Cleese's Monty Python troupe?* Or that there are webs outside the internet, or that one can surf on water?

Yours faithfully,
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*Presumably, some do, such as the authors of the Monte-Carlo code for cosmological-parameter extraction 'MONTE PYTHON'.

REVIEWS

The Exoplanet Revolution, by James Lequeux, Thérèse Encrenaz & Fabienne Casoli (EDP Sciences), 2020. Pp. 207, 23 × 15·5 cm. Price €39 (about £35) (paperback; ISBN 978 2 7598 22210 2).

Keeping up with developments in a fast-moving area such as exoplanets is a difficult task but these authors have done a good job. Furthermore, they have given themselves a broad remit covering everything from the historical discussion of other planets and life, modern exoplanet discovery and characterization, the identification of life, and finally future prospects in the field. All of this is crammed into around 172 pages along with an additional 31 pages of appendices. For a book of this size it is remarkably comprehensive.

I found my progress through the book to be slower than expected. This was because I was lingering over many sentences wondering about their true meaning. This book, or rather the English version of this book, would have benefited greatly from being proof read by a native English speaker: the *franglais* has resulted in a number of clumsy descriptions and sentences, as well as a certain nationalistic writing style! Maybe English books are written in the same style and I have been brainwashed not to notice this. Anyway, I think if these issues were sorted out this would actually be an excellent summary of the current state of knowledge.

Some of the reviews presented are of controversial topics. For example, some of the pioneering exoplanetary-atmosphere results have, more recently, been found to be somewhat less convincing. This is the nature of the scientific method and has led to more robust techniques and a new generation of instruments designed to tackle this problem. More specialist authors would maybe have realized this and been more critical. There are other examples.

Given all the book's idiosyncrasies would I recommend it? While it's certainly a frustrating book it's also comprehensive and interesting. I would happily suggest it for a researcher who already has some background and wants to broaden their knowledge. — Don Pollacco.

Twenty Worlds: The Extraordinary Story of Planets Around Other Stars, by Niall Deacon (Reaktion), 2020. Pp. 208, 21·5 × 14 cm. Price £15·95 (hardbound; ISBN 978 1 78914 338 6).

This book provides a good account of the exciting discovery of a multitude of exoplanets during the last thirty years. As the title suggests, it is laid out on the basis of describing one exoplanet per chapter in what is remarkable detail considering that their existence was conjectural until the last decade of the last century.

The means of discovery of the planets and their probable size and orbits are well described in the approximate order of their development, starting with the clues provided by the radial velocity of their stellar systems, then with perception of their transit effect upon their star, and more recently with gravitational lensing also affecting brightness. The difficulties of obtaining adequately accurate measurements are spelt out and the value of space telescopy and of adaptive-optics systems made clear; one is left almost breathless in awe of the sophistication of modern astronomical instrumentation.

The book is clearly aimed at the interested layman with little or no previous astronomical or atomic knowledge, and therefore includes brief descriptions of spectra, wavelengths, Doppler effects, and the atomic physics giving rise to these phenomena. The lives and deaths of stars are also covered, with a helpful description of heat transmission within stars — radiation and convection — varying according to their magnitude, and mention of the rather startling fact that some exoplanetary orbits are contra-rotatory to their star's spin.

Appropriately, the book opens with a summary description of our own planetary system, classifying its composition as four terrestrial planets, two gas giants and two ice giants. As a Plutophile I was saddened to note its omission from the list (and must question the accuracy of the author's very first statement "Thirty years ago there were eight worlds"), and the book should in fact have defined at the start what the author means by the word 'planet'. On page 67 Pluto is mentioned as a dwarf planet, and semantic inconsistency should be avoided, particularly in books for laymen about specialist subjects. In simple terms most people understand a planet to be a large celestial object, not big enough to develop internal nuclear fusion, which is in orbit around a star. The book under review mentions two exoplanets (PSO J318·5–22 and WISE 0855–0714) which are not in orbit around a star, and also mentions brown dwarfs, which are not stars as commonly understood but are large enough to fuse deuterium and can apparently be found either in orbit round a star or alone. Toss moons into the picture, which can be planet-sized or tiny and are generally understood to be moons because they orbit planets, and it is clear that, at least for the layman, exoplanetary discoveries are calling for a re-categorization of the traditional definitions of celestial objects.

The book is written in an informal discursive style which may well enhance its immediate appeal to the lay reader but which inhibits the rapidity of relocating the many areas of the text which merit rereading. The chapter headings are dramatic and whimsical (and the names/identity codes of the various exoplanets the antithesis of memorable and orderly nomenclature, though this is not the fault of the author), but in general terms the book contains a great deal of information, much of it new and exciting, and opens up a window upon what the author correctly describes as "one of the most dynamic and active areas in all of science".

I gather from this book that its underlying theme, the formation of planetary systems, is now generally accepted as a part of the clumping of gas and dust which leads to the build up of a star or stars at the hub, and not a separate process such as Buffon's collision theory or Kant's idea of an emanation from an existing star, both of which suggested that planetary systems might be rare. Certainly the number of exoplanets now discovered shows that they are not rare, and almost conclusively supports von Weizsäcker's and subsequent ideas about the gas/dust ratios of interstellar space. I should have welcomed some reference to the Titius/Bode Rule — I recollect that the early discovery of the three exoplanets orbiting the pulsar PSR B1257+12 (mentioned in Chapter 20 of the book under review) was reported as evidencing the extension of the Rule to an exoplanetary system — and it would be interesting to know whether subsequent discoveries have further supported it or are tending to show that it is too simple to be true and there is no real consistency in exoplanetary distancing.

The book contains at the end a useful three-page summary of the characteristics of the exoplanets mentioned in the text and our own eight planets, and has thirty-one illustrations, most of which are in colour and in my view excellent for their purpose. The majority are diagrammatic, but a few depict what a viewer might see when standing upon an exoplanet and recall the impressive illustrations of probable space vistas which Chesley Bonestell was producing in the 1950s.

In summary this is an attractive, well-produced book providing much information about new and exciting discoveries being achieved by good old-fashioned astronomical methods, albeit highly sophisticated. It is refreshingly free from the dilemmas existing in other areas of cosmology — wave/particle duality, string theory, multiverses, *et cetera* — and I recommend it as well worth reading by any interested layman (who doesn't feel too strongly about Pluto). — Colin Cooke.

Spacefarers: How Humans Will Settle the Moon, Mars, and Beyond, by Christopher Wanjek (Harvard University Press), 2020. Pp. 389, 22 × 15 cm. Price £23·95 (hardbound; ISBN 978 0 674 98448 6).

Christopher Wanjek's *Spacefarers* is a welcome and timely addition to synoptic views of the future of human space exploration. It delivers on the premise of its subtitle, *How Humans Will Settle the Moon, Mars and Beyond*, with emphasis on the 'How,' illustrating Wanjek's strength of access to space players and ease in integrating both fast-evolving ideas and the important history of how we got to the present moment, a credit to his prolific years as a writer for NASA Goddard and hundreds of space and science articles for major publications. He's tackled big subjects before in *Bad Medicine* and *Food at Work*, and the same talents for digestibly introducing challenging and relevant science are at work in *Spacefarers*, with useful notes and references comprising a reliable gateway work.

The 'How' includes a highly readable treatment of Earth's biosphere and humankind's adaptability for living in space, excellent surveys of current approaches to Moon and Mars development missions, and a well-developed overview of future missions to the outer Solar System, complete with informed speculations on life we may encounter along the way.

As a card-carrying member of several of the many readerships that *Spacefarers* will appeal to — Tokyo-based Partner with Airbus Ventures, board member at NewSpace start-ups ranging from launch systems to satellite and ground-station technologies, researcher with UCL's Centre for Planetary Sciences, JAXA collaborator, and space-law commentator — I find it particularly welcome that Wanjek takes a global and up-to-date view of the host of players accelerating NewSpace activities across the planet. From insightful highlights of Luxembourg's quiet but important role in commercial space activities to how Japan's successes in asteroid-sample collection technically rival China's own impressive Moon-sample return, *Spacefarers* is welcome reprieve from US-centric views of space exploration.

With full credit for taking the risk and avoiding mere reportage, Wanjek offers 'My Prediction' sections as a conclusion to each key chapter. *Spacefarers* hits it on the nose for cheaper rocket flights and their challenges, but misses the role commercial hypersonic and mobile launcher capabilities will introduce; underscores the likely role of Antarctica-like 'science camps' on the Moon but misses the transformative role of tele-operated robotics in lunar development; in its extensive and well-researched section on Mars, foresees colonization and terraforming at the cusp of a US–China space race, while ironically diminishing Mars' attractiveness as a habitat; the further Solar System predictions will be familiar to readers of Kim Stanley Robinson's *2312* and Charles Stross' *Accelerando*.

If Wanjek finds opportunity to write a *Spacefarers* sequel, there will be an important opportunity to include the ever-widening range of technologies that seem likely to re-shape radically the course of NewSpace: from quantum and other advanced computing technologies, to AI and machine learning, and from nanotechnologies fused with synthetic-biology capabilities, to new capabilities and initiatives in the search for extraterrestrial artefacts. Predictions for the NewSpace sector will likely require a new kind of pattern recognition to capture its many new emergent signals.

*Spacefarer*s may best be recommended as a companion work to Daniel Duedney's *Dark Skies*. An accomplished political scientist, Duedney offers a deeper assessment of the new industrial–military–government dynamic now crystallizing around NewSpace. Denser on policy and sharper in its advocacy of a more Earth-orientated use of space technologies, *Dark Skies* provides an important point/counterpoint to Wanjek's own 'boldly but prudently go' approach. Where *Spacefarers* sees a China space race as an accelerator of space development, *Dark Skies* offers us thoroughly reasoned scenarios for how any unfettered space race is likely to exacerbate war here on Earth; *Spacefarers* reports on the 'warehousing' of NASA's asteroid planetary-defence programme, while *Dark Skies* makes a cogent case that a lack of international action and collaboration for asteroid deflection escalates risks for both Earth conflict and natural disaster.

Spacefarers thus offers a solid basis to inform what is becoming an increasingly vital debate on the use and international deployment of space technologies. With Wanjek's highly accessible 'what do you think' style, he makes a key contribution inviting a wider and better informed readership to play its own role. — Lewis Pinault.

Space, Time, and Aliens: Collected Works on Cosmos and Culture, by Steven J. Dick (Springer), 2020. Pp. 799, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 41613 3).

Steven Dick's massive book arrived in the post at a poignant moment, just a few days after 2020 December 1, when the anticipated collapse of the 305-metre-wide dish of the Arecibo radio telescope occurred. Completed in 1963, Arecibo had been an iconic participant in the SETI programme.

This book consists of a collection of essays previously published by Dick over a long writing career, arranged thematically and each with a new afterword. The author writes that the book's theme is the impact of astronomy and space exploration on culture, though the main title would seem to imply something more focussed and exciting. *Space* there is certainly plenty of in this book, and some essays mention the difficulties of communication over great distances. I felt a little cheated by the *Time* aspect. Essays upon systems of time-reckoning and the history of construction of time balls on Earth seem at best marginal to its core theme, and I had been expecting something about time dilation and interstellar travel. The latter are mentioned only towards the end under 'interstellar travel' in less than two pages, while time dilation does not feature in the Index. *Aliens* feature largely *in absentia*. There is no speculation about their form (other than in science-fiction-style illustrations), though we learn of those writers and scientists who had been influenced by science fiction, and that exploration is not a fundamental or necessary characteristic of all terrestrial (and by inference extraterrestrial) societies. The word 'alien' does not appear in the Index.

The essays are collected into seven sections, of which the final has a particularly broad theme: 'Reflections on Humanity and the Cosmos'. A sample of chapter titles includes 'Plurality of Worlds', 'SETI before the Space Age', 'The Drake equation in Context', and 'The Universe and Alfred Russel Wallace'. Steven Dick's writing is always very interesting, thoughtful, and well-researched, and he is very good at covering broad themes. Many readers will doubtless have come across his earlier books such as *Life on Other Worlds* (CUP, 1998).

Much of this book is an interesting read, and it forms a very useful reference work, though for this reviewer it did not live up to the promise of its title. The high cost will probably limit its sales. — RICHARD MCKIM.

The Mythology of the Night Sky: Greek, Roman, and Other Celestial Lore, 2nd Edition, by David E. Falkner (Springer), 2020. Pp. 331, 23·5 × 15·5 cm. Price £22·99/$29·99 (paperback; ISBN 978 3 030 47693 9).

The origins of the constellation patterns are lost in the mists of time, but they were probably introduced to help sailors remember stars that were important for navigation and to help farmers to mark the times of year for planting and harvesting. To make the patterns easier to remember, it would make sense to name the individual stars to represent characters in stories, and quite likely that was the origin of many of the ancient star names.

Myths and legends about the constellations and stars which grew up over the centuries would make the patterns in the sky more interesting and memorable, and there have been various books that have told the tales. Classic examples are those by Richard Hinckley Allen[1], first published in 1899, and Julius D. W. Staal[2], but there are more recent ones as well, for example, one by Ian Ridpath[3], first published in 1988.

Now we have another modern version, which follows a similar pattern to previous books by working through the constellations by season and weaving the mythological tales in at the appropriate place. Some of the stories are quite brief, others run to many pages, particularly the well-known stories of Jason and the Argonauts, the Labours of Hercules, and the story of Perseus, which are told at length. All are clearly written, but (as the author points out in his preface) there are several versions of all these myths, so a particular selection has been made. Falkner also includes in his introduction to Greco–Roman mythology various interesting family trees of the gods; these are all rather complicated, as one might expect.

Where this book differs significantly from others though, is that Falkner does not confine himself to Greek and Roman stories. He provides brief introductions to six other mythologies: Norse, Celtic, Inuit, Hawaiian, Rapa Nui (Easter Island), and Tongva (an indigenous group in southern California), with most detail on the Norse and Celtic traditions. These additional mythologies are needed because Falkner also discusses in some detail the (Roman) names of the planets, and then the names of their satellites and selected dwarf planets and asteroids. Although some of these names are Greco–Roman (although from steadily more unfamiliar deities as their number has increased), other names have been drawn from non-Greco–Roman sources. For example, the third-largest dwarf planet is called Make-Make, after the Easter Island god of creation and humanity, while several of Saturn's satellites are named after figures in Norse mythology.

This is a fascinating and informative book (although the final chapter on astrophotography sits oddly with the rest of the book), but is unfortunately marred slightly by numerous minor typos and a few errors. For example, the text (p. 17) says that the Milky Way is shown shaded in Fig. 2.3, but it isn't. In addition, the table on p. 18 says that M 50 is in Canis Minor (chart in Fig. 2.4); it isn't shown on the chart, probably because M 50 is not in Canis Minor but in Monoceros. The latter is a later addition, and before its introduction Canis Minor may have stretched further south and included M 50. Confusing though.

Nonetheless, this book is a worthy addition to the literature on the names of heavenly bodies, and can be recommended. — Robert Connon Smith.

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Gravity's Fatal Attraction: Black Holes in the Universe, 3rd Edition, by Mitchell Begelman & Martin Rees (Cambridge University Press), 2020. Pp. 322, 24 × 18 cm. Price £24·99/$31·99 (paperback; ISBN 978 1 108 81905 3).

This had better be a good book — I purchased two copies at full market price, ordering a second one from Amazon, when the first (ordered directly from the publisher) had failed to appear for many weeks. Why the urgency? It is to be a textbook for a course called 'Great Ideas of Physics', starting here at University of California, Irvine, on January 4. Amazon delivered in 48 hours; CUP just in time for the spare to be a birthday present for a colleague (born 1957 December 25) who is teaching a similar course at another institution, but I admit to having scrawled a couple of additions and corrections before handing it over.

This 3rd edition is described as fully updated, to include a full new chapter on *LIGO* & *VIRGO* results, the M 87 images from the *Event Horizon Telescope*, and the results of many surveys and simulations from recent years that make use of telescopes and computing power only dreamed of when the 1995 1st edition came out. (The 2nd edition dates from 2010; and this one is described on page *iv* as coming from 2021.) A few things escaped the updating — more is now known about neutrino masses than that they are unfortunately unknown; a dish in Greenland has been added to the *EHT* array; and the tracking of the period of the binary pulsar 1913+16 ended in 2005.

The focus is undoubtedly on black holes (Wheeler properly credited for popularizing the name, not inventing it): big ones, small ones, some as big as your head. Those have a mass of 10^{28} or 10^{29} grams, and scaling-type descriptions of masses, sizes, time-scales, and such are as close as the volume comes to mathematics, deliberately. Several chapters enter into details of jets powered by rotating black holes, especially in active galactic nuclei and X-ray binaries. A brave effort is made to explain impedance matching (not distinguishing between impedance and resistance). That black holes of any mass have a resistance of about 100 ohms is given, not explained, though an adjacent drawing of charge spreading out over a horizon is relevant.

One of the authors suggested that there are perhaps too many simulations shown among the very many elegantly coloured unnumbered illustrations. I don't actually agree — many of them are interesting, and compelling. But they are perhaps the cause of something that bothers me about the volume as a whole: the choice of who gets credit for things. The index includes 123 names of people, of which five are women (and three of the 24 who appear in photographs). Eponyms pick up a few more people (Lense and Thirring; Julia Riley), so it's not precisely that the authors have succumbed to the Great Person hypothesis (well, there was Newton and Halley and then Einstein). But no one is credited with the *Event Horizon Telescope*. *LIGO* and *VIRGO* have only Kip Thorne associated, though the Nobel took in Rainer Weiss and Barry Barish, and some of the earlier prizes, the 'little Scot' Ron Drever. No, I won't mention who built the first detectors (for what are called here some of the time gravitational radiation and sometimes gravitational waves). But these used piezoelectric crystals (lead–zirconate–titanate) which generate electricity when pulled or squeezed, not 'strain gauges'.

I bow to none among the living in my affection for Yakov Borisovich Zeldovich. But the idea of looking for collapsed or frozen stars as binary systems with a massive, non-visible component and X-ray emission came from Okhtay Guseinov. Their names appear in opposite order in the Russian and English versions of their paper. What they suggested was, of course (contrary to page 53), exactly what led to the identification of Cygnus X-I as the first binary with a persuasive black-hole component. That the optical counterpart (HDE 226868) was not in the binary catalogue they used (compiled by Alan Batten) was a sad story, arising from the work of Daniel Magnus Popper. Items like this, which I flagged in my copy as "unfair", are also to be found in the discussion of the discovery of dark matter on various scales, and elsewhere.

So, a volume with lots of good physics and astrophysics, but a little shy on credit to some colleagues. The authors' preface (which should be read) makes special mention of Roger Blandford, Stephen Hawking, Donald Lynden Bell, Andrew Fabian, Richard McCrea, Christopher Reynolds, and Philip Armitage, and for comments on their 1st edition, Colin Norman, Joseph Silk, and Virginia Trimble.

Somewhere around the end of March I will have some idea of what the students in Physics 19 made of the volume (the corresponding course used the 2nd edition a year or two ago), and might report in a short letter. — VIRGINIA TRIMBLE.

Dynamical Chaos in Planetary Systems, by Ivan I. Shevchenko (Springer), 2020. Pp. 376, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 52143 1).

My first brush with chaos came when I was a postgraduate student carrying out a numerical integration of the orbit of a newly discovered, outer Solar System object, 1977 UB. I was baffled by the fact that when I repeated the integration a few months later using an improved orbit, the results I obtained were very different even though the changes to the listed orbit were small. The object, subsequently named 2060 Chiron, was an example of a Centaur and its eccentric orbit resulted in occasional close approaches to some of the outer planets. Nowadays this would be instantly recognized as a classic example of a chaotic orbit but back in the 'dark ages' I was content to put the awkward results aside and work on something else. Within a decade everything had changed as the pioneering work of Boris Chirikov (everyone should investigate the exquisite structure of his standard map!) became more widely known and astronomers such as Jack Wisdom showed how the results from dynamical-systems theory could be applied to understanding chaotic phenomena in the Solar System. The key combination of fast digital computers and improved numerical methods caused a revolution in the subject, with astronomers realizing that concepts such as overlapping resonance and Lyapunov exponents helped them to understand and quantify dynamical phenomena.

Shevchenko's book is a remarkably thorough and timely overview of the subject, suitable for any researcher in the field but ideally one with an appropriate background in Hamiltonian dynamics. After an initial chapter reviewing the essential concepts and techniques, there are two extensive sections on (*i*) resonance and chaos in the Solar System, and (*ii*) the dynamics of exoplanets. Each sub-topic is covered in meticulous detail with full references to and key diagrams from published works, including many by the author. It is well written with only a few minor grammatical quirks and errors. The discovery of systems of multiple, interacting exoplanets means that the chapter devoted to planetary architecture is of particular interest. Which configurations have long-term stability? How wide a gap can a planet clear for itself? Can observations of radial structure in a circumstellar disc be used to infer the locations and masses of undetected planets perturbing such a disc? This is an area where chaos as a tool becomes less descriptive and more diagnostic — the true sign of a subject reaching maturity; this book is a chronicle of that journey. — Carl Murray.

A Short Course in General Relativity and Cosmology, by Reinhard Hentschke & Christian Hölbling (Springer), 2020. Pp. 306, 23·5 × 15·5 cm. Price £44·99/$59·99 (paperback; ISBN 978 3 030 46383 0).

This book is part of Springer's series *Undergraduate Lecture Notes in Physics* (http://www.springer.com/series/8917), which are required to distinguish themselves from typical lecture notes in at least one of three ways: exceptionally clear and concise, an undergraduate introduction to a more advanced or non-standard topic, or a novel approach to teaching. It certainly differs from most undergraduate texts on General Relativity (GR) and cosmology in several ways: it contains about equal parts GR and cosmology; the emphasis is on more-modern aspects of cosmology; most of the 'boxes' scattered throughout the text (in the style of Misner, Thorne, & Wheeler[1]) are worked examples; and the problems at the end of each chapter except the first, about a dozen pages altogether, have very detailed solutions (41 pages) near the end of the book. As such, the book is like (and presumably is) a set of well-written lecture notes. It concentrates more on the forest than on the trees, but that is not a disadvantage; on the contrary, many broader introductions, especially on cosmology, are available (some[2–5] reviewed by me in these pages[6–9]), as are more advanced texts; this book is a useful bridge between the two extremes, especially for those more familiar with old-style cosmology (the classical tests to determine the cosmological parameters) who want to learn more about topics such as the cosmic microwave background, structure formation, and inflation.

After an introductory chapter on Special Relativity, Newtonian gravity, and classical mechanics, tensor calculus is introduced before the field equations of GR (thus, as I wrote[10] about another, more advanced, book[11], "the presentation follows the traditional pattern in GR books, introducing differential geometry and tensor calculus before moving on to physics, though the discussion of special relativity at the beginning whets the appetite"). The first part of the book ends with descriptions of the classical tests of General Relativity and the properties of black holes. The basics of traditional cosmology, concentrating on Friedmann–Robertson–Walker cosmological models, are presented in two chapters, followed by chapters on the thermodynamics of the Universe, accelerated expansion (including discussion of the CMB), and inflation (continuing the discussion of the CMB and the basics of structure formation).

As expected, the flatness problem is mentioned, and, as expected, as if there has been no progress in understanding it in the last 40 years.* Interestingly, although the fine-tuning aspect (Ω must have been incredibly close to 1 in the early Universe) is mentioned, it is almost described as something obvious and unproblematic (which it is), while the instability aspect (if Ω evolves away from 1, why is it still close to 1 today?) is deemed to be more problematic. Although the standard arguments for inflation as a solution to the monopole, horizon, and flatness problems, as well as a mechanism for the origin of primordial density fluctuations, are mentioned, it is also noted that the monopole problem might have vanished with the theories which predicted them but which have now been ruled out, and some problems with the idea of inflation itself are also touched upon. Whether or not one agrees with all the details in some special cases, the book is a good presentation of current thinking in cosmology.

There are fewer typos and so on than in most books I review, and the book itself is well produced. There are several figures, many with colour, throughout the text, and my preferred footnotes rather than endnotes. Four appendices, the longest, at 14 pages, on dark-matter haloes, provide additional details; the fifth contains solutions to the problems and the sixth presents some algebraic computer codes (for MATHEMATICA and MAXIMA). As a textbook, the text doesn't contain normal references, but before the four-page small-print index is a list of 61 papers and books which are specifically referred to in the text for the reader who wants to explore a topic in more depth.

I've often felt the need myself for a book between, on the one hand, popular and introductory-level presentations and, on the other, more advanced textbooks and technical monographs, especially one which covers topics I am less familiar with; I think that this book would serve such a need for others as well. — PHILLIP HELBIG.

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(5) B. Ryden, *Introduction to Cosmology* (Cambridge University Press), 2017.
(6) P. Helbig, *The Observatory*, **135**, 234, 2015.
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(9) P. Helbig, *The Observatory*, **138**, 323, 2018.
(10) P. Helbig, *The Observatory*, **140**, 33, 2020.
(11) S. Carroll, *Spacetime and Geometry: An Introduction to General Relativity* (Cambridge University Press), 2019.
(12) P. Helbig, *Eur. Phys. J. H*, **46**, 10, 2021.

*Don't take it from me. There are so many arguments against the existence of the flatness problem that I've written a 23-page review[12]. Although obviously not common knowledge, many very well-known cosmologists and relativists have argued, in the leading journals in the field, that the flatness problem is bogus, so now, as in the future, I need cite only my review and references therein.

Timing Neutron Stars: Pulsations, Oscillations and Explosions, edited by Tomaso M. Belloni, Mariano Mendez & Chenmin Zhang (Springer), 2021. Pp. 335, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 662 62108 0).

A whole book about timing neutron stars! What would one most hope for? Obviously, up-to-the-minute (or anyhow, year) numbers for the evolution of the period of *the* binary pulsar, 1913+16, which, from its 1975 discovery up to 2005 so beautifully fit the general relativistic prediction! Sadly, no. Only those old data appear, though there is a fairly lengthy discussion by Marta Burgay *et al.* of how pulsar timing is (or ought to be) done and using PPN and PK parameters to test GR (Parametrized Post Newtonian and Post Keplerian). The same chapter has a lovely, colourful 'Venn diagram' of the inventories of different sorts of pulsars (2627 total), including binary, globular cluster, Magellanic Cloud, and millisecond (recycled), and a table of the 74 binary ones with at least one published PK parameter. Diagrams illustrate the evolution of initial main-sequence pairs of different masses to semi-final states of NS × 2 or WD + NS. Intriguingly, systems now seen as white dwarf plus neutron star form with the neutron star coming from the initially *less* massive component, owing to the first, vigorous phase of mass transfer, while the initially more massive star is left too small to become anything but a white dwarf.

What else is here? A total of six chapters, citing 1384 references (these are separated by chapter, so there is surely some duplication). A good many acronyms, helpfully indexed. QPOs are quasi-periodic oscillations (precise cause not agreed upon), which can be as rapid as 1300 Hz, while no rotation frequency larger than 730 Hz has been found, though up to about a kiloHertz should be possible (again, several experts understand why, but they understand different mechanisms).

A very good introductory chapter by M. Coleman Miller addresses a wide range of astrophysical constraints on dense matter in neutron stars, including the continued need for the nuclear physicists either to tell us or to learn from us the proper equation of state of the stuff. Our nuclear colleagues are also needed to deal with the *rp* process (meaning rapid capture of protons), as D. K. Galloway and L. Keek explain in their chapter on thermonuclear X-ray bursts. Accreted material reaches temperatures of 10^8–10^9 K and undergoes CNO cycle and triple-alpha processes, then things that liberate protons. Rapid proton capture extends up to tin (the element with the most stable isotopes), but the initial products are more and more unstable through the process, and soon decay back to the valley of beta stability. Pile-ups occur at Zn-60, Ge-64 , Se-68, and Kr-72, because these have the longest beta-decay time-scales. In case you left your periodic table at home, Kr 'wants' to be somewhere around 84, and 72 'wants' to be Germanium or thereabouts.

The first two editors provide the last chapter, on high-frequency variability in low-mass X-ray binaries (remember the low mass is that of the companions, not the neutron star). Two of their diagrams give the colours of QPOs in units called Crab. The range is 0·6–1·0 for soft-X-ray colour, and 1·0–1·3 for hard-X-ray colour. The Crabs we have known best were all pinkish-orange, but that was after cooking.

There is lots more here, including P. Esposito *et al.* on magnetars and A. Patruno and A. L. Watts on accreting millisecond pulsars; but if you want to know what has become of *the* original binary pulsar, you must go elsewhere. — Virginia Trimble.

Cosmic Odyssey: How Infrared Astronomers at Palomar Observatory Changed Our View of the Universe, by Linda Schweizer (MIT Press), 2020. Pp. 304, 23·5 × 18·5 cm. Price £32/$39·95 (hardbound; ISBN 978 0 262 04429 5).

This is a splendid book reporting splendid science: the achievements of astronomers using the telescopes on Palomar mountain, in particular the 200-inch, told by an insider. The first chapter describes the construction of the 200-inch as the culmination of the series of ever larger telescopes built by Hale, and also introduces us to Zwicky and the beginnings of the search for supernovae. This was undertaken with the 18-inch Schmidt camera, the first telescope on the mountain, which was so successful that it was followed by the 48-inch Schmidt. The synergy of these survey telescopes and the 'Big Eye' is one of the themes of the story. The following chapters are dedicated to different fields of investigation, in each case "following the threads of discovery from origin to culmination". I found this treatment to work very well and to be one of the strengths of the book. We start with the distance scale, and moving through stellar and Galactic evolution to 'peculiar' galaxies and controversies over their origin and interactions — also stemming from early work of Zwicky. Then to galaxies and quasars and their interpretation, a brief history of infrared astronomy from the two-micron survey to ultra-luminous IR galaxies, and large-scale structure. Then closer in to the Solar System* and extra-solar planets before finally closing the circle by coming back to the search for supernovae, now using the powerful, automated *Zwicky Transient Facility*. This tour is structured, comprehensive, and well referenced. I was constantly impressed by the longevity of ideas and the value of long-term programmes sustained by substantial amounts of observing time.

The book is well written in a lively style, rich in anecdote. With input from interviews with many of the participants it tells us *how* the science was done, including wrong turnings, and gives a feel for life at the Observatory. It is intended for a wider readership than astronomers, with distances quoted in light-years, and the author has explained the remarkable phenomena revealed by the observations well. There are only a few places where the non-specialist readers could be bewildered, such as by the reference to the coudé focus below the observing floor (pp. 62–63). This could have been handsomely illustrated with another of Russell Porter's celebrated drawings of the 200-inch telescope, the cutaway showing the foci — perhaps accompanied by a sentence or two explaining why coudé spectrographs were once ubiquitous in large telescopes and are now superseded. This might also inform younger astronomers who may not have seen, let alone used, such instruments.

The book is beautifully illustrated throughout, but there are a few places where more information in the caption would have been welcome: *e.g.*, a scale for the long wake left by Mira illustrated across pp. 56–57, and the location of the X-ray, optical, and sub-millimetre fluxes, or the colours used to represent them, in the composite picture of NGC 5128 on p. 93. Certainly the *ALMA* image of U Antliae on p. 146 needs to be accompanied by a note about the instrument, which is very different from anything encountered before, together with a reference to the paper which provides an on-line movie showing the expansion.

These quibbles do not prevent me from recommending the book highly: there is a lot here for a range of readers, attractively presented. — Peredur Williams.

*Pedant's corner: the detector used for the mid-IR mapping of Jupiter (pp. 215–7) was not cooled by liquid nitrogen, but by the much colder liquid hydrogen.

An Introduction to Observational Astrophysics, 2nd Edition, by Mark Gallaway (Springer), 2020. Pp. 236, 23·5 × 15·5 cm. Price £39·99/$54·99 (paperback; ISBN 978 3 030 43550 9).

William Blake wrote of the UK as "this green and pleasant land". One of the causes of this is also why it is so hard for undergraduate students to obtain real observing experience in this country: one cannot guarantee a single night of good weather within the first few months of an academic year. If you want your students to gain this experience you then either take a chance or supply them with pre-existing data.

Either way, you also need to decide how much help to give. The quickest approach is "Here's a pile of FITS files; hand in your completed project in 12 weeks." The more time-intensive method is to arrange observing sessions with whatever telescope is available and guide them through obtaining astronomical data. This process is complex and complicated, and requires experience in many areas of astrophysics, electronics, and computing.

The textbook under review is a creditable attempt to cover all the necessary knowledge for a range of undergraduate observing projects, and will also be a handy reference source for many amateur astronomers. The 16 chapters cover the nature of light and the magnitude scale, telescopes and light detectors, time and co-ordinate systems, imaging, photometry, lucky imaging, spectroscopy, radio observing, solar observing, astrometry, DSLR cameras, and basic data reduction.

The author has extensive experience of observing with undergraduate students, and the book really reflects this. There are plenty of figures and diagrams, many in colour, although their reproduction is a little fuzzy. The only obvious thing missing is a dedicated chapter on the plethora of on-line tools available. I also think that some information is a bit too basic: for example Chapter 4 discusses 'Time' but does not mention HJD, BJD, or TDB.

So far so good. But there is one big problem with the book: mistakes. The back cover says "updated and *fully* corrected" which immediately makes one ask is it indeed fully corrected, and why did this statement need to be made in the first place? A careful read-through revealed the usual few typos that would be caught by any spell-checker (*e.g.*, "approximagely") and occasional grammatical errors, but also a set of important factual errors that should have been rectified before publication. Some of these are in the figures (*e.g.*, "collomator" in Fig. 14.1 and "atumbra" instead of antumbra in Fig. 13.8) but others are in the main text. On p. 46 time zones are stated to be approximately 1 hour in latitude (should be *longitude*), and immediately afterwards Western European Time is confused with Central European Time. On p. 183 the core temperature of the Sun is given as 15×10^{15} K but is 15×10^{6} K. On p. 57 "precision rate" should be "precession rate".

The most obvious error (to me) is in Figs. 12.2, 12.3, and 12.4, which purport to show a *SuperWASP* light-curve of the transiting planetary system WASP-24. There are two problems: it is not *SuperWASP* data (far too good) and it is not WASP-24 (wrong transit depth and orbital period). It is not even ground-based data, as there are none of those pesky gaps due to the Sun being inconveniently above the horizon. A bit of rooting around solved it: these are observations of Kepler-4 from the *Kepler* telescope. If *SuperWASP* data were this good then NASA and ESA would never have bothered with *Kepler*, *TESS*, and *PLATO*.

So what to make of this textbook? In places it is excellent, and its breadth of coverage is laudable. I would recommend it to undergraduate students and amateur astronomers (with a warning about the mistakes). But a final read-through from a pedantic expert would have been invaluable. Maybe a reprint or third edition will fix things. As a parting shot, I will point out that the copyright notice on page *iv* is preceded by a line saying "2nd editiion". Whoops. — JOHN SOUTHWORTH.

Foundations of Astrophysics, by Barbara Ryden & Bradley Peterson (Cambridge University Press), 2021. Pp. 596, 25 × 19·5 cm. Price £59·99/$79·99 (hardbound; ISBN 978 1 108 83195 6).

General textbooks for astronomy and astrophysics degrees are important components of many degree programmes, but this territory has difficulties concerning the balance to be sought between comprehensiveness, comprehension, and cost. This book, hereafter referred to as 'Ryden & Peterson', scores well on price and clarity, but does this by providing a rather brief treatment of some areas of astrophysics in order to present a thorough discussion of others. One's view on this book is therefore likely to be coloured by the research areas one finds interesting or valuable.

So, to the basics. Ryden & Peterson is nicely presented in hardback with substantial pages of a size intermediate between A4 and A5. The pages are single-column with a generous margin on the left, there are plenty of figures to aid understanding, and the authors are not afraid of equations. The writing style is clear and encouraging. There is a set of 31 colour images on high-quality paper bound near the centre of the book, which is a nice touch but means one has to have to keep leafing to it when "Color Figure [N]" is referenced. There are also a reasonable number of problems at the end of each of the 24 chapters, but the answers are given in a different publication. The index is only seven pages so is not adequate for a textbook of this size. I also found the obligatory reference to Monty Python (footnote on p. 298).

The back cover mentions that it is a "reissue of the 2010 edition", published by Pearson and now out of print. This statement raised some alarm bells in my mind as a suggestion that some of the contents are out of date. One might ask, with some justification, what difference a decade makes to basic astrophysics? It is at this point that I realized that the first scientific papers I wrote were published 16 years ago and I still don't think of them as *old*, so why should this be a problem for a textbook? The answer is that there are places where some updates would have been useful. The obvious example is the list of astronomical constants helpfully placed on the inside front cover, some of which are now out of date due to the IAU Resolution 2015 B3. A second indication is the small amount of space given to the relatively new field of extrasolar planets: 11 pages is very modest for such a popular and fast-moving field, and the content itself misses out on the huge progress achieved in the last ten years, particularly due to the *Kepler* space telescope. A third issue is that gravitational waves are not mentioned (at least not in the index and other obvious places). Many undergraduate students would chafe at this treatment.

My other major gripe with Ryden & Peterson is the brevity of the discussion of many research topics. Orbital mechanics, the Solar System, and stars are awarded many pages. More large-scale concepts, such as galaxies and cosmology, are left to the last part of the book (as they should be) and covered quite briefly (as they should not be). This approach is justified in the preface but nevertheless renders the book slightly unbalanced.

So how does Ryden & Peterson stack up against its competitors? The obvious yardsticks are *An Introduction to Modern Astrophysics* (Carroll & Ostlie) and *Universe* (Freedman & Geller). The current pandemic means I have no access to a recent version of the latter so must restrict my discussion to the former. Carroll & Ostlie is a bit more expensive (£75) than Ryden & Peterson (£60) but much heftier (1400 *versus* 600 pages). It provides a more expansive treatment of those areas skimmed by Ryden & Peterson, and a similarly good exposition of the other topics. However, it also has inadequate information on extrasolar planets (nine pages) and gravitational waves (two mentions) — perhaps I was expecting too much?

A few spot checks on particular topics revealed that Carroll & Ostlie tends to be more comprehensive but Ryden & Peterson is more readable. Both tomes are sufficiently tome-y to take out a glass of wine should the casual (drinking-age) reader forget to apply their knowledge of classical mechanics whilst flicking through the pages. Carroll & Ostlie would likely also disperse a couple of pints of beer with ease, although for once this reviewer felt compelled to let a prediction remain testable but untested. One should not mix wine and beer, especially near electronic devices and a thick carpet.

In summary, Ryden & Peterson provides a very nice treatment of some areas of astrophysics but is rather too brief in others. It is written clearly and engagingly and will be suitable for quite a few modules in a typical undergraduate degree. But the greatly superior content of Carroll & Ostlie more than offsets the 25% higher price charged for that barn-door stopper. Carroll & Ostlie remains the industry standard that I will continue to recommend to my undergraduate students. — John Southworth.

Numerical Methods in Physics with Python, by Alex Gezerlis (Cambridge University Press), 2020. Pp. 586, 25 × 18 cm. Price £39·99/$49·99 (paperback; ISBN 978 1 108 73893 4).

As a subject, numerical methods can be very dry and too mathematical for some physics students, or just something that uses pre-built libraries as closed boxes with scant regard for how they work and, more importantly, their limitations. This book bridges the two by providing the mathematical background and computer code written to show how the many algorithms can be implemented using standard python.

A chapter starts with the motivation behind the topic giving some physics examples and ends with an in-depth exploration of how the techniques covered can be applied to a physics topic. The end-of-chapter problems provide a good mixture of mathematical and python questions, all well thought out to demonstrate many of the issues and pitfalls one faces when using numerical techniques. As is common these days, instructors can thankfully obtain solutions from the publisher's website.

Introduction to python this book is not, nor intended to be, but the first chapter does give a good overview. Extra material is available from the author's own website (https://numphyspy.org/) in the form of Jupyter notebooks. The book starts with pure python, then moves to using NumPy arrays, very aptly, in the chapter on matrices.

The second chapter on number representation and rounding errors is something we should all take heed of, with some very salient points on the dangers of the finite precision of floating-point numbers. Some good examples are given on how formulae can be rearranged to mitigate against some of these issues.

There is very comprehensive coverage of the mathematics underpinning many of the commonly encountered numerical methods. The code presented is clear and well crafted, building on earlier examples in the book to produce relatively short codes that can be readily digested. That they are given in just a single page is very good. As such the author does not use any SciPy implementations of numerical algorithms, but this is a considered and good pedagogical choice to force understanding behind the algorithms. Once understood one could move to pre-built routines with more confidence of how they work.

The quest for brevity in the codes does, on occasion, lead to imports from an earlier script, not of the numerical routines, but of example functions being solved. For the sake of a few extra lines of code, these equations could have been included in script. This can be mildly annoying.

The book has a very readable style with clear explanations of the topics — an almost relaxed style with the author's obvious enthusiasm for subject. As one would expect, all the classical numerical methods are well covered, but also some Monte Carlo methods, giving a helpful introduction to modern techniques that are now widespread in physics and beyond.

This is quite a weighty tome but recommended to anyone interested in, or studying, numerical methods at undergraduate level and beyond. — Barry Smalley.

Annual Review of Earth and Planetary Sciences, Volume 48, 2020, edited by R. Jeanloz & K. H. Freeman (Annual Reviews), 2020. Pp. 683, 24 × 19·5 cm. Price from $496 (print and on-line for institutions; about £385), $118 (print and on-line for individuals; about £92) (hardbound; ISBN 978 0 8243 2048 5).

A welcome read for a dismal year, from where I stand, locked down in Palo Alto for the last nine months.

The majority of the reviews in the 2020 volume focus on seismology and related subjects (including earthquakes, tsunamis, the lower mantle, and heterogeneity of the solid Earth) and the environment (including mass extinctions), seasoned with the odd goodie on space-related subjects (meteorites, the structure of Jupiter) and plate tectonics (during the Archean, no less).

The chapters on earthquake seismology include reviews of the state of stress on faults throughout the earthquake cycle, deep earthquakes, slow-slip events, and the effects of the 2011 Tohoku-Oki earthquake. These are underpinned by updates on fundamental related issues that have enjoyed substantial advances recently, including lower-mantle minerals and the heterogeneity of seismic wave speeds in the mantle.

The review by David Stevenson of our knowledge of Jupiter's interior, as revealed by the current state of play of the still-on-going *Juno* mission, is timely given recent speculations on the possibility of life on Venus and our old best-bet Mars. The interior of Jupiter is more complex than simply solid-state hydrogen and contains also at least some heavy elements. Back on Earth, the Solar System is studied using Antarctic meteorites, the inventory of which continues to expand, including samples from both Mars and Moon.

The large category of chapters on climate and climate-related topics cover glacier change, palaeoclimate, climate extremes and related hazards, moist heat stress, and past and present large extinctions. A fascinating chapter on extinct South American ungulates (hooved mammals, including horses, rhinoceroses, cattle, pigs, giraffes, camels, *etc.*) brings home the enormity of what we have lost — this little-known (to some) extinct group included 50 families, over 250 genera, and many hundreds of species. A chapter on the ecological response of plankton to environmental change bridges the subjects of climate change and extinctions.

The final chapter, on the subject of 'carrying capacity', invites immediate inspection if only to find out what that means. It refers to the ability of planet Earth to sustain the exploding consumption and waste of the 'Human System'. The paper models the extremely complicated system of interactions and feedbacks between humans and other planetary systems and phenomena. The reader will not be surprised to hear it is all a disaster, going to get worse, and will end in catastrophe, but this is something easier to understand at the end of 2020 than it might have been a year earlier.

On the first day of the New Year, that is probably an appropriate place to stop. — Gillian Foulger.

Annual Review of Astronomy and Astrophysics, Volume 58, 2020, edited by Ewine F. van Dishoeck & Robert C. Kennicutt (Annual Reviews), 2020. Pp. 789, 24 × 19·5 cm. Price from $496 (print and on-line for institutions; about £367), $118 (print and on-line for individuals; about £87) (hardbound; ISBN 978 0 8243 0958 9).

The opening chapter of this year's *Annual Review* is an autobiography of James Gunn. In my little world of binary stars and radial velocities I was of course aware of Gunn's work with former Editor of this *Magazine* Roger Griffin, but I had no real idea what an amazing polymath he is, both as a practical instrumental astronomer and theoretician, as exemplified by his lead in the Sloan Digital Sky Survey; it's a really inspirational story.

If one word can sum up the research described in this weighty volume, it must be 'formation'. Black holes are first on the menu with a discussion of how the most massive ones (up to $10^9\ M_\odot$) may have been created, and a later chapter details searches for their smaller relations (10–$10^5\ M_\odot$). Black holes surely also have a role in AGN whose jets and discs are considered to be shaped by magnetic fields.

Star formation features in several chapters, starting with three close examinations of the interstellar medium which provides the material (in one of which the 2200Å bump I well remember from *IUE* days puts in an appearance), and following on with the chemical evolution within stars and the development of proto-planetary discs. These deliberations lead naturally on to galaxy formation which is examined locally with *Gaia* data on the early history of the Milky Way, star-forming galaxies at $z \sim 2$, and what can be gleaned at high redshift from the ubiquitous Ly-α line. These studies demonstrate the enormous leaps in observational power through such devices as integral field spectrographs.

The Sun gets a mention when observations of MHD waves in the corona provide a free laboratory for plasma physics; and the role of astronomy in education rounds out another successful compilation. — David Stickland.

Open Skies: The National Radio Astronomy Observatory and its Impact on US Radio Astronomy, by Kenneth I. Kellermann, Ellen N. Bouton & Sierra S. Brandt (Springer), 2020. Pp. 652, 24 × 16 cm. Price £44·99/$59·99 (hardbound; ISBN 978 3 030 32344 8).

At a small meeting of the US National Committee of the International Union of Radio Sciences (URSI) convened in Washington DC on 1933 April 27, Karl Jansky (1905–1950) announced that the centre of our Milky Way is a source of cosmic radio noise. A radio engineer at the Bell Laboratories, Jansky had first noticed the source of static early in 1932, and throughout the year he meticulously observed it. By December 1932 he could inform his father that "the stuff, whatever it is … comes from outside the solar system." Within a week of the presentation in Washington, Bell Labs ramped up the publicity, resulting in coverage in the *New York Times* and international newspapers. Jansky's fundamental discovery in physics was not followed up by the astronomical community in the US. In the first decade following WWII there was no national campaign in the US for radio astronomy, whereas the physicists and radio engineers in Britain, Australia, and the Netherlands were by then well ahead in the 'cosmology game'. But not forever.

The National Radio Astronomy Observatory was established in 1956, its purpose being to make available to scientists from any institution facilities for research in radio astronomy. The instrumentation provided was too costly for any individual universities to develop, build, and operate. NRAO quickly developed an open cooperative culture, rolling out a visiting-scientist programme in late 1959. This history spans six decades of discovery. The authors have diligently mined the vast archives of NRAO and many other institutions. The huge volume's organizational structure is not strictly chronological, adopting instead chapters of about 50 pages for each major area of NRAO's contributions. This results in a beautifully vivid narrative bringing readers, general and professional, closer to the action, the pioneers, and their discoveries. Many photographs not seen before in the public domain add interest. Notes and bibliographies at the end of each chapter will effortlessly guide future scholars. A handy timeline of NRAO history features in an appendix. The comprehensive index runs to 20 pages. *Open Skies* is Open Access: sharing and distribution allowed, in any medium subject to appropriate credit. It is a remarkable example of how to make an informative and accessible history of a scientific or technical institution that goes way beyond being 'for the record'. It is a landmark publication in the history of modern astronomy, a true masterpiece exhibiting the highest standards of scholarship. — Simon Mitton.

NASA's First Space Shuttle Astronaut Selection: Redefining the Right Stuff, by David J. Shayler & Colin Burgess (Springer), 2020, Pp. 589, 24 × 17 cm. Price £24·99/$37·99 (paperback; ISBN 978 3 030 45741 9).

In pre-Apollo days the Project Mercury astronaut Gordon Cooper Jr. (1927–2004), the first American to spend an entire day in space, said "All this talk about brains (*i.e.*, scientists) and dames in space is bunk. As for the ladies, to date there have been no women — and I say absolutely zero women — who are qualified to take part in our space programme". Well thank goodness this attitude changed quickly. And this book is about that change.

The USA's National Astronautics and Space Administration have a great love of acronyms, and Shayler and Burgess, who, in the human space-exploration field, are well-known experts and prolific authors, present us with nearly 600 pages on TFNG.

TFNG stands for the 'thirty-five new guys' who were selected in 1978 January to fly on the Space Shuttle. Gone was the insistence on astronauts being 'The Right Stuff', a gang of heroic, macho, military test pilots who initially went into orbit and to the Moon. This new group of 35 'guys' contained twenty who were 'merely' mission specialists. These were non-pilots who could even be women or from the minorities. They did however have to have doctorates, mainly so that NASA were able to cut down the number of applicants to 8079. In fact six *were* women and four were from the minorities. NASA came of age in the late 1970s. For the very first time in the history of the space agency, women and minorities were not only eligible to apply to be astronauts, they were actively encouraged to do so.

Shayler and Burgess follow the space careers of the thirty-five new guys in great detail. We are presented with potted histories of their early lives, their university qualifications, and their motivations. Much time is spent investigating the details of their NASA training. Most have been interviewed. Oral histories have been consulted. We are presented with an in-depth history of the 35 brave, clever, and dedicated people who initially flew the Space Shuttle. The book does much more than concentrate on their successes. There were also frustrations. Disasters like *Challenger* and *Columbia* did not help, especially as they exposed the badly rushed launch schedule that was often coupled with chronic complacency, arrogance, and systematic smugness. It was clearly not easy working on a key-stage of space exploration that never quite lived up to expectation.

What I specially liked about this book was its emphasis on intricacy and detail. The stories were well told, well-illustrated, well referenced, and never dull. I have often been asked if, given the chance, I would go into space. I always respond by saying that I would be far too frightened. After reading Shayler and Burgess, I still am, but I now know why. — David W. Hughes.

The Artemis Lunar Program: Returning People to the Moon, by Manfred 'Dutch' von Ehrenfried (Springer), 2020. Pp. 307, 24 × 17 cm. Price £24·99/$34·99 (paperback; ISBN 978 3 030 38512 5).

In 2017 December US President Donald Trump launched his 'Space Policy Directive 1' which (once again) re-directed NASA's human space programme towards the Moon. In 2019 May this programme, to land "the next man and the first woman" on the Moon by 2024, was named Artemis after the twin sister of Apollo and, *inter alia*, the lunar deity in Greek mythology. Artemis is the third serious proposal by a US Administration to return astronauts to the Moon since the Apollo missions (following in the footsteps of the Space Exploration Initiative and Constellation programmes of Presidents George H. W. and George W. Bush, respectively), and it is too early to tell whether it will fare any better; certainly the 2024 date for the first lunar landing is generally considered wildly optimistic. Nevertheless, the origins, proposed architecture, and present status of the Artemis programme will be of great interest to space enthusiasts (and lunar scientists!), and this slim book by Manfred 'Dutch' von Ehrenfried aims to provide this information for its readers. As a NASA insider, who worked on US human space missions from the beginning, with Project Mercury through to *Skylab*, von Ehrenfried is well-placed to take stock of the Artemis programme as it gathers momentum.

The book focusses almost entirely on the technical aspects of Artemis (*i.e.*, proposed launch vehicles, crew capsules, landers, power sources, radiation protection, spacesuits, *etc.*), and the overall mission architecture that will exploit the proposed *Lunar Gateway* space station to be placed in orbit about the Moon. The discussion of these technical elements is comprehensive and informative. I learned interesting things from these sections, especially with regard to the rather unusual 'near rectilinear halo orbit' proposed for the *Gateway* and some developments in nuclear power and *in-situ* resource utilisation (ISRU) concepts of which I was unaware and glad to learn about. There is especially good coverage of likely commercial contributions to the Artemis programme, which will be a significant difference from Apollo and probably very enabling both financially and politically. There is rather less coverage of the likely international contributions, although ESA's contribution of the *Orion Service Module* to at least the first few Artemis missions, and Canada's contribution of a robotic arm (*Canadarm-3*) to the *Gateway*, are duly covered.

There are short discussions on both the scientific objectives of Artemis and its political context, but I think that both deserved greater emphasis. The scientific benefits of returning to the Moon seem obvious enough (see, *e.g.*, the report of the Artemis Science Definition Team*), but given that all previous attempts to return to the Moon in the last half century have failed for political rather than technical reasons I do think this aspect deserved more attention. Although when it was written the outcome of the 2020 US election was unknown, it was certainly known that an election was imminent and so some discussion of how the programme might fare given a change in Administration would have been interesting. Still, I accept that the author has a technical rather than a political background, and that discussion must now wait until we see whether or not Artemis is continued by the Biden Administration and, if so, on what time-scale.

I found the book to be generally well-written, but feel that it could have been better referenced. For example, there is a long list of technical NASA reports cited in the reference section, but the usefulness of these is limited by a lack of internet links or any other means for readers to access them. On the other hand, one novel feature that I did find helpful was the inclusion of numerous links to relevant YouTube videos; although it was a bit annoying having to type in the rather long URLs, the videos that I watched were very informative and I doubt that I would have found them otherwise. My only real gripe with the book is that, as is often the case for books written by an American author with a US readership largely in mind, the use of units is often an inconsistent mixture of metric and imperial systems. Generally, metric units are provided followed by imperial values in brackets, although this hasn't been applied consistently and there are some errors (*e.g.*, on p. 19 where 726,000 kg is said to correspond to 72·6 tons, and p. 52 where 96·35 mm is equated to 0·25 inches; let's hope that similar errors aren't made in constructing the Artemis hardware ...).

Overall, I was glad to read this book, and I learned some new things from it. I am happy to recommend it to anyone interested in a brief summary of the technical aspects of the Artemis programme as conceived in its early years. For the sake of lunar and planetary science, we can only hope that the programme survives and that more detailed histories, both technical and political, of the long-awaited human return to the Moon will be written in the coming decades. — Ian Crawford.

*Available at https://www.nasa.gov/news/reports/index.html

The Large-Scale Structure of the Universe, by P. J. E. Peebles (Princeton University Press), 2020. Pp. 422, 23·5 × 15·5 cm. Price £50 (paperback; ISBN 978 0 691 20983 8).

Principles of Physical Cosmology, by P. J. E. Peebles (Princeton University Press), 2020. Pp. 718, 23·5 × 15·5 cm. Price £62 (paperback; ISBN 978 0 691 20981 4).

Quantum Mechanics, by P. J. E. Peebles (Princeton University Press), 2020. Pp. 419, 23·5 × 15·5 cm. Price £66 (paperback; ISBN 978 0 691 20982 1).

I doubt that there was any cosmologist who was not delighted when they heard the news that Jim Peebles had been awarded the Nobel Prize for Physics in 2019. Throughout the careers of most of today's cosmologists, Jim has been a towering figure, as well as being a generous and gentlemanly scientist. In celebration of his prize, Princeton University Press has issued three of his famous books in matching paperback format. *Quantum Mechanics* is a delightful book, but since the books celebrate his prize, let me focus on the cosmology texts. *The Large-Scale Structure of the Universe* was first published in 1980 and is full of technical detail that provided the main training for who knows how many generations of cosmologists, and it is still a book that rewards with its insight and with the rigour that it instils. It is a book to dip into — to understand a technique or study a topic, and my well-read and battered copy dating from 1980 has always been a favourite. *Principles of Physical Cosmology* is more comprehensive and more suitable for reading from cover to cover, and gives a wide-ranging view of cosmology in the early 1990s. The world-view of 1993 is interesting retrospectively, since much has changed, including strong evidence for cosmic acceleration, and the book was written at a time when Peebles was not sure that the ΛCDM theory was a good description of the Universe, despite it being so much his own. A great addition to the book is the transcript of his Nobel lecture, which is a fascinating read, and a record of his remarkable role in building today's standard model of cosmology. — Alan Heavens.

Radio: Making Waves in Sound, by Alasdair Pinkerton (Reaktion Books and the Science Museum, London), 2019. Pp. 240, 20·5 × 15 cm. Price £18/$20 (hardbound; ISBN 978 1 78914 078 1).

We astronomers have our own historians of radio astronomy. Think of looking for books and articles with authors like James Stanley Hey, Henk C. van de Hulst, Kenneth Kellermann, Woodruff T. Sullivan III, and Wayne Orchiston. Here, however, is a micro-history, from Jansky's merry-go-round *via* Penzias and Wilson, Lovell, the Parkes dish, Arecibo of blessed memory, and the coded message it sent to M13 in 1974, to the *VLA*, the *Giant Meter Wave Radio Telescope* in Pune, and the *Spectral RadioHeliograph* and *FAST* in China. You are somewhat unlikely to learn anything new from this treatment, indeed you may have to do a bit of unlearning of statements like "quasars and radio galaxies are undetectable by optical astronomy".

But there is much fun to be had. We meet Queen Victoria in 1898, exchanging Morse code Marconigrams with Prince Edward on board ship. The first musical broadcast in Britain was Dame Nellie Melba in 1920. Caruso, a decade earlier, from the stage of the Metropolitan Opera, assisted by Lee deForest does not make the cut.

Moving closer to the present, you probably already know that the Volkswagen was not ready to *wagen* the *volk* until after World War II. The *Volksempfanger* (People's Receiver), on the other hand, enabled the *volk* to *empfangen* the words of the Führer from 1936 onward. Jump forward again to 1960, to find Sir Robert Watson-Watt (titular inventor of radar) driving briskly through Canada, pulled over and fined for speeding. His reaction? "My God! If I'd known what they were going to do with it, I would never have invented it!"

Incidentally, the current Chicago catalogue [in which Dr. Trimble found this book — Ed.] has several other books that touch on astronomy in interesting ways. Matthew Shindell's *The Life and Science of Harold C. Urey* (University of Chicago Press, 2019) introduces its readers to the discoverer of deuterium, and where would we be without it in trying to constrain the baryon density of the Universe! David Kaiser's *Quantum Legacies* (University of Chicago Press, 2020) also has gravitational waves, Hawking radiation, and various assaults on the cosmic microwave background (although the *Planck* image in black and white is singularly uninformative). Alberto A. Martinez points out in *Burned Alive* (Reaktion, 2018) that Giordano Bruno was accused of no fewer than 54 heresies. Recanting many, he held by multiplicity of inhabited worlds, was indeed executed for heresy, and was one of only two individuals burned alive (*vs.* hanged, *etc.*) among 189 executions in Rome, 1598–1604. The other heretic burned was probably Celestino Arrigoni, who had actually been one of the witnesses against Bruno, and is considerably less well known these days. David Cahan's *Helmholtz* (University of Chicago Press, 2018) also dabbled in astronomy, but only for about 21 scattered pages out of 937. — Virginia Trimble.

Other Books Received

Astronomy Education, Volume 2: Best Practices for Online Learning Environments, edited by Chris Impey & Matthew Wenger (IoP Publishing), 2020. Pp. 155, 26 × 18·5 cm. Price £75 (hardbound; ISBN 978 0 7503 1717 7).

At a time when the coronavirus is still having a severe effect on schools and universities, on-line learning is very much in evidence, and this book is a very up-to-date and comprehensive guide to how it is best approached, particularly for astronomy.

Introduction to Stars and Planets: An Activities-Based Exploration, by Alan Hirshfeld (IoP Publishing), 2020. Pp. 171, 26 × 18·5 cm. Price £120 (hardbound; ISBN 978 0 7503 3689 5).

An excellent primer for early-years undergraduates, this book contains a large number of short chapters on the Sun, stars, and planets, each followed by a number of exercises in the form of worksheets for the student. It could reasonably be used by individual students (especially in the current covid crisis) or by teachers to supplement their lessons.

OBITUARY

Derek McNally (1934–2020)

Derek McNally was an editor of this *Magazine* from 1961 to 1963, starting shortly after joining UCL as a lecturer. Supervised by Bill McCrea, his PhD, on 'Problems of interstellar and intergalactic matter', was as wide-ranging as the title suggests, and set in place the principal research interests that occupied him in the following years: star formation, and the interstellar medium (in particular, diffuse interstellar bands).

His lasting legacy, however, results primarily from the enabling and community roles in which he served. He was active in the RAS, as Secretary 1966–1971, Vice-President 1971–1972, and Treasurer 1996–2001. His interests in education were reflected nationally in his Presidency of the Junior Astronomical Society*, 1981–1983, and on the international stage with the Presidency of IAU Commission 46, 'Astronomy Education & Development', 1973–1976. He went on to become IAU General Secretary 1988–1991 (with associated positions in the preceding and following triennia), introducing the structural framework of Divisions. As a vigorous advocate for the preservation of the astronomical environment, he edited the book *The Vanishing Universe* (1972), became Chairman of the ICSU Working Group on Adverse Environmental Impacts on Astronomy, 1993–1997, and went on to chair the IAU Working Group of the same name, 1997–2000. Asteroid 4326 McNally is named in recognition of his contributions.

I first encountered Derek when, as an undergraduate, I attended his lecture course on 'Positional Astronomy'. It must be admitted that the course was no more engaging than the subject may suggest, although with hindsight it was pioneering in its way, with Derek's accompanying textbook being one of the first to be illustrated with precise, computer-generated diagrams of spherical trigonometry. It was only later, when we became colleagues, that I came to recognize what a warm and supportive man he was. His dry and self-deprecating humour comes through in his account of 'Life as IAU General Secretary', where he recollects events of 'his' IAU General Assembly, no. XXI, held in Argentina in 1991, not so very long after the Falklands War (I can imagine him playing heavily on his *Irish* ancestry), involving a welcoming speech by President Menem (apparently blithely unaware of any distinction between astrology and astrophysics), and now perhaps most remembered for the infamous fire at the venue earmarked for the high-profile presentation of the first *HST* results.

Derek was born in Belfast 1934 Oct 28, graduating from QUB with a BSc in 1956 and an MSc in 1957. He then migrated to Royal Holloway, obtaining his doctorate in 1961 (and marrying his wife, Shirley, in 1959). He joined the UCL Astronomy Dept. at the University of London Observatory†, Mill Hill, in 1960, and was based there throughout his career, excepting a Fellowship at Yerkes, 1963/4. He was appointed Assistant Director at the Observatory (under the Perren Professor, C. W. Allen) in 1966, and was Director 1986–1997, a title reflecting the *de facto* role he had played for some considerable time previously. On retirement, in 1999, he took up a visiting fellowship at the University of Hertfordshire. A regular swimmer, he was fit and vigorous for most of his life, enjoying recreational interests in archaeoastronomy, travel, geology, birdwatching, and walking. Only towards the end of his life did he become physically and mentally frail, suffering a severe stroke in summer 2019. He died peacefully on 2020 May 15 after testing positive with COVID-19, and is survived by his daughter and son, Candida and Donal. — IAN HOWARTH.

*Now the Society for Popular Astronomy. †Now UCL Observatory.

Here and There

A SPECTRAL EVENT?

1970: Enrico Fermi 1st demonstrates nuclear chain reaction in Chicago — *2021 Calendar of the American Association of Physics Teachers*, page for December.

BACK TO THE FUTURE

... the platform [of the Arecibo telescope] falling catastrophically into the dish below on 1 December 2021. — *Astronomy Now*, 2021 January, p. 15.

WE'RE MORE IMPORTANT THAN WE REALIZED

... and the New Moon occurring when the Earth casts a full shadow over the Moon. — *What Does Rain Smell Like?*, 535 Books, 2019, p. 48.