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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2022 April 22 at 16^h 00^m

STEVE MILLER, *Vice-President*
in the Chair

The Chair. Good afternoon everyone, I hope you can hear me. For those of you who don't know me, my name is Steve Miller and I'm currently one of the Geophysics Vice-Presidents of the Royal Astronomical Society, and I'm chairing this meeting because neither our President nor our Vice-President Elect is available today. This meeting is taking place *via* a webinar. If you look at the top left of your screen you should see a small green shield and that will tell you that you're using the most up-to-date version of Zoom and that it is secure. The meeting is being recorded — you should all have been given notice of that. Questions at the end of the lecture, which I'll be introducing shortly, can be submitted by the chat facility found at the bottom of your screen. Your questions will only go to the panellists and they will then be read out by Council member Dr. Belinda Wilkes.

Today we have Dr. Sanne Cottaar of the University of Cambridge. She will be delivering the Harold Jeffreys Lecture for this year. After studying geophysics at Utrecht University, Sanne completed her PhD at the University of Berkeley, California, in 2013, on 'Heterogeneity and Flow in the Deep Earth'. She then became a postdoctoral researcher at the University of Cambridge funded by a Drapers Company Research Fellowship from Pembroke College. In 2015, she became an Assistant Professor at the University of Cambridge in global seismology. Currently, Sanne holds an ERC Starting Grant to zoom in and understand the Earth's major internal boundary, the core–mantle boundary. So Sanne, over to you.

Dr. Sanne Cottaar. [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*. The core–mantle boundary (CMB) lies roughly halfway to the centre of the Earth and divides the metallic core from the rocky mantle. The boundary also divides two very different regimes of convection: the turbulent convection in the liquid outer core, *i.e.*, the geodynamo that causes Earth's magnetic field; and the convection of the solid mantle on geological time-scales, responsible for plate tectonics and intra-plate volcanism. The CMB interface plays a major role in coupling thermal, chemical, and dynamical processes on either side. Little is known about these interactive processes and their spatial and temporal variation, mostly because of our limited knowledge of heterogeneous structures on the CMB.

Seismology is the main technique to image the CMB structure. Seismic waves have shown ultra-low-velocity zones (ULVZs), which are thin, anomalous patches of extremely slow seismic velocities on the CMB. In my talk I show evidence for the presence of ULVZs and explain how we map them and determine their internal structure. I also discuss their potential relationship to surface volcanic hotspots and speculate on their nature and origin.]

The Chair. Sanne, thank you very much indeed for that. That was absolutely fascinating. Belinda should have been following the questions coming into the chat and I also see there is another little button called Q&A. There seem to be 14 comments in the chat and two in the Q&A, but I'm going to hand over to Belinda to sort out exactly what's what and to put the questions to you. Thank you again.

Dr. Belinda Wilkes. Yes, thanks Sanne, that was fascinating, particularly for an astrophysicist like myself, looking down instead of up, especially how you do these observations. There's one question in the Q&A, which I'll do first, and then I'll go back to the chat. It's from Summer Gelacey who says: "Could the ULVZs be the non-mixed remains of Theia?" I don't know what that is, but maybe you do.

Dr. Cottaar. I'm not entirely sure what it is, but it might be an impact. There are some ideas that the material that sits around here is left over from a meteorite impact or the core of a meteorite impact that has left-over material at the top of the outer core of the ULVZ — which is, I guess, another potential anomaly, and we could also have similar isotopic signatures that could be being entrained in the mantle plumes here. I hope I interpreted that question correctly.

Dr. Wilkes. Me too! In the chat, there are several questions from Jeffrey Greenspan. I'll take the first and then see if there are some other questioners before going further down. So his first question is: "What are relative rates of reactions between the mantle and outer-core *versus* the rate of upward migration through the mantle? Do differences in these rates influence properties such as magnetic field or seismic activity?"

Dr. Cottaar. Concerning the heat-flux rate, any lateral variations definitely have an influence on the magnetic field and magnetic-field generation. In terms of material, flux is actually quite unknown and is quite debated. And it's even debated in what direction material is fluxing or going from the mantle to the core or the other way; I think you can make it go both ways, as far as I understand this field. One may also ask, if that reaction happens, whether you can entrain it away from the core–mantle boundary, or if you just end up with a thin layer of crust and that remains stable over time; so people have been looking at morphological instabilities to cause this flux of material or cause outer-core material to be trapped within the mantle. But there's a lot of uncertainty on this and uncertainty within the flux, so it's really still speculation as to what fraction of this is coming from the core and if it can be entrained from ULVZs in these mantle plumes. This whole dynamical picture is not fully constrained.

Dr. Wilkes. There's a question from Jack Moore who says: "Thanks for the great talk. About the potential for melt at the CMB, could I ask what the implications would be for reflection/transmission coefficients of CMB interacting phases?"

Dr. Cottaar. Yes, it would be a variable. And we did look into this, but then the ScS waves wouldn't really be sensitive to it, because it would just observe a liquid, but PcP would; these are the longitudinal waves that reflect off the core. They are very, very tricky waves though, because they are quite small in amplitude and we've found so far in studies that the amplitudes vary massively, and so I think you can easily hide a fuzzy boundary within this. The other thing that I've glossed over is obviously the topography on these boundaries, which also affects the amplitudes. And the observations are so varied that you can hide all sorts of these layers in here. This is why we were really trying to find a probe that had travel times and which was a bit more robust than looking at amplitudes. But the predictions would surely change with a fuzzy boundary for the longitudinal waves.

Dr. Wilkes. Another one from Cyodie Agboola who says "Thanks for the lecture. Aside from the high resolution of the bracket S waves, are there any other reasons for this floating seismic phase over other seismic phases such as ScS, ScP, PcP, *etc.*?"

Dr. Cottaar. These are waves that have reflected off the boundaries and they do get used to look at the ULVZ; we have used these waves that cause little reflections off the top of the ULVZ. But the vertical travel times in these ULVZs are quite minor, so when you use these phases, they are only a couple of seconds apart, and you have to go to quite high frequencies to differentiate these pre- and post-cursors in phases. And they're actually quite weak in amplitude as well, so when you use these phases, we typically have to stack multiple seismograms together to see it. I actually think an advantage of the shear-diffracted waves is that we can see these in the broad data that is quite unique for seismic, we don't have to do any data stacking to bring it out; and you can see these normally and they are delayed by 30–40 seconds, so much more than the couple of seconds that you would get for vertically propagating waves. But then again, the vertical ones would have a very different resolution, and different trade-offs. So ideally we could combine these two phases in some way, and we have looked at ScS waves on Hawaii, and see that they do have evidence for much more morphology in these ULVZs than the diffraction waves can see because they just average over the full structure; and so I think the combination of these will surely be needed really to understand the ultra-low velocity zones.

Dr. Wilkes. Another one from Jeff Greenspan, "Is the upper part of Earth's outer core dissolving the lower part of Earth's mantle?"

Dr. Cottaar. Because these are iron-enriched, there is a thought that the iron cannot go in, iron cannot remain there but will go into the outer core. Or is it the other way? So that is really another difficult question and thinking that there might be a dense primordial layer at the base. There's a problem for mineral physicists.

Dr. Wilkes. There's one from AC: "Are magnetic-field anomalies such as the South Atlantic Anomaly correlated with any of these features?"

Dr. Cottaar. I don't think there's a direct correlation, but there are attempts to understand what kind of heat-flux variations arise from having these piles of anomalies and also having cold slabs hit the core–mantle boundary where there can be a higher heat flux; and what effect that has on the overall convection patterns in the mantle and what the magnetic field would observe. But there is a general problem that computationally we cannot fully model how vigorous that convection is — it's just too big a computational problem, and so there are these open questions about how it behaves. Also, how our magnetic field flips around and if this is also correlated with how flux variations are at the core, at the boundary. So while we see enough evidence that there is a connection between these two, it's not fully understood, but I know there is some research that is trying to explain the South Atlantic Anomaly due to what is happening on the mantle side.

Dr. Wilkes. I'll go down to Jeff Greenspan's next one: "How do characteristics of the Earth's core–mantle boundary affect reversals of the magnetic field?"

Dr. Cottaar. That is potentially related to these heat-flux variations and there has been some research showing that there's a correlation with times when more slabs are arriving at the core–mantle boundary, potentially causing an increase in reversal. The reversals and the relationship with this, as far as I'm aware, is not fully understood.

The Chair. So, Belinda, I'm having to keep an eye on the time for this meeting. I think Sanne has answered a lot of questions already, but I wonder if you could pick out just one final question for Sanne before we say thanks very much again and let her go.

Dr. Wilkes. A second one from Cyodie Agboola is: "What is the origin of the mega-ULVZ in your study? Is it a thermal or compositional anomaly? Or probably a combination of both?"

Dr. Cottaar. Well, I don't think it can just be thermal. The seismic velocities are just too extreme that we cannot explain it with temperature that the outer core would have. So it has some compositional components of iron being a prime candidate for that. As well as that, the boundaries are quite sharp to cause these waves to be trapped and so there has to be some sort of compositional boundary and can be a fuzzy thermal boundary. But once it's compositional, it has to be a combination of both — since this anomaly sits on the core it will heat up, so it will also be quite hot, so some of that velocity reduction is heat and some of it is compositional anomaly.

The Chair. Thank you all for the questions. An absolutely fascinating talk and thank you very much indeed again, Sanne. I just want to remind everybody that the AGM is on Friday the 13th of May at 4 pm. Finally I give notice that the next monthly A&G Open Meeting of the Society will be on Friday the 7th of October; that seems an awfully long way off, and maybe we can all actually physically get together by then. But thank you all very much indeed for coming along and for your attention, and with that I will end the meeting.

CORNISH ASTRONOMERS IN THE ASTRONOMICAL SOCIETIES 1820–1920

Steven Phillipps

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Historically Cornwall was dominated by the copper- and tin-mining industries and its science was equally dominated by geology and engineering, with apparently little time spent looking up rather than down. Alan Chapman's book *The Victorian Amateur Astronomer*[1], for instance, makes no reference to Cornish amateur observers (though two professionals originally from Cornwall appear). There are only four mentions of Cornwall in the *Biographical Dictionary of Astronomers*[2] (one of them to Sir William

Lower of St.Winnow, who was a friend of Thomas Harriot and a pioneer telescopic observer in 1610). Nevertheless, further Cornish men and women and others living, at least temporarily, in the county have displayed an interest in astronomy. In the present paper, we review those with connections to the major national astronomical societies, the Royal Astronomical Society (RAS) and the British Astronomical Association (BAA) — with some detours into the Royal Society and elsewhere — in the century from the formation of the RAS in 1820.

Antecedents

Prior to the formation of the RAS (originally as the Astronomical Society of London) in 1820, the foremost repository for astronomical research was the *Philosophical Transactions of the Royal Society*. The first Cornishman to make such an astronomical contribution appears to be the Hon. Francis Robartes, who was baptised at Lanhydrock, near Bodmin, in 1650, the son of the Earl of Radnor. He served as an MP for a whole succession of Cornish constituencies from 1673 (Bossiney) to 1718 (Bodmin)[3,4], though spending much of his time in Ireland on parliamentary business. He was particularly active in the Convention of 1688 which legislated the replacement of James II by William and Mary following the 'Glorious Revolution'. Also a noted composer and scholar, he was elected a Fellow of the Royal Society in 1673 due to his interest in the theory of sound, and was twice a vice-president of the Society (1704 and 1717). His single astronomical paper, read to the RS in 1693 November[5], was 'Concerning the Distances of Fixed Stars', in which he correctly deduced a minimum distance to Sirius from "Monsieur Hugens"'s inability to resolve stellar discs even with his largest magnification telescopes and the assumption that stars are "generally of the bigness of our Sun". (Note that he published his papers as 'Roberts'.) In 1704, Queen Anne's consort, Prince George of Denmark, selected Robartes as one of the referees[6] for the planned, and ultimately highly contentious, publication of Astronomer Royal Flamsteed's observations and star catalogue in *Historia Coelestis*. Flamsteed, who feuded with the other two main protagonists, Newton and Halley, considered that "Mr Roberts was an easy, good-natured man, but knew little of the business".

The Rev. Richard Haydon (1706–1788) was born in Devon, but after obtaining his BA at Oxford in 1729 and MA at Cambridge in 1738 he became headmaster at Liskeard Grammar School for many years. He was later in holy orders back in Devon[7]. A noted mathematician as well as astronomer, he observed the 1761 transit of Venus as recorded in a letter sent from "Leskeard" to "John Bevis. Doctor of physic" which was published in *Philosophical Transactions*[8]. Bevis notes that Haydon's observations were "the best circumstanced of any I have yet seen made in England" and had been made "with a telescope of Mr. Short's, armed with Mr. Dolland's new micrometer". (Bevis, incidentally, was the discoverer of the Crab Nebula.)

The next transit in 1769 was observed by another Cornishman, Rev. Malachy Hitchens (1741–1809)[9], though from the Royal Observatory, Greenwich. Hitchens (often, but most likely incorrectly for a Cornishman, rendered as Hitchins) was born at Little Trevince in Gwennap, in the heart of the copper-mining area around Redruth and Camborne. Originally a miner like his father, he moved to Devon to assist Benjamin Donn with the surveying for his map of that county. (Hitchens' uncle was map maker Thomas Martyn.) Matriculating at Oxford in 1763 (though not graduating until many years later), in 1767 he was recommended by Savilian Professor Thomas Hornsby to Astronomer Royal Nevil Maskelyne for a position as a 'computer' for the *Nautical Almanac*. He was promoted to 'comparer' (essentially a supervisor) two years later, remaining in that role for the rest of his life. At first working from Devon, where he had become a curate, he spent some periods at Greenwich, and his observations of the transit were relayed to the Royal Society by Maskelyne[10]. (We can also mention here John Bradley (1728–1794), nephew and one time assistant of the former Astronomer Royal James Bradley, who was sent to Cornwall by the Board of Longitude to observe the 1769 transit from the Lizard Point[11], so as to determine its exact position.) Hitchens returned to live in Cornwall in 1775 when he became vicar of St. Hilary near Penzance where he employed several local assistants as computers[12]. He was also a tutor of Davies Giddy (later Gilbert; see below).

Another Hitchens connection was the self-taught mathematician and schoolmaster John Hellins (*c.*1749–1827), originally from Devon. He was introduced to Maskelyne by Hitchens and became one of the assistants at the Royal Observatory from 1773 to 1776, though Maskelyne[13] evidently did not think much of him at the time: "though capable of the common business of observing, (he) was the least serviceable Assistant I ever had, especially in the calculation of observations". From 1779 to 1783 he was curate at Constantine, between Falmouth and Helston. While it is not clear if he carried out astronomical work while in Cornwall, in 1782[14] he did communicate a paper to the Royal Society, *via* Maskelyne, which presented 'A new method of finding the equal roots of an equation by division'. He later submitted papers *via* Maskelyne with more obvious astronomical connections[15], such as the snappily titled 'An Improved Solution of a Problem in Physical Astronomy; By Which Swiftly Converging Series are Obtained, Which are Useful in Computing the Perturbations of the Motions of the Earth, Mars, and Venus, by Their Mutual Attraction. To Which is Added an Appendix, Containing an Easy Method of Obtaining the Sums of Many Slowly Converging Series Which Arise in Taking the Fluents of Binomial Surds, &c.'. He was by this time a vicar in Northamptonshire and was himself an FRS (elected 1796), winning their Copley Medal in 1799 for his work on planetary perturbations.

1820–1890

Moving to the main era for this paper, the first Cornishman to join the Royal Astronomical Society was the ubiquitous 'Cornish Philosopher' Davies Gilbert (1767–1839)[16,17]. Born Davies Giddy, the son of the curate at St. Erth, near Hayle, he later (1816) adopted his wife's surname, Gilbert, to allow them to inherit her uncle's extensive properties in Sussex. He attended Penzance Grammar School and then at Hitchens' suggestion studied at Donn's Mathematical Academy in Bristol, subsequently obtaining his MA at Oxford in 1789. He had inherited his maternal grandfather's Tredrea Manor[18] in St. Erth, and as a major landowner became High Sheriff of Cornwall in 1792 and MP for Helston in 1804, then Bodmin from 1806. Scientifically, he encouraged the career of Humphry Davy, the archetypal Cornish scientist of the 19th Century, and worked with the likes of Richard Trevithick on mining engines. He was already an FRS in 1792 and was its president from 1827 to 1830 (in succession to his protégé Davy). He published several papers in *Phil. Trans*. on topics as diverse as the catenary curve (with tables for constructing the Menai Bridge) and 'The Expediency of Assigning Specific Names to All Such Functions of Simple Elements as Represent Definite Physical Properties; with the Suggestion of a New Term in Mechanics'[19]. He joined the Astronomical Society in 1820 February and was vice-president in 1825 and 1838 but did not publish anything on astronomy[20]. He was president of the Royal Geological Society of Cornwall from its foundation in 1814, a fellow of the Linnean Society, and a fellow of the Society of Antiquaries, publishing *A Parochial History of Cornwall* in several volumes as well as works in the Cornish language. His 'improving spirit' did not extend to his workers though; as a Tory politician he argued against educating the masses as it would be "prejudicial to their morals and happiness; it would teach them to despise their lot in life … instead of teaching them the virtue of subordination, it would render them factious and refractory, as is evident in the manufacturing counties; it would enable them to read seditious pamphlets, vicious books and publications against Christianity …".[21] (The present author should admit some bias here, being descended both from Cornish mining families and from workers in a manufacturing county.)

Although not a fellow of the RAS, Robert Were Fox (1789–1877) was another FRS, elected in 1848. A member of a notable family of Quaker merchants in Falmouth, Fox was primarily a geologist, also studying what we would now call geophysics, for instance, establishing the temperature variation with depth in mines[22]. He also published a paper in 1831 on solar–terrestrial physics, linking terrestrial magnetism with observations of aurorae[23]. His brother Charles founded the Royal Cornwall Polytechnic Society in 1833.

The next Cornishman who did join the RAS (in 1845) was Edwin Dunkin (1821–1898)[24] who was born in Truro where his father, William, one of Malachy Hitchens' original computers (see above), was still working on *Nautical Almanac* calculations. (William had been at Penzance Grammar School with Humphry Davy and also studied with Davies Giddy[12].) Following his father's death in 1838, Edwin was recommended by the now Davies Gilbert for employment as a computer at the Royal Observatory, reducing planetary and lunar observations. In 1840 Airy promoted him to a position in the new magnetic and meteorological department and in 1845 he moved over to astronomical observations. Over the years Dunkin took on numerous roles looking after the Observatory's instruments and was also co-opted by Airy for activities such as the pendulum experiments in Harton colliery (to explore the density of the Earth; Airy had made a previous attempt at Dolcoath mine near Camborne in the 1820s), observations of a total eclipse in Norway, and determining the longitude of Paris relative to Greenwich[25]. He contributed numerous papers on these various topics, his contemporaries considering one on the Sun's motion relative to nearby stars[26] to be his most important. He eventually rose to the position of Chief Assistant in 1881 under Airy's successor Christie. He became an FRS in 1876, was elected Secretary (1870) and President (1884) of the RAS, and was President of the Royal Institution of Cornwall in 1890 and 1891. Away from the Observatory, he was an assiduous populariser of astronomy, producing articles for numerous periodicals and authoring books including *The Midnight Sky. Familiar Notes on the Stars and Planets*.

His brother, Richard Dunkin (1823–1895), was also born in Truro before their father relocated to the new Nautical Almanac Office in London in 1832. Like his brother, in 1838 Davies Gilbert recommended him for a position in the new department at Greenwich set up to reduce all the planetary and lunar observations made there between 1750 and 1830 (he would have been only 15 years old at this point). In 1847 he followed his father's route to the Nautical

Almanac Office where he retired as a first-class assistant in 1883, thereupon returning to Truro. He had become a Fellow of the RAS in 1851[27] "although he never contributed a paper to its Proceedings".

Between the two Dunkins, another, more famous, Cornishman had joined the RAS. John Couch Adams (1819–1892)[28] was born on a farm in Laneast on the Launceston side of Bodmin Moor[29]. He was sent to attend a school in Devonport run by his mother's cousin, the Rev. John Couch Grylls, and observed Halley's comet from nearby Landulph in 1835. He entered St. John's, Cambridge, in 1839 and was Senior Wrangler four years later. He started his work on perturbations of the orbit of Uranus[30] on vacation back in Cornwall and gave solutions for the mass and position of the perturber to Challis in Cambridge and Airy in Greenwich in 1845. However, as is well documented, a delayed search allowed Galle in Berlin to discover Neptune the following year, based on the (published) calculations of Le Verrier. Adams nevertheless won the Copley medal of the Royal Society for this work[31] and was admitted as a Fellow in 1849. He had joined the RAS in 1846 and became President for 1851–53 and 1874–76[32]. He also worked on lunar theory and the connection between meteors and comets as well as numerous mathematical topics, contributing 60 papers, mostly to *MN*.

His brother William Grylls Adams (1836–1915)[33], also an alumnus of St. John's, was professor of Natural Philosophy at King's College London for nearly forty years in succession to James Clerk Maxwell. He became president of the Physical Society in 1868 and was elected an FRS in 1872. He mainly worked on polarization, sending one paper on the subject to *MN*[34], on magnetism and on electrical power. He also supplied an observation of the solar eclipse of 1870 in Sicily[35] and was on the Board of Visitors at the Royal Observatory.

A Cornishman who travelled rather further to become an astronomer was Andrew Elvins (1823–1918). He was born in Polgooth, a few miles from St. Austell, which is claimed to have had some of the earliest tin mines in the county. He worked at a local mine from the age of ten but while apprenticed to a tailor studied at night school, becoming particularly interested in geology. He emigrated to Canada in 1844 and in 1860 moved to Toronto, working in a tailoring business, and began to study astronomy. In 1868 he and some friends proposed an astronomical society, 'The Toronto Astronomical Club', and the same year Elvins contributed his first papers to the *Astronomical Register*, with ideas on tides, sunspots, and comets[36]. After being at a low ebb, a revived society became 'The Astronomical and Physical Society of Toronto' in 1890, and eventually 'The Royal Astronomical Society of Canada' in 1903, with Elvins as vice-president[37]. He was still contributing to their meetings when he was 88 and observed the aurora when aged 95[38].

In 1869 W. F. Denning of Bristol started a relatively short-lived national organization which he called the Observing Astronomical Society. Its original committee included Henry Michell Whitley (1845–1928) of Truro. The observations made by the society's members were published in the *Astronomical Register* and Whitley contributed on the transit of Mercury[39] and aurorae amongst other things. In 1885 he observed the nova (now known to be a supernova) in the Andromeda Nebula[40] from Westminster where, following in the footsteps of his father, he worked as a civil engineer. He also contributed to the *English Mechanic*.

Remarkably, it seems that after Gilbert there were no further RAS Fellows actually living in Cornwall until 1874[41]. The gentleman then elected was Lieut.-Col. William Edwards Michell (1840–1893), of The Fort, in the newly developing town of Newquay. He had been born in Truro, the son of the Registrar of the Court of the Vice-Warden of the Stannaries of Devon and Cornwall, and educated at Christ Church, Oxford. He was a significant landowner and eventually commanded the "2nd Brigade Western Division, R.A. [Royal Artillery]; late Royal Cornwall and Devon Miners Artillery Militia", in which he had been commissioned as first lieutenant in 1861[42]. He published papers on Cornish antiquities in the *Journal of the Royal Institution of Cornwall* but does not appear to have made any astronomical contributions[43].

If we are allowed temporary residents, we can add another 1870s FRAS. In 1881, "Mr Brett, writing from Newquay", supplied an observation of the recent 'great comet' to *The Observatory*[44]. This is almost certainly John Brett ARA (1831–1902), the well-known pre-Raphaelite artist, who spent his summers around that time painting Cornish coastal landscapes. He became a fellow of the RAS in 1871 just after observing an eclipse from Sicily[45] where he was a member of the party with Professor W. G. Adams (see above). Notwithstanding a dozen science papers in *MN* or *The Observatory*, however, he was frequently in quite vitriolic dispute with his more established contemporaries as a result both of his sometimes unconventional astronomical interpretations ("these observations met with almost a storm of incredulity in some quarters when communicated to the Society") and of his views on the RAS establishment (especially the Council) itself[46]. His obituary[47] notes that his "characteristically emphatic remarks were a well-known element in the discussions" and indeed he lost few opportunities to snipe at the scientific establishment, even managing it in a book review in this *Magazine*[48]. (Another visitor, Henry J. Townshend, President of the Leeds Astronomical Society[1] and a regular correspondent to the BAA, reported seeing a bright meteor from North Cornwall in 1896[49], but, as he was presumably merely on holiday, we shouldn't really count this!)

Captain George William Read (1848–1907) of Penrhyn was elected an FRAS in April 1888[50]. He was a master mariner, born in Whittlesey, Cambridgeshire, who obtained his master's certificate in London in 1873. He was already a Fellow of the Royal Geographical Society before joining the RAS. Nothing is known about his astronomical interests.

George Daniel Sutton Higgs (originally Daniel Sutton; 1841–1914) was the son of a Cornish agricultural labourer but was born in Clawton, just on the Devon side of the Tamar. He somehow acquired a significant and surprisingly broad education[2] and by 1861 was a watchmaker's apprentice. We can presume that he already had an interest in astronomy at this point and when he subsequently lived in Launceston in Cornwall (where one of his children was born). Around 1865 he moved to Cumberland and then on to Liverpool where he was listed in the next census as 'George Higgs', a watchmaker. He used his technical skills to construct a remarkably high-quality solar spectrograph, and by the late 1880s was supplying photographic spectra to the RAS[51]. In 1893 he published his notable *Photographic Atlas of the Normal Solar Spectrum*. Contemporaries considered his work as good as any from professional observatories[52] and George Ellery Hale visited the laboratory at his home. Higgs was a prominent member of Liverpool Astronomical Society from 1886, later becoming its president, and of Liverpool Physical Society, and was elected an FRAS in 1890[53].

1890–1920

William James Harding (1853–1899) joined the recently founded British Astronomical Association in 1892[54]. He was born in Polperro and obtained a post as supernumerary computer at the Royal Observatory in 1870. He was then successful in a Civil Service Competitive Examination to gain a staff post at the Nautical Almanac Office in 1875. He also assisted David Gill with reductions of the Cape Parallax Observations.

Frederick Skinner (1860–1927) was born in Falmouth and from about 1882 worked at the Falmouth Observatory[55] taking meteorological measurements. He then moved to the Liverpool Observatory at Bidston[56] as senior assistant to John Hartnup Jr. and later W. E. Plummer, where he was responsible for the regulation of ships' chronometers and also carried out telescopic observations. Plummer and Skinner's observations of the two comets of 1894 were published in *MN*[57].

James and Edward Tangye from Illogan near Redruth were two of five Quaker Tangye brothers who founded the mechanical engineering company of that name in Birmingham which constructed the hydraulic lifting jacks needed to launch Brunel's *Great Eastern*. After retiring back to Illogan in 1872, James (1825–1912) built his own observatory[58]. His nephew Alfred (1870–1900), living in Redruth and listed as a "student of mathematics" in the 1891 census, must have developed a similar interest and in 1898 his father Edward proposed him for membership of the BAA[59]. Unfortunately he had little chance to contribute as he died two years later.

Rev. John Horsley Haslam (1850–1904) was born at Baldhu, just west of Truro, where his father was the vicar. After Cambridge he too became a cleric, with positions in Essex, Birmingham, and Gravesend among others, building his own observatory at each location. He was elected an FRAS in 1902[60] and in 1903 took the opportunity to ask the Astronomer Royal a question about the probable physical separation and orbital speeds of binary stars[61].

In 1905, Rev. Augustin Morford of Saltash was in a party, led by Father Aloysius Cortie S. J. of Stonyhurst College Observatory, to observe the solar eclipse visible from eastern Spain and whose observations were included in a report to *The Observatory*[62] and in a paper presented at the RAS[63]. Father William Hudson Augustin Morford (1850–1923), from Staines in Middlesex, was a Catholic priest, and then Canon, at the Franciscan Friary in Saltash and was later the Very Rev. Canon at St. Scholastica's Abbey in Devon. He also supplied sunspot observations to the BAA[64] and was a member of the Marine Biological Association.

Wilson Lloyd Fox (1847–1936) came from the same extensive Cornish family as Robert Were Fox (see earlier). His father was a merchant and mine and coal proprietor in Falmouth. He, instead, became a solicitor and registrar to the county council. From 1877 to 1931 he was also secretary of the committee of the Falmouth Observatory which was one of only three official magnetic observatories in the UK (with Kew and Stonyhurst College). It was also a meteorological observatory and Fox was particularly interested in this area, being a Fellow of the Royal Meteorological Society. He was a member of the Royal Cornwall Polytechnic Society from 1865 and its president 1922–24[65]. He joined the BAA in 1904 and provided occultation observations to their journal[66] as well as recording sunspots and submitting regular counts of meteors.

In 1908, Fox and Agnes Fry (of another Quaker family, the owners of Fry's Chocolate in Bristol, and herself a noted botanist, astronomer, and writer) proposed Miss Vere Roberts of Morvah, Falmouth, for membership of the BAA[67]. Miss Roberts, born in Winchester in 1881, was the daughter of an art-school teacher and at the 1911 census was recorded as "living on own means". She was still living on her own means in Cornwall in 1939. Her only contribution to the BAA seems to have been in 1910 when she and Fry proposed Edmund

Houghton, then living in Florence, as a BAA member. (How the two ladies knew Houghton, a photographer who apparently led a rather Bohemian lifestle in Italy, is unclear.)

George Percy Bailey MA (1867–1939) of St. Ives joined the BAA in 1911, one of his proposers being J. A. Hardcastle[68], the BAA secretary (and grandson of Sir John Herschel). He was employed by Cambridge University to give Extension Lectures on astronomy at towns around the South-West[69]. Originally from Huddersfield, he had supplied a paper on meteors to *Nature*[70] in 1902 while an assistant master at Stonyhurst College. He was proposed as an FRAS by Father Cortie in 1921, by which time he was living in Tamworth.

In 1912 'Mr and Mrs Wilson' sent observations of meteors seen at Looe to the BAA[71]. This was the pioneer female RAS fellow (elected 1916[72]) Fiammetta Wilson (*née* Helen Frances Worthington[73], in Lowestoft; 1864–1920) and her husband Sidney Arthur Wilson (1875–1925). Though based primarily in Totteridge near Bexley Heath, the Wilsons must have spent considerable time in Cornwall as further reports, from Portscatho as well as Looe, occur in each year up to 1916. Originally a musician, she became a BAA member in 1910. Taking over running the BAA's Meteor Section during the Great War, "Mrs Wilson was justly regarded as the brightest ornament and the most exhilarating presence in the little community of meteoritic observers", though she also observed aurorae and comets. She was awarded Harvard's Edward C. Pickering Fellowship for Women for 1920–21, but sadly died before receiving the notification[74]. Her husband, originally from Aldershot and a clerk at the Bank of England, also joined the BAA in 1910 and co-authored a paper on that year's occultation of Mars[75].

Henry Spencer Toy (1889–1980) from Helston (also at Ashville College, Harrogate) was elected an FRAS in 1914[76] and joined the BAA the following year. In the 1911 census he had been recorded as 'university student'. In the 1930s he was headmaster of Launceston College. His brother Francis Carter Toy D.Sc. worked at the British Photographic Research Association Laboratories, publishing in *Proceedings of the Royal Society* and *Nature*. It was Francis' UCL professor, Alfred Porter, who proposed Henry to the RAS, and while the latter did not publish any observations he did, in turn, propose numerous other astronomers to the RAS and BAA.

Also joining the BAA in 1915 was Lewis Guy Pierson[77] (1897–1957), the view from whose then family residence, Bothwicks, near Newquay, had been the subject of one of John Brett's paintings (see earlier). Born in Bodmin, after Cambridge he became an assistant science master at Marlborough College and was president of the Wiltshire Natural History Society for many years.

Thomas Herbert Lesbirel Hony (1866–1944) was the manager of Lloyds Bank in Fowey for many years, having been born in Liskeard. A keen observer, after becoming a member in 1916, he supplied the BAA with reports of meteors[78]. Still active in his seventies, he provided an account of an aurora visible from Cornwall in 1943[79]. He was well-known in the South West for his astronomy articles in numerous local papers. He was elected an FRAS in 1922[80].

Mr. Hony was involved, indirectly, in something of a controversy regarding the priority of discovery of the very bright Nova Aquilae 1918. W. F. Denning had received a letter stating that while observing a bright meteor, Captain E.V. Piper at Fowey "saw a bright strange star" (around the position where the nova was first 'officially' seen a day later). Denning noted in *Nature*[81] that "The whole of the facts and circumstances of the observation have been investigated by Mr. T. H. L. Hony, of Fowey, who is an amateur astronomer, and is convinced of the perfect trustworthiness of the details". The BAA were initially inclined to accept this as the discovery observation, but the reported brightness (the same as seen the following day) and the fact that other observers, including Denning himself, had seen nothing two hours earlier led them to discount it as a mistake in the date[82]. (The report from a Prof. Laskowski at Geneva was similarly discounted, but for some reason is accepted in Wikipedia.) Captain Edmund Vincent Piper (1858–1936), the son of another master mariner, was one of Denning's regular correspondents concerning meteor counts and spent his whole life in Fowey. He obtained his Master's certificate in 1891 but was later a provisions merchant.

Harold Notley, then resident in Tregoddick, Flushing, near Falmouth, joined the BAA in 1917[83]. The seconder for his candidature was Walter Maunder, of sunspot-cycle fame, one of the BAA's founders and stalwarts. Despite this support, he must have let his membership lapse as he joined again in 1929, when living in Selsey near Chichester. He is almost certainly the Harold Francis Hopton Notley (1885–1946), born in Wiltshire, recorded as the manager of a market garden in Chichester in 1939.

An interesting note in *The Observatory*[84] in 1915 had revealed that of the 506 Fellows of the RAS based in England, only four lived in Cornwall, compared to 187 in London, 32 in Cambridge, and 27 in Kent. Another joined in 1918 in the person of the Rev. (Arthur) Harold Young Baxter, MA Cantab[7] (1879–1965), of Tresillian, Mylor near Falmouth, proposed by Lieut.-Col. F. J. M. Stratton[85] (later the RAS president). He was born in Birmingham and was a deacon in Liverpool after graduating in 1903 but did not take priest's orders. He became a school master in Mylor but enlisted in 1915, joining the Buckinghamshire Regiment. Returning to his position after the war, he remained in Falmouth after he retired.

One further pre-1920 Cornish member of the BAA was John Edward Nankivel Tremewan (1887–1970) of Sandhill House, Perranporth[86], who joined in 1919 and is unusual on two counts. First, rather than the middle classes that dominated even the BAA, he would have counted as a 'tradesman' — he was a house painter and decorator, though his father was an agricultural agent and his mother an artist and music teacher. Second, he and his brother Tom had just been released from jail. Strongly religious, and influenced by their mother's pacifist Quaker friends, they were conscientious objectors during the Great War and were imprisoned for refusing army service[87]. John later ran an ironmongers in Perranporth for many years.

It is not clear exactly when Arthur Stanley Williams (1861–1938), a legendary amateur variable-star and planetary[88,89] observer moved to Cornwall, but he submitted a paper on Nova Persei to *MN* from St. Mawes in 1919[90], so certainly makes our cut-off date. Born in Brighton, he worked as a solicitor in Hove until retiring. He had begun observing Jupiter in 1878 and was responsible for the still-used terminology for the belts and zones. From around 1885 he added observations of variable stars and was the first person in Britain to use photography in the search for new variables. He was a founder member of the BAA and became an FRAS in 1884. Also a keen yachtsman, he won the Challenge Cup, the highest honour in cruising for a single-handed sail from Falmouth to Vigo in Spain and back when he was nearly 60. After retiring to St. Mawes, opposite Falmouth, he lived as somewhat of a recluse in a moored barge, with his observatory on the shore close to where it was beached, but this did not prevent him winning the RAS Jackson-Gwilt Medal in 1923. He later moved to the less-exposed Feock near Truro.

In summary, despite the rather small population, between 260 000 in 1821 and a peak of 370 000 in 1871, our tally for 1820–1920 astronomers appears to be five RS Fellows born in Cornwall (all before 1880) and eighteen FRAS (including four of the FRS), ten of them born in the county and eight resident there, as well as eleven others associated with the BAA or other societies, eight of them Cornish. This gives a total of nineteen Cornishmen with astronomical society connections over the century and eleven other, at least temporary, residents (two of them female). Perhaps surprisingly, of the thirty, six were 'professionals', two professors and four at observatories, while, less surprisingly, six others were school masters or clergymen.

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ORDERING THE UNIVERSE WITH NAKED–EYE OBSERVATIONS

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The geocentric universe, in its most developed form as set out by Ptolemy, was a remarkably successful and coherent theory. It did not, however, specify the order of the planets, that is, which

was closer to Earth and which farther away. One would naively think that seeing one planet pass in front of another would settle the matter. In practice such mutual phenomena happen too rarely for them to have been useful. Even in principle, it turns out that most naked-eye observations of a central event would show nothing conclusive, with the exception of some occultations by Venus that would demonstrate it to be the lowest (nearest) planet. However, if one's theory were good enough to allow conclusions from not seeing changes, one could find that Mars is probably lower than Jupiter and Saturn, and possibly that the overall order is Venus–Mars–Jupiter–Saturn–Mercury.

The order of the Universe

The geocentric theory of the Universe, as most highly developed by the Greco–Roman astronomer Ptolemy, was a great achievement of mathematical astronomy and held the field for several centuries. However, one thing it did not specify was the ordering of the planets. Clearly, the Moon was closest to Earth (lowest) because it occulted all other planets (as well as stars); but otherwise the theory was ambiguous. The positions of each of the moving bodies could be calculated without reference to the others. There was a consensus that the slower-moving planets should be farther away, but even then the relative heights of Mercury, Venus, and the Sun were unknown, since their average motions were the same.

Prompted by the 2021 Great Conjunction of Jupiter and Saturn, I wondered whether an occultation of the latter by the former (instead of just a close passage) could have given some information*. Obviously, a telescope would show one passing in front of the other, but such an instrument was not available to the ancients. Instead, a naked-eye observer would be limited to observing changes in brightness.

However, a calculation of actual events shows that they happen far too rarely to have been useful to ancient astronomers. In a compilation covering the years 1557 to 2230[1], S. C. Albers found three possibly observable Venus–Jupiter events (rejecting those too close to the Sun); two observable events involving Mercury; and two observable Mars–Jupiter events. For astronomers in a limited region of Earth, these seven events would be reduced to at most two, possibly none. There was a complete lack of Jupiter–Saturn events. Even without actually performing the calculations for the period whose observations were available to Ptolemy (roughly 750 BCE to 150 CE), we can be confident that at best a handful of events could have been seen. It is not suprising that none are mentioned in the *Almagest*[2].

Let us change the question. Supposing an unlimited time of observation, or some reliable record of mutual events handed down over time, what could an ancient geocentric astronomer *in principle* have concluded from mutual planetary events?

*The term 'occultation' is used when the body passing in front is larger than the one behind, `transit' when the reverse is true. Since the planets are of roughly similar apparent sizes, either might be used for planet–planet mutual phenomena; here I stay with 'occultation.'

Data

For the following calculations I used mean distances, speeds, sizes, and magnitudes of planets from a textbook at hand[3] plus data from a reasonably recent almanac[4]. Since the object is a set of indicative calculations of generic phenomena, I sought no great accuracy; complications like limb darkening and the aspect of Saturn's rings are ignored. For occultations involving only outer planets, calculations were done at opposition. For those involving inner planets, calculations were done at Mercury's mean greatest elongation, 22°·8, taken as about the effective limit of observability. Input data are listed in Table I.

TABLE I

Basic data for planet mutual phenomena. Mercury is only listed at its greatest elongation; Venus is listed at near and far elongations of 22°·8, the outer planets at that elongation and opposition.

	22°·8 or near		*Opposition or far*	
Planet	*Magnitude*	*Size (arcsec)*	*Magnitude*	*Size (arcsec)*
Mercury	−1·7	7·3		
Venus	−0·1	53·6	−3·6	10·9
Mars	1·9	3·9	−2·01	17·9
Jupiter	−1·5	38·0	−2·70	46·9
Saturn	0·6	15·9	0·2	19·4

Calculations

All transits were assumed to be central. A naked-eye observer would see two planets approach each other until they formed a single object, with a combined brightness given in the calculations. As one covered the other it would dim over the period shown, remain at that lower level for the duration of 'totality', then recover.

What can a visual observer detect? There is anecdotal evidence of exceptional variable-star observers who can make estimates good to 0·05 magnitude. However, they are rare, and of course have calibrated comparison stars to use. As a rule of thumb we can probably take a dip of 0·1 magnitude to be the limit of what an experienced observer might notice, with the caveat that if it happens slowly, or with nothing of similar brightness to serve as a reference, the threshold for detection could be much larger.

The results for outer planet events are given in Table II. The case of Jupiter occulting Saturn, the original prompt for this study, has a dip of 0·07 magnitude happening over hours. It would surely pass unnoticed. Indeed, variations in brightness due to changing air-mass alone would mask it. Phenomena involving Mars are marginally better, but would still show nothing to the naked-eye observer.

TABLE II

Outer planet mutual phenomena.

Planet	*Magnitude outside*	*Magnitude totality*	*Ingress minutes*	*Totality minutes*
Mars on Jupiter	−3·16	−3·05	32	52
Mars on Saturn	−2·14	−2·03	26	2
Jupiter on Saturn	−2·77	−2·70	143	203

TABLE III

Inner planets mutual phenomena.

Planet	*Magnitude outside*	*Magnitude totality*	*Ingress minutes*	*Totality minutes*
Venus (near) on Mercury	−1·92	−0·7	3·8	24
Mercury on Venus (far)	−3·77	−3·25	12	5·8

For the inner planets there are two possibilities with Mercury at greatest elongation: Venus on the near side of its orbit could occult Mercury, and Mercury could occult Venus on the far side of the latter's orbit. Results are shown in Table III. A near-Venus event would be very clear: a large, mostly unlit crescent Venus covering Mercury gives an unmistakable drop in light, and does it rather quickly. (Indeed, if we could arrange this to happen near Sirius, at mag. −1·6, it could be spectacular.) Venus, then, is clearly closer than Mercury. The other possibility is more equivocal. A drop to about half the original brightness in a few minutes would seem to be clearly observable. However, there are no stars nearly this bright to use as comparisons. It would certainly be different from the other situation observationally.

The final group of mutual phenomena occur when the inner planets pass in front of outer planets, with results shown in Table IV. The near-side occultations by Venus of Jupiter would show that Venus is the lower planet pretty clearly; with Saturn, it is less evident. For Mars, the drop in brightness would be on the edge of perception, though perhaps if it happened near a suitable comparison star it might be seen. Occultations by Mercury of the outer planets show nothing perceptible, as do the situations with Venus on the far side of its orbit passing in front of them.

TABLE IV

Mutual phenomena, inner planets on outer.

Planet	*Magnitude outside*	*Magnitude totality*	*Ingress minutes*	*Totality minutes*
Venus (near) on Mars	−0·26	−0·1	1·7	22
Venus (near) on Jupiter	−1·76	−0·1	34	14
Venus (near) on Saturn	−0·56	−0·1	19	44
Mercury on Mars	−1·74	−1·7	5·5	4·8
Mercury on Jupiter	−2·36	−2·34	3·8	16
Mercury on Saturn	−1·82	−1·80	3·4	3·9
Venus (far) on Mars	−3·61	−3·60	3·0	5·3
Venus (far) on Jupiter	−3·75	−3·73	4·3	11
Venus (far) on Saturn	−3·62	−3·61	3·9	1·8

Analysis

Far from being a sure way to order the geocentric universe, as one might naively think, planets passing in front of each other turn out to be generally uninformative to the naked eye. The only clear observations would show Venus to be lower than Mercury and Jupiter, and possibly Saturn and Mars.

There is a possibility of learning more, though it requires us to take a further (and much larger) step away from actual history. Consider the case of Mars transiting Saturn. The combined object would retain its red colour throughout the event. One might reason, then, that Mars could not have been covered, and thus was nearer.

This is predicated on the assumption that the nearer planet did in fact pass in front of the more distant one. For this one must have predictions accurate to within a planetary diameter, a matter of seconds of arc. Now, the accuracy of the Ptolemaic theory varies with the position of the planet in its orbit and with the observations used to calibrate it. An indication of the uncertainty of the actual theory is given by two instances in which a planet is declared to have occulted a star (ref. 2, p. 477, n. 17 and p. 522, n. 16) when modern calculations show a miss by 12 and 15 arc minutes. For predicting occultations or transits, then, it was not up to the job. Ancient observers would be in a position analogous to that of W. H. Smyth examining the close double star ζ Herculis. He reports[5] that during one apparition he saw a red spot on the disc of the primary, which he took to be the fainter and redder secondary star in transit. But lacking any orbital prediction or feel for how large the disc of a star actually was, he could not be sure, and alternatively says it could have been "a spurious image or colour."

However, if we postulate a theory (or some other condition) that allows us to be confident that an occultation did occur and thus to learn from not seeing anything happen, more conclusions are possible. As noted, we could conclude that Mars is lower than Jupiter or Saturn by the colour of its transits. And if, say, our naked-eye observer sees Jupiter shine as brightly as ever as it reaches Saturn, he might conclude that Jupiter must be the nearer. Similarly, the failure of Mercury to dim any of the outer planets could be interpreted as it lying at a higher altitude, a distinctly unsettling idea for the fast-is-close consensus. With these additions, our geocentric universe has the planets in the order Venus–Mars–Jupiter–Saturn–Mercury.

Conclusions

Seeing one planet pass in front of another turns out to be generally uninformative to the naked eye. Historically, it happens too rarely to be of interest. Even in principle, it could only show that Venus is the closest planet beyond the Moon. In retrospect, this is not surprising. The nearer planets are generally closer to the Sun and thus of higher surface brightness, so the occulted planet contributes less to their combined light. The exception, Mercury, has little effect because it's so small.

I am indebted to an anonymous referee for the suggestion of a set of phenomena that provides an illuminating contrast: mutual events of Jupiter's Galilean satellites. Of course these are not visible to the naked eye, but in binoculars and small telescopes the moons show no discs and observations are similarly limited to changes in brightness. Such observations are more useful than planet mutual events for two main reasons. First, they are far more common, hundreds happening every six years as Earth passes through their orbital plane. Second, the moons are of similar surface brightness, so the combined light typically drops by a half-magnitude or more, easily noticed by comparison with other moons. In addition, there are eclipses, which are impossible for planet–planet mutual phenomena. The Observatoire de Paris coordinates campaigns to use visual observations to update the moons' ephemerides[6].

For planet mutual phenomena, it's only if we postulate an anachronistically accurate method of prediction and an unhistorical run of events that we could put the geocentric planets in order. It is ironic that the invention of the telescope, which alone could have made mutual phenomena useful for the geocentric universe, instead proved its undoing.

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 12: THE F-TYPE TWIN SYSTEM ZZ BOÖTIS

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ZZ Boo is an F-type detached eclipsing binary system containing two almost-identical stars on a circular orbit with a period of 4·992 d. We analyse light-curves from two sectors of observations with the *Transiting Exoplanet Survey Satellite* (*TESS*) and two published sets of radial velocities of the component stars to determine their physical properties to high precision. We find masses of 1·558 ± 0·008 $M_\odot$ and 1·599 ± 0·012 $M_\odot$, and radii of 2·063 ± 0·006 $R_\odot$ and 2·205 ± 0·006 $R_\odot$. The similarity in the primary and secondary eclipse depths has led to confusion in the past. The high quality of the *TESS* data means we can, for the first time, clearly identify which is which. The primary star is conclusively hotter but smaller and less massive than the secondary star. We define a new high-precision orbital ephemeris and obtain effective temperatures using the *Gaia* parallax of the system. The secondary star is more evolved than the primary and a good agreement with theoretical predictions is found for a solar chemical composition and an age of 1·7 Gyr.

Introduction

Detached eclipsing binaries (dEBs) are a fundamental source of measured properties of normal stars[1–3] and are widely used to explore and calibrate our understanding of the properties of stars[4–6]. dEBs containing evolved stars are

Table I

Basic information on ZZ Boo.

Property	*Value*	*Reference*
Right ascension (J2000)	13:56:09·52	12
Declination (J2000)	+25:55:07·4	12
Henry Draper designation	HD 121648	13
Hipparcos designation	HIP 68064	14
Tycho designation	TYC 2002-624-1	15
Gaia DR3 designation	1450355965609917568	12
Gaia DR3 parallax	9·3946 ± 0·0324 mas	12
TESS Input Catalog designation	TIC 357358259	16
B magnitude	7·158 ± 0·015	15
V magnitude	6·781 ± 0·010	15
J magnitude	5·982 ± 0·021	17
H magnitude	5·867 ± 0·038	17
K_s magnitude	5·830 ± 0·023	17
Spectral type	F3 V	18

particularly helpful in tracing stellar evolution[7–9], especially if the two stars have similar masses but significantly different radii.

In this work we analyse a new space-based light-curve and published radial velocities (RVs) of the dEB ZZ Boo in order to determine its physical properties. The motivation for this series of papers is given in ref. 10, and a review of the impact of space-based photometry can be found in ref. 11.

ZZ Boo (Table I) was found to be a spectroscopic binary by Shajn[19], who presented the first RV curves of this object. Gaposchkin[20] announced the discovery of deep eclipses based on archival photographic plates. Gaposchkin[21] followed this up with a determination of the physical properties of the system based on a light-curve from 1554 photographic plates and the RV curves from Shajn[19]. Miner & McNamara[22] presented seven photographic spectra and derived orbits in agreement with those of Shajn[19]. McNamara *et al.*[23] presented a photoelectric light-curve with good coverage of the eclipses, which was subsequently reanalysed by Cester *et al.*[24] and Botsula[25].

Popper[26] presented extensive spectroscopy of ZZ Boo based on photographic plates from the 3-m *Shane* telescope at Lick Observatory. He analysed these, plus the McNamara *et al.*[23] light-curve, and determined the masses and radii of the system. Whilst the masses were very well established by the RVs, the radius measurements had errors of over 3% due to the similarity of the stars and the limited quality of the photometry. Further RVs, which appear to be significantly more precise than those from Popper[26], are advertised in a conference proceedings by Lacy[27] but remain unpublished. Finally, a good spectroscopic orbit has been presented by Nordström *et al.*[28].

The spectral type of the system was given as F2 V by Hill *et al.*[29] and as F3 V by Abt[18]. These supersede earlier assessments[19,22]. Most recently, Kang *et al.*[30] analysed a single high-resolution (resolving power R ≈ 80 000) échelle spectrum taken at orbital phase 0·583 to determine the effective temperatures ($T_{\rm eff}$) and metallicities of the stars, and their light ratio. From a detailed chemical abundance analysis they determined that the primary star (star A) has chemical abundances slightly lower than those of the Sun and suggested a similarity with the λ Boötis stars, although the abundance pattern is nowhere near extreme enough to match that class of chemically peculiar star[31]. They found the secondary star (star B) to have solar abundances with the exception of a 0·90 ± 0·06 dex overabundance of oxygen based on two spectral lines, and thus the two stars to have a significantly different abundance pattern.

In this work we revisit ZZ Boo to redetermine its masses and radii to high precision based on the plethora of published RVs and on a new space-based light-curve. Detailed scientific motivations can be found in refs. 10 and 11.

Observational material

The NASA *Transiting Exoplanet Survey Satellite* (*TESS*) observed ZZ Boo in sectors 23 (2020/03/18 to 2020/04/16) and 50 (2022/03/26 to 2022/04/22), in both cases in short-cadence mode[32]. The light-curves show an uncomplicated light variation consisting of two eclipses of almost identical depth, plus a sinusoidal variation outside eclipse due to the ellipsoidal effect (Fig. 1).

We downloaded these data from the MAST archive* and converted the fluxes to relative magnitude. The simple aperture photometry (SAP, ref. 33) is well-behaved and the pre-search data conditioning SAP (PDCSAP) data are errant,

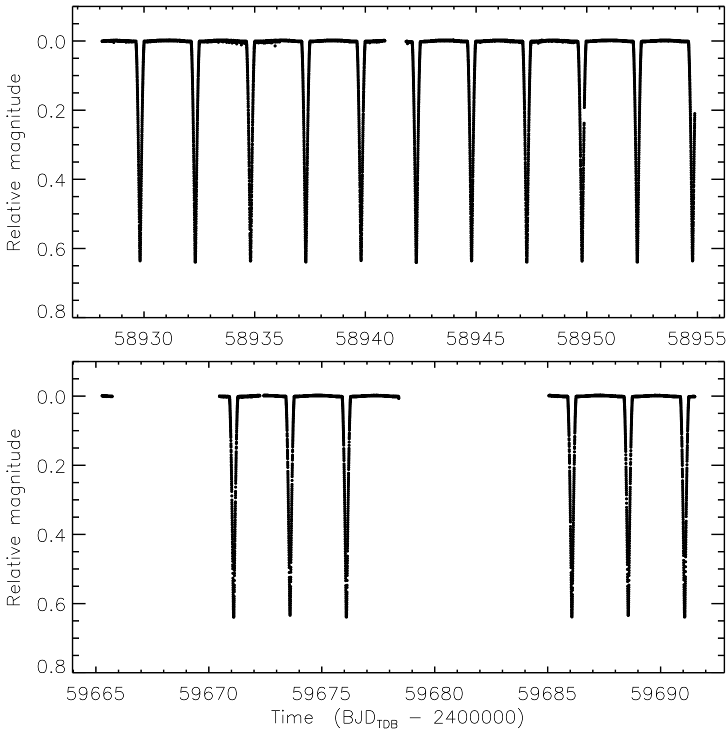

Fig. 1

TESS short-cadence SAP photometry of ZZ Boo from sectors 23 (top) and 50 (bottom). The flux measurements have been converted to magnitude units then rectified to zero magnitude by the subtraction of low-order polynominals.

* Mikulski Archive for Space Telescopes,
https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

so we used only the SAP data in our analysis. We made no cut on the quality flag for sector 23 because even the data flagged as lower quality seemed to be of similar quality to the rest. Quite a lot of data points are not available for sector 50, and for this sector we required the QUALITY flag to be set to zero. Our analysis therefore included 18 564 data points from sector 23 and 10 456 from sector 50. We ignored the data errors as they are too small, preferring instead to determine the precision of the photometry from the scatter around the best-fitting model.

We queried the *Gaia* DR3 database* in the region of ZZ Boo. A total of 17 additional sources are listed within 2 arcmin. The brightest of these is fainter than ZZ Boo by 7·78 mag in the G_{RP} passband (a light ratio of 0·00077) so we conclude that there is negligible contaminating light from nearby stars that are sufficiently distant from our target to be resolved by *Gaia*.

Light-curve analysis

We first combined the SAP light-curves from the two sectors. Then we removed three short stretches of data to avoid the possibility of them biassing the solution: the stretch between BJD 2458953·5 and 2458954·9 because it contains an eclipse that is only partially covered; the small set of points around 2459665·5 because they are distant from other points and contain no eclipse; and the data in the interval 2459677·3 to 2459678·5 because they cover only out-of-eclipse phases and the first ten minutes of an otherwise-unobserved eclipse.

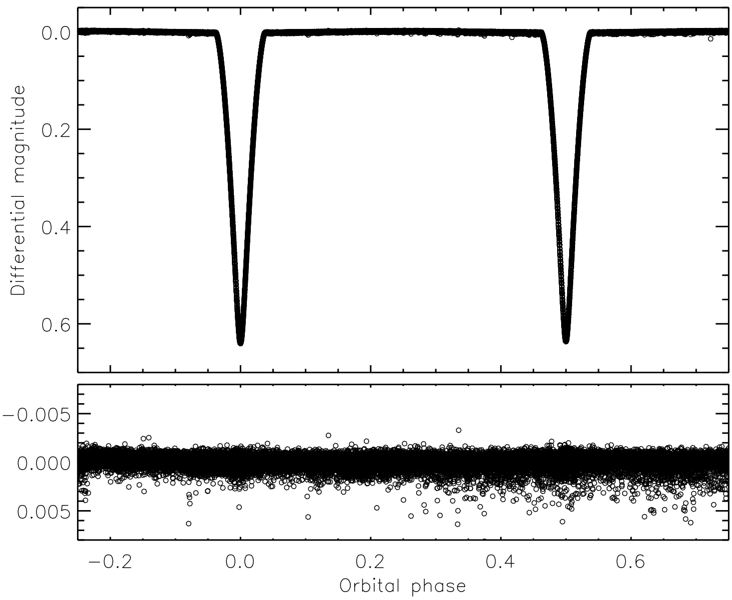

FIG. 2

Best fit to the full *TESS* light-curve of ZZ Boo using JKTEBOP. The residuals are shown on an enlarged scale in the lower panel.

*https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=I/355/gaiadr3

We designated the deeper of the two eclipses as the primary eclipse, at which time the primary star (hereafter star A) is eclipsed by the secondary star (hereafter star B). Although the eclipses are of very similar depth, the distinction between the two is clear in the *TESS* data. Based on this definition, star A is hotter, smaller, and less massive than star B. Past confusion as to which is the primary and secondary star is discussed below.

The *TESS* light-curve of ZZ Boo was fitted using version 42 of the JKTEBOP★ code[34,35]. We fitted for the orbital period (P) and time of mid-eclipse (T_0), choosing as our reference time the primary eclipse closest to the midpoint of the data from sector 23. The fractional radii of the stars were included as their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$), both of which were fitted, as were the orbital inclination (i) and the central surface-brightness ratio of the two stars (J). After some tests we ruled out the presence of significant orbital eccentricity and thus adopted a circular orbit. Third light was found to be insignificant but was included as a fitted parameter to ensure its uncertainty was captured.

For limb darkening (LD) we adopted the quadratic law and forced the two stars to have the same coefficients due to their similarity. We fitted for the linear LD coefficient ($u_{A,B}$) and fixed the quadratic LD coefficient ($v_{A,B}$) to a theoretical value from Claret[36].

The best fit is shown in Fig. 2 and is extremely good. The residuals show a slight excess to fainter magnitudes: these data points are a subset of those flagged as less reliable in sector 23. Upon investigation we found that they have a negligible effect on the solution, so we did not reject the flagged data. The fitted parameters are given in Table II.

TABLE II

Adopted parameters of ZZ Boo measured from the TESS light-curves using the JKTEBOP *code. The uncertainties are 1σ and were determined using Monte Carlo and residual-permutation simulations.*

Parameter	*Value*
Fitted parameters:	
Time of primary eclipse (BJD_{TDB})	2458942·300638 ± 0·000004
Orbital period (d)	4·99176522 ± 0·00000010
Orbital inclination (°)	88·6361 ± 0·0044
Sum of the fractional radii	0·23669 ± 0·00008
Ratio of the radii	1·0691 ± 0·0014
Central surface-brightness ratio	0·98003 ± 0·00033
Third light	−0·0001 ± 0·0008
Linear LD coefficient	0·246 ± 0·005
Quadratic LD coefficient	0·22 (fixed)
Orbital eccentricity	0·0 (fixed)
Derived parameters:	
Fractional radius of star A	0·11440 ± 0·00011
Fractional radius of star B	0·12230 ± 0·00006
Light ratio ℓ_B/ℓ_A	1·1203 ± 0·0029

Uncertainties in the photometric parameters

To determine the uncertainties of the fitted parameters we ran 10 000 Monte Carlo and residual-permutation simulations[34,37] using JKTEBOP tasks 8 and 9. In past work we have found that these uncertainty estimates are reliable[38–40].

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

The residual-permutation simulations return slightly larger error bars, possibly due to the non-Gaussian nature of the residuals, so were used as the final uncertainties (Table II).

The uncertainties are extremely small, and beyond the level of precision to which we consider the light-curve model reliable. Maxted *et al.*[38] demonstrated a precision of 0·2% in the radii of the EB AI Phe, which is totally-eclipsing so is better-suited to such measurements. Based on this, we recommend imposing a minimum uncertainty of 0·2% on r_A and r_B.

Due to the small values of the uncertainties, we explored whether the solution really is as well-determined as it seems. We ran a set of fits in the same way as above but with k fixed at values between 0·90 and 1·20 in steps of 0·002. We chose this parameter as it is correlated with all other parameters of interest in the JKTEBOP fit (r_A, r_B, i, $\mathcal{J}$, $u_{A,B}$). We assigned a single error bar of size 0·702 mmag to every *TESS* data point to give a reduced χ^2 of $\chi^2_\nu = 1{\cdot}0$ for the best fit found above. A plot of the results (Fig. 3) shows that there is a single well-defined χ^2_ν minimum at the best-fitting k found above.

We then ran a set of fits for the same grid of k values but with the LD fixed to the theoretically-predicted values of $u_{A,B} = 0{\cdot}30$ and $v_{A,B} = 0{\cdot}22$. This is also plotted in Fig. 3 and shows a much narrower minimum in χ^2_ν at a slightly lower value of k. The best fit with fixed LD coefficients has an r_A lower by 0·81%, an r_B higher by 0·14%, and a χ^2 larger by 151. We conclude that this additional dependence on stellar theory produces a slightly different and worse fit that can be safely ignored, and that it is better to fit for LD when it is well determined by the available data.

We also ran a set of fits that were the same as the default solution but assuming $L_3 = 0$, which are also shown in Fig. 3. The overall best fit is almost identical to the default solution, but the χ^2_ν minimum is narrower because the fit

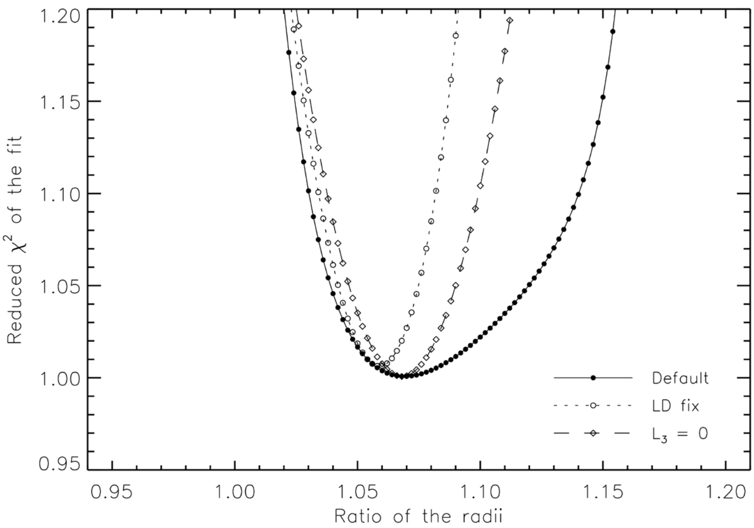

FIG. 3

Quality of the fit to the *TESS* data of ZZ Boo as a function of the ratio of the radii. Three different sets of solutions are plotted, as given in the legend.

is more constrained. Based on these tests, we are confident that the parameters in Table II are reliable and that the measured uncertainties are not clearly underestimated (apart from our argument above for a minimum of 0·2% on the fractional radii).

Orbital ephemeris

We now had a precise set of photometric parameters and a good orbital ephemeris. However, a higher-precision ephemeris defined over a longer timescale would be useful in our analysis of the RVs in the following section. We therefore measured the times of individual eclipses in the *TESS* data and performed a literature search to obtain reliable eclipse times for earlier epochs. All published epochs were either stated or assumed to be on the HJD_{UTC} timescale and thus converted to BJD_{TDB} before analysis.

We paid careful attention to ensuring that we chose the deeper of the two types of eclipse as the primary. The high quality of the *TESS* data makes this choice definitive, for the first time, as the eclipse depths can be determined to be 0·639 mag for the primary eclipse and 0·634 mag for the secondary eclipse (see Fig. 4). The similarity of these numbers has led to confusion in the past (see discussions in refs. 26 and 24) and demands care in interpreting orbital phases in past publications.

Once we had assembled the available times of minimum we used the ephemeris from only the *TESS* data in Table II to assign cycle numbers and eclipse types (primary or secondary) to them. We then fit them with a straight line to obtain a final orbital ephemeris:

$$\text{Min I} = \text{BJD}_{\text{TDB}}\ 2458942{\cdot}300641(7) + 4{\cdot}991765196(61)E, \qquad (1)$$

which is very precise because the eclipses are deep and V-shaped so are excellent fiducials, and because the first and last eclipses in the *TESS* data are separated

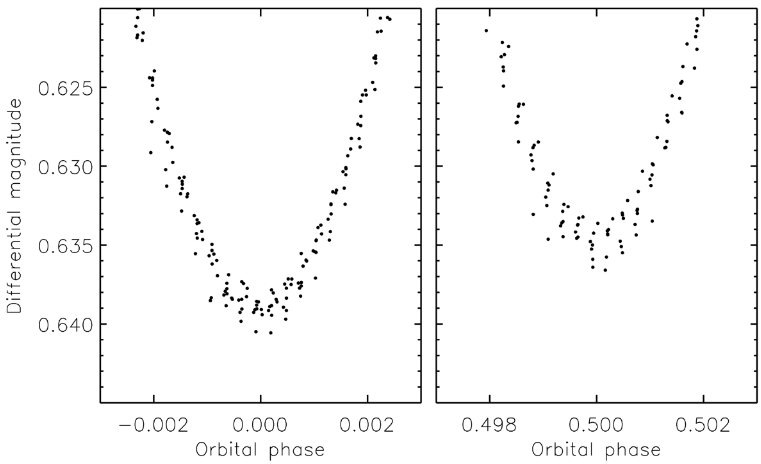

Fig. 4

Extreme close-up of the primary (left) and secondary (right) eclipses in the *TESS* data to show their different depths.

TABLE III

Times of published mid-eclipse for ZZ Boo and their residuals versus the fitted ephemeris.

Orbital cycle	*Eclipse time* (BJD_{TDB})	*Uncertainty* (*d*)	*Residual* (*d*)	*Reference*
−4082·0	2438565·9196	0·0100	0·0045	23
−3208·0	2442928·7177	0·0004	0·0002	41
−1237·0	2452767·4840	0·0016	0·0031	42
−800·0	2454946·39396	0·00050	0·00136	43
−720·0	2455345·7334	0·0007	0·0004	44
−2·5	2458929·821188	0·000010	−0·000040	This work
−2·0	2458932·317080	0·000008	−0·000031	This work
−1·5	2458934·813016	0·000019	0·000022	This work
−1·0	2458937·308911	0·000007	0·000035	This work
−0·5	2458939·804750	0·000010	−0·000009	This work
0·0	2458942·300615	0·000007	−0·000026	This work
0·5	2458944·796554	0·000009	0·000030	This work
1·0	2458947·292415	0·000012	0·000008	This work
1·5	2458949·788231	0·000014	−0·000058	This work
2·0	2458952·284195	0·000006	0·000023	This work
146·0	2459671·098352	0·000010	−0·000008	This work
146·5	2459673·594232	0·000005	−0·000011	This work
147·0	2459676·090125	0·000005	−0·000000	This work
149·0	2459686·073665	0·000006	0·000009	This work
149·5	2459688·569536	0·000005	−0·000002	This work
150·0	2459691·065431	0·000006	0·000010	This work

by 761 d. The times of minimum and their residual *versus* the final ephemeris are given in Table III. There is no evidence for non-linearity in the eclipse timings, in the sense that a quadratic fit to the timings gives an almost identical fit with a quadratic coefficient much smaller than its uncertainty.

We have extrapolated this ephemeris back to times of eclipse given by past authors to see how it compares to previous work. The time of primary minimum given by Popper[26] actually corresponds to a secondary minimum, so the masses of the two stars quoted by him should be swapped. The times of primary eclipse given by Miner & McNamara[22] and McNamara *et al.*[23] are indeed primary eclipses according to our ephemeris.

Radial velocities

Three sets of RVs have been published for ZZ Boo. Those from Popper[26] comprise 42 per star, were tabulated in that work, and were re-analysed here. Those from Nordström *et al.*[28] include 30 RVs per star, are available electronically from the CDS, and were also re-fitted here. Those from Lacy[27] are available only in plot form; we have been unable to access the original measurements so did not use them in the current work.

The Popper[26] RVs were fitted using JKTEBOP using the orbital period from the previous section and fitting for the velocity amplitude and systemic velocity of each star individually. We also fitted for the ephemeris zero-point to allow for any inaccuracies in the ephemeris or reported time-stamps, in light of our experience with ZZ UMa[45]. The Popper RVs are tabulated with time to three decimal places, RV to one decimal place, and no uncertainties. We therefore weighted the RVs for individual stars equally. We found, as expected, that we had to swap the identity of the two stars due to the different choice of which is the primary star. Uncertainties in the fitted parameters were determined using Monte Carlo simulations (see Paper 6, ref. 40). Our results are given in Table IV and are in excellent agreement with those of Popper[26]. Our systemic velocities

TABLE IV

Spectroscopic orbits for ZZ Boo from the literature and from the reanalysis of the RVs in the current work. All quantities are in km s^{-1}. The values from Popper[26] and Nordström et al.[28] have each been swapped to account for their different identification of which is the primary star.

Source	K_A	K_B	V_c	$V_{c,A}$	$V_{c,B}$	*rms residual*
Popper[26]	93·1 ±0·2	90·2 ±0·3		−28·4 ±0·2	−28·1 ±0·3	
This work	92·98 ±0·22	90·18 ±0·31		−29·72 ±0·21	−29·53 ±0·25	1·30, 1·60
Nordström *et al.*[28]	92·02 ±0·72	89·85 ±0·56	−29·50 ±0·27			1·86, 2·39
This work	92·31 ±0·16	90·12 ±0·29		−29·55 ±0·11	−29·12 ±0·19	0·53, 0·90
Final values	92·54 ±0·32	90·14 ±0·17				

are slightly lower: this is due to the addition of a +1·4 km s^{-1} correction by Popper from observations of an RV standard star, which he applied to his systemic velocities but not the individual RVs. The RVs and the best fits are shown in Fig 5.

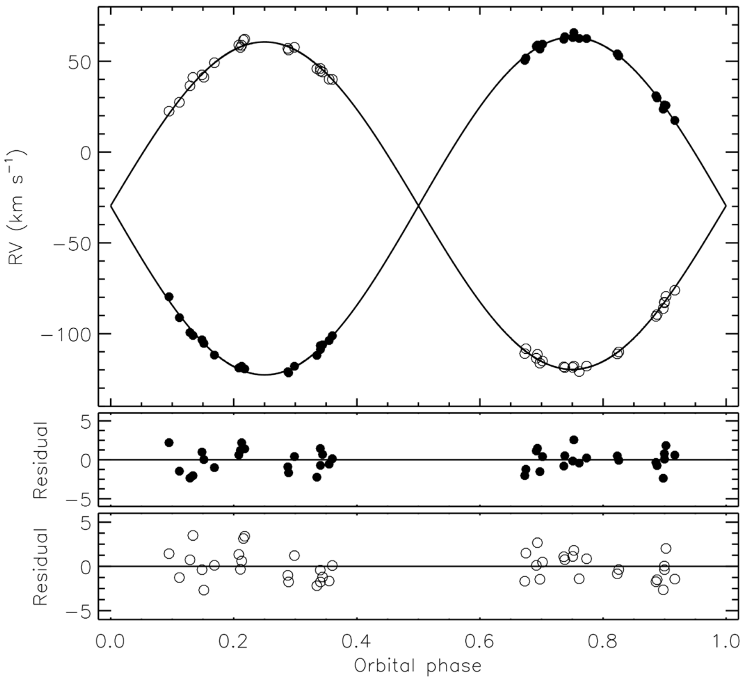

FIG. 5

RVs of ZZ Boo measured by Popper[26] (filled circles for star A and open circles for star B) compared to the best-fitting spectroscopic orbits from JKTEBOP (solid curves). The residuals are given in the lower panels separately for the two components.

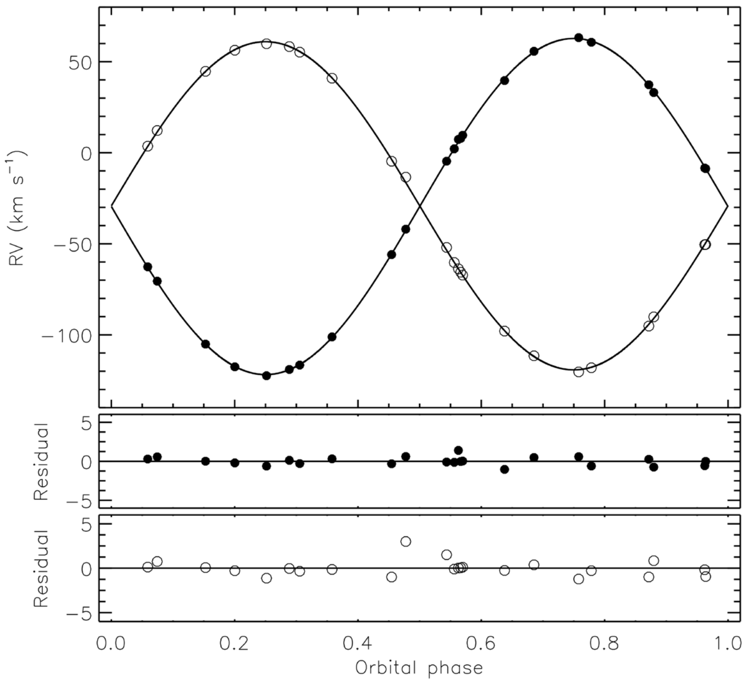

FIG. 6

RVs of ZZ Boo measured by Nordström *et al.*[28]. Other comments are as in Fig. 5.

For the Nordström *et al.*[28] RVs we proceeded in the same way but were forced to reject some observations. A subset of the spectra were obtained during eclipse and show a much larger scatter around the best fit, so we rejected all spectra taken within ±0·03 orbital phases of the midpoint of an eclipse. We also rejected the RVs from epoch 2447922·9251 because both were 5 km s^{-1} closer to the systemic velocity than predicted by the best fit — this could have been caused by an incorrect time-stamp or a problem with the observation itself. This left 23 RVs per star, which were fitted as were the Popper RVs. We had to swap the identities of the two stars here as well. The results are given in Table IV. Our results are in reasonable agreement with those of Nordström *et al.*[28], but with some differences due to our rejection of data we considered unhelpful. The RVs and the best fits are shown in Fig. 6.

Table IV shows that the spectroscopic orbits from the two sets of RVs agree well for star B but not for star A. The disagreement is lower than if we had adopted all of the Nordström RVs rather than rejecting those we considered to be less reliable. We decided that the best option was to combine the two velocity amplitudes for each star *via* a weighted mean. We then multiplied the error bar in the velocity amplitude of star A by the square-root of the χ^2_ν of the average to account for the small discrepancy between the two datasets. The results remain high-quality measurements of the orbital motion of the two stars.

Chromospheric emission

In order to investigate the possibility of magnetic activity, the Ca II *H* and *K* lines of several dEBs in this series have been observed using the *Intermediate Dispersion Spectrograph* (*IDS*) at the Cassegrain focus of the *Isaac Newton Telescope* (*INT*); see Paper 11, ref. 45. ZZ Boo is not a promising target for chromospheric emission due to its relatively high $T_{\rm eff}$, but was nevertheless included as its brightness meant a good spectrum could be obtained using minimal observing time. A single observation of 120-s duration was obtained on the night of 2022/06/07 in excellent weather conditions. We used the 235-mm camera, H2400B grating, EEV10 CCD and a 1-arcsec slit and obtained a resolution of approximately 0·05 nm. A central wavelength of 4050 Å yielded a spectrum covering 373–438 nm at a reciprocal dispersion of 0·023 nm px^{-1}. The data were reduced using a pipeline currently being written by the author, which performs bias subtraction, division by a flat-field from a tungsten lamp, aperture extraction, and wavelength calibration using copper–argon and copper–neon arc-lamp spectra.

The spectrum was obtained at orbital phase 0·5101 and is shown in Fig. 7. The Ca *H* and *K* line centres exhibit a higher flux than the synthetic spectrum provided for comparison, but this can be attributed to the rotational velocities of the component stars plus the velocity difference of 11·2 km s^{-1} between them at the time of the observation. There is no clear evidence for chromospheric emission (as expected) or for spot activity in the light-curves. We conclude that ZZ Boo does not show magnetic activity detectable with the currently available data.

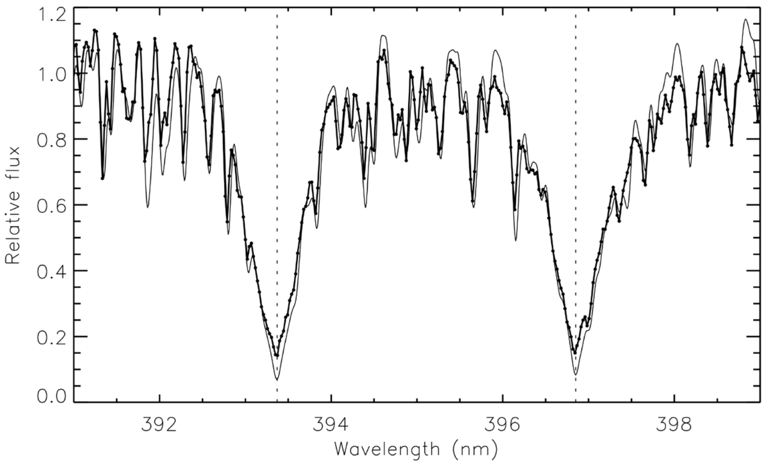

FIG. 7

Observed spectrum of ZZ Boo around the Ca II *H* and *K* lines (thick upper line with points) compared to a synthetic spectrum for a star with $T_{\rm eff} = 6700$ K, $\log g = 4{\cdot}0$ and solar metallicity from the BT-Settl model atmospheres[46,47] (thin line without points). The *H* and *K* line central wavelengths are shown with dotted lines. The spectrum of ZZ Boo has been shifted to zero velocity and normalized to unit flux.

Physical properties of ZZ Boo

We calculated the physical properties of ZZ Boo using quantities determined from the light-curve (Table II) and RVs (Table IV), standard formulae[48], and the reference solar values from the IAU[49]. The error bars on r_A and r_B were increased to 0·2% following the discussion above. We used the JKTABSDIM code[50], which propagates uncertainties using a perturbation approach. The results are given in Table V and show that the masses are determined to 0·5% and 0·8%, and the radii to 0·2% precision. The relatively low precision of K_A, due to the minor disagreement between the two sources of published RVs, is the main source of uncertainty in the masses. The radii are measured to a precision an order of magnitude better than the previous determination by Popper[26] due to the high quality of the *TESS* light-curve. The measurements of ZZ Boo are now good enough for it to be included in the *Detached Eclipsing Binary Catalogue* (*DEBCat**, ref. 3)

TABLE V

Physical properties of ZZ Boo defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 49).

Parameter	*Star A*	*Star B*
Mass ratio	1·0266 ± 0·0040	
Semi-major axis of relative orbit ($R^N_\odot$)	18·024 ± 0·035	
Mass ($M^N_\odot$)	1·5572 ± 0·0080	1·599 ± 0·012
Radius ($R^N_\odot$)	2·0626 ± 0·0057	2·2050 ± 0·0062
Surface gravity (log[cgs])	4·0016 ± 0·0019	3·9550 ± 0·0023
Density ($\rho_\odot$)	0·1775 ± 0·0011	0·1491 ± 0·0009
Synchronous rotational velocity (km s^{-1})	20·905 ± 0·058	22·348 ± 0·062
Effective temperature (K)	6720 ± 100	6690 ± 100
Luminosity log($L/L^N_\odot$)	0·893 ± 0·026	0·943 ± 0·026
M_{bol} (mag)	2·507 ± 0·065	2·382 ± 0·066
Distance (pc)	106·5 ± 1·4	

The T_{eff} values of the stars are very similar: from the surface-brightness ratio we find a T_{eff} ratio of 0·99497 ± 0·00008. The F3 V spectral type of the system corresponds to a T_{eff} of 6720 K (ref. 51), Popper[26] gave 6669 ± 31 K for both stars, and Nordström *et al.*[28] used template spectra at 6750 K for their RV measurements. However, rather higher T_{eff} measurements of 6860 ± 20 K and 6930 ± 20 K were found by Kang *et al.*[30], prompting us to obtain our own values. We thus determined the distance to the system using the surface brightness *versus* T_{eff} relations from Kervella *et al.*[52], the *K*-band apparent magnitude from 2MASS (Table I), and adopting an interstellar extinction of $E(B-V) = 0{\cdot}00 \pm 0{\cdot}01$ because the system is close to the Sun. We found the best agreement with the *Gaia* parallax distance (106·44 ± 0·36 pc) if the stars have a T_{eff} of 6705 K, and assigned a conservative uncertainty of 100 K. Accounting for the small T_{eff} difference we therefore adopted values of 6720 and 6690 K. An improved T_{eff} measurement using the *Gaia* parallax and apparent magnitudes will be presented in future.

From Table V we can see that the primary star is hotter, but smaller and less massive than its companion. The higher T_{eff} is confirmed to very high significance from the surface-brightness ratio in Table II. Both are significantly evolved, so this situation is not anomalous. We compared the properties of the

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

component stars to predictions from PARSEC models[53] *via* the mass–radius and mass–T_{eff} diagrams[54,55]. Assuming a solar chemical composition (fractional metal abundance $Z = 0.017$), we found a good match for an age of 1·7 Gyr. The T_{eff} values of the stars are slightly too low for their radii, and a better agreement would be obtained for T_{eff} values larger by 50 K. This is in line with the higher T_{eff} values found by Kang *et al.*[30]. We plot a Hertzsprung–Russell diagram in Fig. 8 which shows that the stars are reasonably consistent with the PARSEC models and that they are evolved into the upper half of the main-sequence band.

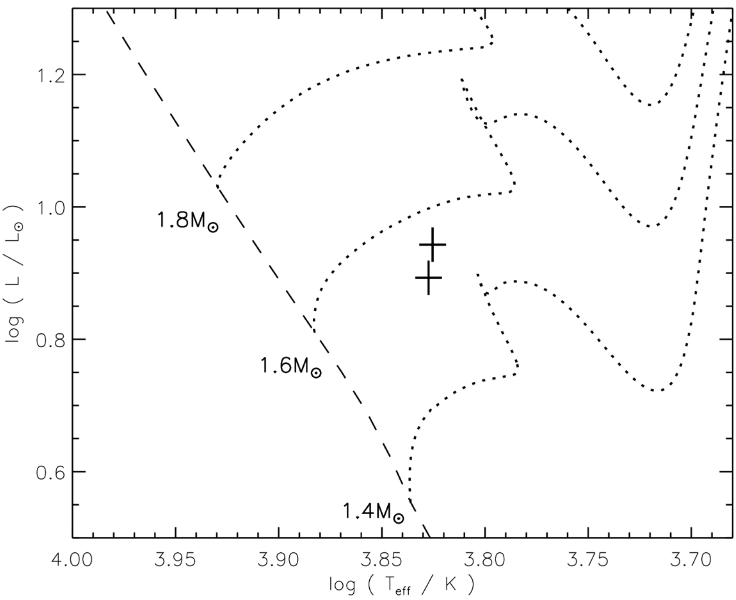

FIG. 8

Hertzsprung–Russell diagram showing the components of ZZ Boo (solid crosses) and selected predictions from the PARSEC models[53] (dotted lines) beginning at the zero-age main sequence (dashed line). Models for 1·4, 1·6, and 1·8 $M_{\odot}$ are shown (labelled), for a metal abundance of $Z = 0.017$.

Summary

ZZ Boo is a well-known and extensively studied dEB containing two F3 V stars of very similar mass but significantly different radii orbiting with a period of 4·992 d. We have analysed the light-curves of this object from two sectors of the *TESS* mission, obtaining photometric parameters to very high precision. We have reanalysed two available sets of RVs to determine the spectroscopic orbits of the stars and thus their full physical properties. Divergent T_{eff} determinations exist in the literature so we obtained our own by requiring the distance to the system to match that measured from its *Gaia* parallax.

Following standard conventions, we defined the primary eclipse to be deeper than the secondary eclipse, and star A to be at inferior conjunction during primary eclipse. Although the eclipse depths are very similar they are measurably different in the *TESS* data so, for the first time, it is possible to define unambiguously which star is star A. We find that it is hotter but smaller and less massive than its companion: the surface-brightness ratio is convincingly below 1·0 whereas the mass ratio is conclusively above 1·0. We assembled a set of published and new times of minimum light and obtained a new ephemeris from which orbital phases can be calculated to high precision for the forseeable future.

The two stars have evolved into the second half of the main-sequence band, and the greater evolution of star B is clear. The properties of the system are consistent with the PARSEC models for an age of 1·7 Gyr and a solar chemical composition. The similarity of the two stars, coupled with their slightly different evolutionary status, means ZZ Boo may be useful in future for helping to constrain and calibrate theoretical models of stellar evolution. A spectral analysis based on high-quality spectra would be helpful to determine the atmospheric parameters of the two stars more accurately.

Acknowledgements

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CORRESPONDENCE

To the Editors of 'The Observatory'

The View from the Bottom

History in textbook astronomy is rarely as simple as it is presented to be. For instance, an astronomical expedition does not end until the formal report is written. The author is normally the senior member, writing as if at great height above events. But what if the reporter was the most junior member of an expedition? His or her viewpoint would be from the 'bottom' looking up!

In 1869, Professor Stephen Alexander (1803–1883; Princeton University) submitted his précis, on that year's solar eclipse, as a United States government document.[1] In it, it is easy to miss that Alexander brought with him, to the path of totality, a last-minute addition to his team: one of his undergraduates. This anonymous Princetonian ("Kepler Copernicus") wrote of his experiences, too.[2] Were there any differences in the two men's stories?

We learn from our correspondent for the student newspaper that — far from Alexander going it alone — there were no less than five young assistants along to help him (at least two of whom fell in love with young women on the train).[3] Alexander details the effort required of his team for set-up in remote Ottumwa, Iowa; no one else is mentioned.[4] Copernicus tells us of the railroad men, carpenters, and other locals who helped but also quotes 'an Irishman' grousing, "Och, Pat, do you know that these men get $5,000 for a few days' work up there, and we are taxed to pay for it?"[5]

The formal report stresses that a temporary hilltop observatory was constructed according to specifications written by the Superintendent of the United States Nautical Almanac Office (Alexander's sponsor).[6] Copernicus skips this and finds it more interesting that: ". . . many ladies visited the Hill on Friday . . . as a return, all who were present received handsome bouquets, with ribbons and cards attached, with the names of the fair donors."[7]

Alexander recalls a fawning citizenry, ". . . who endeavored even to anticipate their wants, their earnest wish to supply them with kindness as evidently heartfelt as it was unostentatious."[8] Copernicus sees an Ottumwa more diverse in its opinions: "A man in town reported that there was a lot of fools up on the hill to see an eclipse. He asserted that there never had been such a thing and never would be."[9]

Alexander's version of eclipse activities unfolds just as planned.[10] Copernicus's is bumpier: "The transit instrument had been very carefully fixed on a table and its bearings ascertained. In the meanwhile someone came along and turned the instrument and its telescope toward the High School, had a view, and then very nicely put it back; and though very neatly replaced, all the previous calculations had to be also neatly replaced . . .

Two of us were on guard on Thursday night. Early on Friday morning a heavy rain and wind set in. Our roof was not made to endure such treatment, and soon began to leak very badly. The chronometers, &c., were put under an umbrella we fortunately had. Then one corner of the roof blew off entirely.

The telegraphic wire hung over the corner of the screen [to protect an instrument until totality], so that persons might pass under the wire . . . some person caught his foot in the wire and broke it, so all the record after that time was lost. The person also at the chronometer misunderstood a sign of the Professor's, and did not record the time several seconds before the totality."[11]

Official reports make it into our textbooks. Yet remember that for every Alexander, in his shadow probably stands a Copernicus!

Yours faithfully,
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On Militarization of the Moon

As one of the book's contributors, I enjoyed the review by Ian Crawford of *The Human Factor in the Settlement of the Moon* and his conclusion that "…on balance I think the editors have done a good job in producing a wide-ranging summary of societal issues that will surely be relevant if and when humans choose to settle our nearest celestial neighbour."[1]

Still, while I join the reviewer in sincerely hoping that there will be no international military competition on the Moon, the current facts indicate our expectations may need to be modified. Since the book was published, the Administrator of NASA, Bill Nelson, warned in an interview in the German newspaper *Bild* on 2022 July 2, that, "We must be very concerned that China is landing on the moon and saying: 'It's ours now and you stay out.'"[2]. This warning by a senior US official reflects the US Administration's concern over potential Chinese threat to exclude the US from the Moon.

Further, while the reviewer rightly invokes international treaties which forbid militarization of the Moon and Outer Space, there are key signatories missing from a more recent treaty specifically concerning the Moon, and these include the US and China[3]. The treaties, and the concerns from not all of them being binding, are addressed in the book.

I suggest our reaction to this situation should be to work side by side with the best informed to lessen the consequences of what will probably be a military presence in space.

Yours faithfully,
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REVIEWS

Understanding the Diversity of Planetary Atmospheres, edited by François Forget *et al.* (Springer), 2022. Pp. 591, 24 × 16 cm. Price £159·99/$219·99 (hardbound; ISBN 978 94 024 2125 5).

This substantial volume is a set of papers taken from a topical collection published in *Space Science Reviews*, inspired by a meeting held in 2018 at the International Space Science Institute in Bern, Switzerland. The number of known exoplanets continues to rise rapidly* and research into exoplanetary science increases at a similar rate. The sheer number and range of exoplanetary environments have introduced the possibility of broad statistical studies into planetary evolution and characteristics. Of the 5000+ known exoplanets, many are thought to have atmospheres, which immediately raises questions about why some planets develop and retain atmospheres, yet others do not. Despite the clear novelty and excitement value of exoplanets, Solar System planets and their atmospheres remain important to the study of exoplanets for two reasons. Firstly, exoplanetary science encourages a fresh look at better-known atmospheres: the ice-giant planets Uranus and Neptune turn out to be exemplars of a significant family of exoplanet atmospheres. Secondly, the huge distances involved can make it difficult to obtain and analyse exoplanet data from Earth or near-Earth space, so the analogies offered within our own Solar System can be surprisingly useful.

The book follows the broad approach outlined above. Some chapters consider the formation, development, and, potentially, loss of planetary atmospheres, both within our Solar System (with Mars as a case study of atmospheric loss) and beyond. There are several chapters on atmospheric dynamics, from giant planets to super-rotation to a comparison with brown dwarfs. Brown dwarfs are objects resembling stars that are not massive enough for fusion of hydrogen. Their hydrogen atmospheres make them high-mass, hotter versions of the giant planets. Because of this, and as brown dwarfs can be easier to observe than exoplanets, their dynamics and atmospheres can be used to study giant-planet dynamics more generally.

One paper highlights generic processes in atmospheric chemistry that lead to common modelling approaches. The tools and techniques that can be used to understand planetary atmospheres are also considered, specifically, atmospheric retrievals and the applicability of space missions within our Solar System. The volume includes a case study of an exoplanetary system, TRAPPIST-1, containing several terrestrial-size and terrestrial-mass planets. If these exoplanets had atmospheres, they could potentially be habitable, a question of huge interest to humanity. The tools, techniques, and existing work to investigate this question are reviewed, and (spoiler alert) some possibilities are found, particularly TRAPPIST-1e (the fourth planet out) which may be able to sustain surface liquid water. Finally, there is a touching tribute to the late Adam Showman (1968–2020) who contributed to four of the papers, one as first author.

This book does live up to its title on diversity of planetary atmospheres, giving a useful overview of the state of the art of every aspect — from origin and loss of atmospheres to their weather systems and how best to study them. The inclusion of a broad-brush overview paper might have provided a gentler introduction to the subject for the undergraduate-project student or beginning graduate student. Such an approach can be particularly useful for interdisciplinary topics

*At the time of writing over 5000 exoplanets are listed on the Caltech Exoplanet Archive.

such as exoplanetary science, which sits between astronomy, geophysics, and atmospheric science. This growing research area may attract scientists (not just early-career individuals) with backgrounds in any of these fields as well as the more traditional physics and mathematics. A strength of this volume is that the book is rich in helpful graphics and diagrams that illustrate the many interwoven processes at work in this complex and fascinating topic. — Karen Aplin.

The Elephant in the Universe: Our Hundred-Year Search for Dark Matter, by Govert Schilling (The Belknap Press of Harvard University Press), 2022. Pp. 376, 21·5 × 14·5 cm. Price £23·95/$29·95 (hardbound; ISBN 978 0 674 24899 1).

This is an English-language book (not a translation*) by a well-known Dutch popular-science writer (who even has an asteroid named after him). As Peebles[1] (reviewed in these pages[2,3]) wrote, there are several kinds of dark matter: "the astronomers' subluminal matter", "the particle physicists' nonbaryonic matter", and "the cosmologists' dark matter"; this book covers them all, but without making the distinction so explicit (the Dutch subtitle — see footnote — reflects that trinity to some extent, though). (Which of those types might turn out to be the same and whether there is some alternative explanation for some phenomena attributed to dark matter remain to be seen.) The title will probably cause many readers to think first of 'the elephant in the room', which refers to something obvious which people avoid discussing even though they should. That doesn't really fit here, and the book starts with a famous poem[4] (though based on much earlier sources) about how various blind men differ in their description of an elephant based on the small part which each has sampled.

After the poem is a foreword by Avi Loeb (whose book[5] on a completely different topic was recently reviewed[6] in this *Magazine*) and the seven-page introduction, about half of which is a summary of the contents. The 25 main chapters are divided into three parts which roughly reflect the different types of dark matter mentioned above: 'Ear' is mainly about the astronomers' subluminal matter, 'Tusk' mainly about the cosmologists' dark matter, and 'Trunk' mainly about the particle physicists' non-baryonic matter but also includes chapters on current 'tensions' in cosmology and possible explanations.

While this is a book mainly about science, many scientists are mentioned by name, several of whom were also interviewed for the book, and for a score or so there are capsule biographies. There is some discussion of the politics of science, individual scientists' motivations, and so on. While not taking sides on the science, in such areas Schilling doesn't hold back on his opinion regarding such things as the secrecy of the *DAMA* experiment (a laboratory experiment which has claimed to have detected dark matter and the predicted seasonal oscillation in the number of events, but which has not been confirmed by any other experiment). He does mention more names than in most popular-science descriptions of the history of dark matter, his description of the saga starting with a century-old paper by Kapteyn[7]. Most of the usual suspects are here (see my summary in these pages[8] for more details and references).

Of course, no description of the history of dark matter would be complete without mentioning Vera Rubin, whom Schilling would certainly have interviewed had she still been alive (we do get an interview with her long-term collaborator Kent Ford). Schilling discusses her work and the observatory

*There is a Dutch version, *De Olifant in het Universum: Donkere materie, mysterieuze deeltjes en de samenstelling van ons heelal* (same title, different subtitle), but it was translated from English by Eddy Echternach.

named after her but also important figures less known to the general public, such as Albert Bosma. My impression is that her contribution is properly appreciated (by Schilling and by almost everyone else familiar with the field) as one of many in a very long tale stretching back decades or even centuries (depending on what one considers to be dark matter). Alas, neither would any description of the history of dark matter be complete without mentioning the question whether Vera Rubin was somehow overlooked (especially with regard to a Nobel Prize) and if so whether (as most who claim that also claim) that was due to the fact that she was a woman. The journalist Schilling lets many (mostly women but also some men who have made substantial contributions to the field) have their say (either in his own interviews or in quotations from other sources). Lisa Randall claims that dark-matter work deserves a Nobel Prize, but perhaps none will be awarded, since Rubin has died, adding that "[t]he elephant in the room is gender" when discussing other female scientists claimed to have been overlooked. Katherine Freese: "Rubin and Ford ... deserve a Nobel Prize". Neta Bahcall: "[H]er ground-breaking work confirmed the existence of dark matter". Seth Shostak: "It's true that Vera came late to the party", going on to point out, as does Schilling, that Rubin never claimed priority and had cited works by Bosma and Mort Roberts and collaborators. Albert Bosma: "[Bahcall's piece] oversimplifies the dark matter problem. ... a lot of reinterpretation ... is outright wrong". Sandra Faber is reported as stating that Rubin's current record in history has actually been helped by the fact that she was a woman before adding "Bosma's thesis is brilliant. Two hundred years from now people will certainly realize how important his contributions have been."

The elephant in the room is that no-one has been awarded a Nobel Prize for what is normally thought of as dark matter, which seems in line with the conservative (in that respect) interpretation of Nobel's will by the Nobel Foundation, insisting on an "invention or discovery", which in the case of dark matter would probably imply either direct detection or having ruled out all other possible explanations (as was the case for the 2020 awards for theoretical and observational research on black holes). So believing that she was passed over for a Nobel Prize means believing that the Nobel committee would have, despite its behaviour in similar cases, thought that dark-matter research is worth a Nobel Prize, thought that Rubin should receive one, possibly shared with others, but decided to award none rather than award (at least a share of) one to a woman; the second is believable (if given the first), the first and third less so. If a Nobel Prize is awarded for astrophysical dark matter, then the correct thing to do would be to split it between the three who contributed most who are still alive; Rubin would probably have been on that list had a Prize been awarded before her death.

Of course, only a small part of the book is about Vera Rubin, and astrophysical dark matter, in particular flat rotation curves of spiral galaxies, is just one topic. But her story is told as part of a larger story, and various lines of evidence in favour of perhaps various kinds of dark matter are presented in a balanced way. Again with the page count roughly reflecting the size of the corresponding community, supporters of MOND and similar alternatives to (some kinds of) dark matter also get a voice. Schilling thus covers a lot of material, but the 25 chapters structure it well and one doesn't lose sight of the forest for the trees. I noticed no real mistakes and only a few things I put down to typos or bad editing. There are a few black-and-white figures, mostly photographs, scattered throughout the book. There are no footnotes. The end notes (indicated by superscript numbers in the main text) are mostly references to primary literature. The thirteen-page small-print index is especially thorough.

Perhaps because Schilling is primarily a journalist (though self-taught both in that field and in astronomy), his book is balanced, rather than presenting a more or less thinly disguised plea for one's own point of view, as is the case with some popular-science writers who work in the field in question. (There is nothing wrong with that, and in fact some of the best popular-science writing is in that vein — the late Stephen Jay Gould comes to mind — but it can be confusing for non-experts who aren't aware of what is consensus, what is speculative, and what is generally regarded as just wrong.) While it is true that WIMPs get more pages than other dark-matter candidates, that is probably due only to the fact that more research has been devoted to them. His impartiality is one reason to recommend the book. All in all, it is a non-technical, historical, personal, up-to-date, correct, balanced, well-written, and well-researched book. — PHILLIP HELBIG.

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Particles in the Dark Universe. A Student's Guide to Particle Physics and Cosmology, by Yann Mambrini (Springer), 2021. Pp. 502, 23·5 × 15·5 cm. Price £74·99 (paperback; ISBN 978 3 030 78138 5).

This book is not for the faint hearted. So say Keith Olive, P. J. E. Peebles, and Joseph Silk, in their foreword. All three are thanked as mentors by author Yann Mambrini, who was formerly a student of the late Pierre Binetruy. The author is at 'Laboratory of the Physics of the Two Infinities Irene Jolio-Curie (IJCLab) CNRS/University Paris-Saclay, Orsay, France'. His target readership includes theoretical physicists who deal with particle physics in the Universe, dark-matter detection, and astrophysical constraints; particle physicists who are interested in models of inflation or reheating; and astrophysicists who work with quantum-field-theory computations. The author says he hopes to catch them at the master's degree level, and the questions he quotes some of his students as having asked in class suggest they are impressively masterful!

So what is here? First an introduction to the observations generally regarded as evidence for dark matter, probably consisting of cold particles. There follow extensive chapters tracing the history of the Universe (Chapter 2) from the Planck time, through inflation and reheating (Chapter 3), from reheating to the Cosmic Microwave Background being liberated, and then (Chapter 4) methods of direct detection, and (Chapter 5) a dog's breakfast of properties of galaxies, radiative processes, relativity, Sommerfeld, Schrödinger, Coulomb, and Yukawa, and structure formation. There are also Appendices dealing with cosmology and astrophysics, particle physics, neutrino physics, and "Useful statistics".

Exercises for the student are scattered through the text (some 'show thats' and some calculations), and each chapter has its own references. His favourite relativity text is Hartle, and his favourite advanced electromagnetic text Jackson.

In keeping with his particle-physics background, Mambrini attempts to express everything in units of GeV^{-2} , but claims in the preface that it is always possible to convert jansky to joule and that the necessary conversion factors are in the Appendix (Appendix E actually). Some are wonderful! Did you know that the age of the Universe is $6{\cdot}6 \times 10^{41}$ GeV? But neither joules nor janskys appear. To my antiquated astronomical mind, the joule is an energy, while a janksy is 10^{-26} watts per square metre per Hz. This is at least energy per unit area, even if you let the reciprocal time in Hz cancel the time in watts = joule per second. Thus I don't see how you can convert one to the other, no matter how many reciprocal GeV you exert.

The sections I found it easiest to cope with were ones dealing with topics I thought I might already understand (solar neutrinos, Big Bang nucleosynthesis). For you it might be these, or others, or all, or none.

Some items are interesting even if one doesn't entirely grasp the derivations. We are, for instance, assured that "no 5σ signal in a particle experiment has up to this point ever turned out to be a fluctuation." On the other hand, Fred Reines used to point out that half of all three-sigma results turned out to be wrong. The author provides an interesting name for one of the reasons. Consider the case where you have found something that you think has only a 10^{-3} chance of being a statistical fluctuation (whether it is the number of counts in a particular energy bin or the excess rate with which red-headed dogs caught collywobbles last year). Before deciding whether this is a great truth, you must multiply by the number of other results that you would have found equally interesting (excess count in 24 other possible channels, excess collywobbles in each of the other dog samples with different colour hair). If that number is fairly large, your great truth is likely to degenerate to a statistical fluctuation. The author calls this the Look-Elsewhere-Effect or LEE. The only name I had known before was "multiply by the number of other cases you would have found equally interesting", which does not lend itself to acronymization.

None of the physicists, mathematicians, *etc.*, whose work is quoted or who has given a name to a diagram, effect, or process gets a first name. You won't even notice this for Einstein, Feynman, Gell-Mann , or Landau, but I claim ten bonus points for Wendell Furry, who had a theorem about the vanishing of the expectation values of all Feynman diagrams with an odd number of legs (I have a secret suspicion that this is what makes tired light not work as an alternative to cosmic expansion, but wouldn't bet on it).

The copy-editing process at Springer has not served the author well. This sometimes impedes understanding. For instance, in a discussion of MoND (which Mambrini does not regard as very attractive) we are told "But there is an ensign between the properties required of the neutrinos and current data". Promotion of the ensign to second lieutenant seems unlikely to help.

There must have been something contagious about the anti-editing, to be seen, if we give the foreword writers (who are all native speakers of English) the last word. They assure us, "Split into two chapters, the reader will find ... " — Virginia Trimble.

What is Dark Matter?, by Peter Fisher (Princeton University Press), 2022. Pp. 189, 21 × 13·5 cm. Price £28/$35 (hardbound; ISBN 978 0 691 14834 2).

Peter Fisher is a particle physicist and professor (and, until recently, department head) at the Physics Department of MIT. Perhaps for that reason, this book concentrates more on particle dark matter than another book[1] reviewed[2] in these pages (see p. 37), and is pitched at a slightly lower level; at a bit more than half the length it is of course less detailed and is meant as a very general non-technical introduction to dark matter. The book opens with some very general physics background before discussing astronomical evidence for dark matter; it then introduces the standard model of particle physics followed by a discussion of what dark matter is not (*i.e.*, candidates which have been ruled out). That sets the stage for the discussion of particle dark matter such as WIMPs and axions and its direct detection in the lab, observing its decay by various astronomical means, and, to a lesser extent, detecting dark-matter particles produced in accelerators. (Those methods have been termed — though not in this book — 'shake it', 'break it', and 'make it'; to those one might add 'fake it', *i.e.*, explain phenomena normally attributed to dark matter by some other mechanism such as modified gravity — MOND is mentioned briefly in the book.)

I found several things disturbing or at least annoying, such as quoting the distance of the Moon as "239,228 miles or 385,000 km". The distance varies, of course, but no sort of average distance is a round number in any units — 239 228 is obviously converted from the round figure 385 000 (the exact value of the conversion is 239 227·90901), recalling the museum guide who said that a dinosaur skeleton was 220 000 030 years, seven weeks, and three days old. ("Well, I started working here 30 years, seven weeks, and three days ago, and back then they told me it was 220 million years old.") I don't think that introducing the parsec would be too much for readers, but in any case "lt-yr" and multiples such as "klt-yr" and "Mlt-yr" are not common notation (for what it's worth, the official IAU abbreviation for 'light-year' is 'ly' and that of ISO 80000 'l.y.'.) It has been decades since I've seen indigo being listed as one of the rainbow colours in a new book. Rather bizarre is the claim, mentioned both in the text and in the glossary, that 'nebula' is German for 'foggy'. Actually, German for 'foggy' is '*nebelig*'. Apart from the fact that both German '*Nebel*' and English 'nebula' both come from Latin '*nebula*', such detail is superfluous (even if it were correct). The unqualified remark that a billion is a million million in the UK is at best confusing, since the short scale has become increasingly common there in the last half century or so. He also repeats the common confusion regarding the term 'Hubble constant', claiming that that refers only to the value today and that in the early days of relativistic cosmology it was not understood that it can vary with time. (In contrast to the cosmological constant Λ, which is, by definition, constant in time, the Hubble constant gets its name from the fact that it is the constant (for all D at a given time) coefficient in the equation $v = HD$ relating the recession velocity to the proper distance, the so-called Hubble(–Lemaître) Law.) Similarly, the claim that supernova cosmology discovered that galaxies "receded faster than predicted by Hubble's Law" is simply wrong; in an FRW universe, galaxies always recede at the velocity given by the equation above[3]. (It is also not the case that the pre-supernova-cosmology standard cosmological model included the Hubble Law while the current version no longer does.) In any case, no-one has (yet) directly (in any meaningful sense) measured the recession velocity of any object at a cosmological distance. The first-order result of supernova cosmology is that supernovae appear fainter than expected. Even with a generous interpretation of his claim, that result means that, because the current Hubble constant is fixed and the Universe is accelerating, in the past supernovae were receding *less* rapidly (which means that light from an object at a given redshift just reaching us now has travelled a longer distance, which is the reason for the object appearing fainter). Einstein's first paper on relativistic cosmology didn't include "something like a cosmological constant", but rather *the* cosmological constant itself. Dark energy (whether a cosmological constant or something more complicated) doesn't "drive the expansion of the universe": universes without dark energy can expand, and those with can contract. An image of the gravitationally lensed quasar 2237+0305 (the 'Einstein Cross') is described as five, rather than four, images of one quasar (the central, noticeably different, image is the lensing galaxy; one does expect a fifth image behind the lens galaxy, but *much* fainter). Microlensing does not rule out primordial black holes of several million solar masses being most of the dark matter. MOND modifies the law of gravity at *small accelerations*, not *large distances*. I'm not sure how he arrived at the claim that "[d]uring its first 10^{-36} seconds, the universe was small enough that light could travel across it in the time the universe had existed." At the end of the chapter on the standard model of *particle physics*, there is a paragraph on MOND and a reference to the previous chapter, where it is mentioned; the paragraph seems completely out of place and the reference at least makes it appear that it is not a copy-and-paste error. Spelling 'Lemaître' as 'LeMaître' is bizarre; at least we don't have 'FriedMann'. The glossary entry for 'tidal force' mentions tides on Earth caused by the Sun but not those caused by the Moon.

Most of the mistakes (there are more) involve astronomy, astrophysics, or cosmology, presumably reflecting the fact that the author is a particle physicist (though that shouldn't be an excuse). In all chapters, though, there are things which are confusingly formulated, and goofs such as mentioning the colour of a curve in a black-and-white diagram. Proper editing would have corrected such oversights, but in many respects the author seems to be genuinely confused.

There are a few black-and-white figures scattered throughout the book, footnotes rather than endnotes, and the book ends with a too-detailed glossary (I don't think that any reader needs to be told what an astronomer is) and an index of eleven pages each. Although not a bad book on the whole, there are too many annoying things which could have been easily fixed by good editing and proof reading by someone familiar with astronomy and cosmology: simple mistakes, matters of style, suggestions for further reading which are good but not relevant to the subject, a too-strong emphasis (especially for an introductory book) on particle dark matter. The book is part of the *Princeton Frontiers in Physics* series. It is useful to have introductory books at this level; hopefully others in the series are better produced. (One is by Avi Loeb who, as I recently noted in these pages[4], is a fine writer.) Schilling's book[1] covers a bit more ground and is more balanced and better written, so I find myself recommending that book rather than this one as a non-technical introduction to dark matter. — Phillip Helbig.

References

(1) G. Schilling, *The Elephant in the Universe: Our Hundred-Year Search for Dark Matter* (The Belknap Press of Harvard University Press), 2022.
(2) P. Helbig, *The Observatory*, **143**, 37, 2022.
(3) E. R. Harrison, *ApJ*, **403**, 28, 1993.
(4) P. Helbig, *The Observatory*, **142**, 184, 2022.

General Relativity and Gravitational Waves. Essentials of Theory and Practice, by Sanjeev Dhurandhar & Sanjit Mitra (Springer), 2022. Pp. 207, 24 × 16 cm. Price £54·99 (hardbound; ISBN 978 3 030 92334 1).

This book is targeted at students completing a master's-level course on General Relativity and gravitational waves. It aims to provide a student with no previous background in relativity with enough knowledge to understand the principles underlying gravitational-wave detection. It achieves this aim well. The topics covered include Special and General Relativity, differential geometry and black holes, before finishing with gravitational waves. These provide a good introduction to General Relativity, while still focussing on the tools necessary to understand gravitational waves. Each new concept is first motivated physically before the mathematical description is introduced, meaning that the mathematics is always placed in context. Particular highlights of the book are the chapters on the equivalence principle and on the classical tests of General Relativity, which are both short but concisely and completely cover the material. The presentation in the book is generally very clear and to the point. Key derivations are clearly highlighted in text boxes and each chapter ends with a selection of useful exercises illustrating the themes of the chapter. Where the book falls short is in some of the choices made about what topics to include. Having stated that the aim of this book is to have all necessary material in a single volume, the authors regularly refer to other books and scientific papers for certain results. While in many cases this is justified by technical complexity, some derivations could easily have been included in this volume and enhanced its value. In the section on gravitational-wave detectors, there is a thorough description of ground-based interferometers, but the description of space-based detectors and pulsar timing arrays is cursory at best, and no attempt is made to highlight key differences. The chapter on gravitational-wave data analysis gives a very distorted view of this topic, focussing almost entirely on detection through matched filtering, and effectively ignoring parameter estimation. The authors should have devoted a few pages to describing the Bayesian methods that underpin the majority of current gravitational-wave inference. These omissions could make this a frustrating book to use when teaching a course, as it constrains the topics that could be included. Nonetheless, there is still much to like, in particular the way in which the mathematics is motivated by the underlying physics. It will make a good addition to a gravitational-wave physicist's shelf. — Jonathan Gair.

Principles of Multimessenger Astronomy, by Miroslav D. Filipović & Nicholas F. H. Tothill (IoP Publishing), 2021. Pp. 255, 26 × 18·5 cm. Price £75/$120 (hardbound; ISBN 978 0 7503 2338 3).

Multimessenger Astronomy has become a 'buzzphrase' since the publication in 2016 of the first measurements of gravitational waves. The basic sense was that the advent of measurements using gravitational waves had broken the monopoly of electromagnetic radiation in observational astronomy. This was known not to be strictly true, because information from outside the Earth had been received and interpreted in the form of cosmic rays since the first decades of the 20th Century, and neutrinos from the Sun and from supernova SN1987a had, before the turn of the millenium, opened another channel to our understanding of the wider Universe. In their textbook *Principles of Multimessenger Astronomy*, Miroslav Filipović and Nicholas Tothill aim to present a students' systematic introduction to the sub-fields included in the term.

The first and biggest chapter of the book gives a descriptive overview of the whole subject, in terms of the techniques used for the full gamut of observations. This includes the authors' definitions of the four main channels for receiving information from the universe: photons, cosmic rays, neutrinos, and gravitational waves. They have chosen not to include a major source of our knowledge, the physical and chemical analysis of meteorites, lunar, cometary, and Martian samples, presumably because they think this would have made an unwieldy contribution. A list of the following chapters gives us 'Electromagnetic

Radiation', 'The Measurement of Cosmic Messengers', 'The Transfer of Electromagnetic Radiation through Space', 'The Earth's Atmosphere', 'Emission Mechanisms of Electromagnetic Radiation', 'Particle Physics: Gamma Ray, Cosmic Ray, and Neutrino Astronomy', 'Gravitational Waves and their Production', and 'Obtaining and Interpreting Astronomical Data'.

When reading the book I kept very much in mind its textbook aims, and asked myself how useful the contents and format would be if I were studying the subject. A complete answer would depend very much on the stage of my studies and background. A 'standard' physics student whose course did not include astronomy would gain the most. The chapter on electromagnetic radiation, for example, gives a good account of its basic properties and relates them to black-body emission, spectra, and polarization over the full range of the observational spectrum in astronomy. It uses the relevant physical equations and describes their implications with good diagrams. Given previous familiarity with Maxwell's equations, this chapter would make attractive and instructive reading, and it ends with recommendations for related books and articles. The following chapter then goes on to describe the principles of measurement, starting with electromagnetic waves, and including cosmic rays and neutrinos. This chapter is not really detailed enough, and anyone wanting to master the technique for any specific 'messenger' would need to consult more specialized texts. This chapter is followed by a short chapter on the processes which moderate the transfer of radiation through space. Later in the book we are given a more detailed account of continuum and line emission mechanisms as the basis for interpeting atomic and molecular spectra. Here again, in these two chapters, the book does not aim to be self-contained, but to act as an essential link between the physics and the astronomy. In preparing an observational astronomer for research, the disturbing effect of the Earth's atmosphere is an often overlooked topic, and it is well dealt with in this book, which includes discussions of opacity, and turbulence as it affects astronomical seeing, with a look at how they are overcome on large ground-based telescopes.

When reading the chapters on the newest fields, those on astroparticle physics and gravitational waves, I was pleased with the comprehensive cover of principles, a little less content with the descriptions of the detection methods, and surprised that there was really almost no treatment of the astronomical sources. It was at this point that I understood that the book by itself is incomplete, and was informed that a second volume on the practice of multimessenger astronomy was now available. I was asked to review the present book on its own, so I will have to extrapolate, and assume that the deficit I noticed here will be dealt with in the second book.

In the final, and very practical, short chapter, the authors deal with coordinate systems, and stellar magnitudes, and give an introduction to the basic tools of optical astronomy, including spectrography, polarimetry, data storage, and a multimessenger virtual observatory. A set of appendices covers measurement units, wavebands throughout the electromagnetic spectrum, and references to astronomical software.

As well as to physics students who want an introductory way into modern astronomy, the book should be of interest to graduate students in physics who are starting astronomical research. I have to admit that I found the colour of the printed text, grey rather than black, lacking in contrast. The use of colour in the illustrations generally works well, although some of the figures could have better contrast and sharpness. Taken overall the book would be a good addition to the libraries of astronomical institutions, although the cost, at $120, is not low for an individual student's budget. — John Beckman.

Multimessenger Astronomy in Practice, by Miroslav D. Filipović & Nicholas F. H. Tothill (IoP Publishing), 2022. Pp. 490, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 2342 0).

The second book, entitled *Multimessenger Astronomy in Practice*, is a comprehensive textbook which covers all of the individual divisions of astronomy outlined in the first book [see previous review], plus a couple of extra sections. It has an unusual format, in that most of the chapters are multi-authored, and the total number of authors contributing to the book is 16. This is not entirely surprising, given the scope of the material and the effort required to explain the wide range of subject matter, but it does give the volume an aspect of a conference proceedings, or perhaps a set of review articles.

The first chapter sets the scene by describing some of the types of astronomical sources which are being detected by the newer astronomical techniques. Pointing out that information from the external Universe has been detected and measured in the form of cosmic rays for over a century, so that strictly speaking the term 'multimessenger' implying techniques other than those using electromagnetic radiation could have been employed since the early 20th Century, we are told that it was introduced widely after the observations of gravitational-wave sources in 2015. The sources mentioned in Chapter 1, gamma-ray bursts, supernovae in general, the nuclei of active galaxies, black holes over a range of masses, neutron stars, are generally high-energy objects, detectable using high-energy electromagnetic radiation, but also *via* neutrinos and cosmic rays, two of the non-electromagnetic messengers which have come into practical use in recent decades.

The first substantial chapter, however, deals with radio astronomy. It can be considered an introductory textbook covering most aspects of radio-astronomical techniques, with a range of figures giving examples of the different types of radio-telescopes, followed by examples of their results. It discusses the different mechanisms of radio-continuum emission, and also of spectral-line emission, dealing briefly with polarization, Faraday rotation, and maser emission. The chapter reads easily, and the reader is introduced to how the different types of data from the different types of instruments are handled. The concepts of working with interferometers and their data are well managed with clear diagrams. We are then shown observational results from different types of sources, stellar, interstellar, and on galactic scales. A physics student without previous knowledge of radio astronomy would certainly be put nicely into the picture. But at this point in reading the book I asked myself whether, in a sense, the comprehensive overall scope has made it difficult to go deeply enough into detailed method. I will return to this point later in the review.

The following chapter deals with mid- to far-infrared and submillimetre astronomy. Its style is somewhat different from that of the previous chapter: it gives a wide coverage of the different types of sources and the techniques, both photometric and spectroscopic, with which they are observed. The stress on star formation and the physics of the interstellar medium is natural at these wavelengths. It also has a special section on the specific telescopes and sites for observing in this range, as it is peculiar in being observable from the ground, from airborne platforms, and from space, depending on the detailed wavelength sub-range within this overall range. The difference in style is that there is less physical explanation but more factual information here than in the previous chapter.

The chapter on visual and near-infrared astronomy begins with the briefest of historical summaries, and claims its place as the basis for multimessenger studies. It deals with detectors and their techniques, with observational limitations, specifically angular resolution and the importance of the point-spread function, and gives a list of optical photometric surveys which play a basic role in modern astrophysics, mentioning the powerful upcoming *Rubin Observatory*, and listing the major problems in which optical astronomy continues to play a dominant role, such as the nature of dark energy, and the distribution of dark matter. It has a section on the optical follow-up of sources discovered by their gravitational waves, and deals with the important topic of events which require timing. The authors of this chapter have not wanted to present physical methodology. There is some contrast with the following chapter on ultraviolet astronomy, in which there is considerable technical description of the satellite observatories, as well as descriptions of spectral-line and continuum studies of stars (notably hot stars), the interstellar medium, normal galaxies, and active galaxies.

The X-ray and gamma-ray chapters together do offer a solid introduction to high-energy astrophysics. The physics of X-ray detectors and of X-ray telescopes is well described and quantified. We are shown how high-resolution X-ray spectroscopy of astronomical sources is performed, and are introduced to X-ray polarimetry. There follows systematic descriptions of X-ray emitting processes in the Sun, main-sequence stars, and white dwarfs. Considerable physical detail is then, justifiably, presented on X-ray emission from the end stages of stellar evolution, supernova remnants, and neutron stars, with very good treatment of X-ray binaries, both neutron-star and black-hole binaries. The X-ray chapter ends with accounts of X-ray emission from individual galaxies and from galaxy clusters. The gamma-ray chapter is similarly comprehensive, and as well as treating the full range of astrophysical particle accelerators capable of producing gamma-rays, also covers predictions of possible links between gamma-ray emission and dark-matter constituents. Specific gamma-ray topics, such as superbubbles and gamma-ray bursts, are also described, and we are given information about current and future gamma-ray telescopes and arrays.

Neutrino astronomy is introduced by a useful outline of the physics of neutrinos, including their interactions and the now well-established phenomenon of neutrino oscillations. We are then given sections on neutrino production in stars such as the Sun, and in massive stars, as well as the production of neutrinos in supernovae. The physical inferences from the detection of the neutrinos from supernova 1987A are clearly explained. We are given summaries of the detection methods for astronomical neutrinos in different energy ranges, including the highest energies, and shown how individual sources, including extragalactic sources, have been identified by their production of gamma-rays coinciding with a burst of neutrinos, by detecting at least one neutrino with PeV energy. As well as the 'traditional' ways to detect neutrinos, such as the large-volume detectors deep in the Earth, in water, or within the Antarctic ice, more recent and future experiments are described. The use of the largest detector of high-energy cosmic rays, the *Pierre Auger* detector, for detecting the neutrinos produced by ultra-high-energy cosmic-ray interactions in the atmosphere, is explained, as well as radio techniques which will be more sensitive than optical methods at the highest energies. New installations using new techniques, on mountain ranges, and to be placed on the Moon, give us a good idea of the variety of directions in which neutrino astronomy is moving.

The high point of any book on multimessenger astronomy ought to be the chapter on gravitational-wave detection. The chapter in this book is written by an expert directly involved in the *LIGO* experiment which first made these detections. Starting with the beautiful indirect verification of the prediction of gravitational waves in General Relativity by the Hulse–Taylor binary pulsar, we are shown the first direct detection by *LIGO* of a black-hole-merger event. There follow sections on present and future gravitational-wave detectors, and on compact-binary coalescence, which until now has provided all the detections. This is presented at a good technical level, as is an explanation of the signals expected from different types of detectable events, and how these events can be analyzed to give astrophysical information. We are shown how to distinguish black-hole–black-hole mergers from binary-neutron-star mergers, and hybrid mergers of the two types of objects. This is followed by a description of a new range of tests of General Relativity made possible in principle with gravitational waves, and a description of how the new technique will help us to understand core-collapse supernovae and other bursting sources. Finally, as detectors multiply and become more sensitive, we expect to detect a complete background from the numerous individual events occurring throughout the Universe. The chapter is brought to an end with over ten pages of references. This type of reference lists ends each of the chapters. I will comment briefly on this later, but here I want only to remark how fortunate it must be for a scientist to be surnamed Abbott.

Following this major chapter on gravitational waves, there is a minor chapter on dark matter. This deals with the dynamical astrophysical arguments which have led to the adoption of dark matter as a necessary component of individual galaxies and galaxy clusters, and is followed by descriptions of dark-matter searches, both astronomical and in the laboratory. We know that cosmological models which incorporate dark matter are consistent with the observations of the cosmic-microwave-background fluctuations, and that particle physics has a place for more than one type of dark-matter particle, but that the most sensitive laboratory searches have not come up with any candidates. The chapter describes this situation, but in a comprehensive volume it might have been interesting to give some technical details of alternative scenarios, if only to explain why most physicists active in the field do prefer the dark-matter explanation.

It is unusual to find a chapter on SETI in a serious textbook, and the authors are clearly aware of this, because they take considerable pains to stress that SETI should be considered a respectable part of astronomical study. This reviewer tends to agree with them. Now that exobiology has become drawn into mainstream astronomy because of the breakthrough in the observation of exoplanets, and that searches for biosignatures on planets in habitable zones are within the goals of a project as important as the *James Webb Space Telescope*, it makes sense to set about tackling the question of whether we can obtain information about possible intelligent life outside the Earth. The chapter aims at bringing us up to date on techniques, ranging from the traditional radio searches, through optical, and on to possible high-energy detections of extraterrestrial activity *via* the output of nuclear explosions. The authors quantify the energies needed for a civilization to emit detectable signals, and the sensitivities we will need to detect them. Many of the proposed hypotheses of how an advanced civilization would develop its communications and its use of energy which have been proposed in the SETI context are described, and the possibility that we are already under surveillance is briefly considered. Within its size limitations this is a useful introduction to the subject.

As a further innovative offer, the final chapter deals with data science in the context of multimessenger astronomy. The reason to do this is explained in terms of the increasingly overwhelming quantities of data being produced in modern astronomy, which is certainly an entirely valid point to note, even before the *SKA* begins to unload a whole internet's worth of radioastronomy data per day onto the community. We are already well into the age of Big Data, and astronomy can be, and has been, a pioneer in the computer techniques needed to handle this and make it intelligible. The challenges facing all observational astronomers who need to obtain data from archives of different regimes, certainly in frequency, and nowadays also non-electromagnetic, and in many cases to cross-match these in order to identify and map their sources, are described. The possible use of neural-network algorithms and other modern methods of pattern recognition are outlined, and examples in mapping and redshift measurement are explicitly presented. Of course we are going to learn much more by using all the possibilities of combining data which we are now being offered. But there are pitfalls in an approach which is too 'gung-ho'. When we combine the data from millions of similar objects to extract (valid) statistical conclusions, we are at the mercy of methods which in general we have not developed, and we may well overlook crucial diagnostic details which painstaking inspection of data from far fewer galaxies could have revealed.

I would see this volume as a handbook for a new graduate student preparing to carry out research in astronomy. Each chapter has an extended list of references to published papers which make sense in that context. I do not consider the variations in style and depth which are due to the multi-messenger (*i.e.*, multi-author) way the book is written to be a negative factor, and I am sure that the combined knowledge and experience of the team gives a more authoritative result. However, I feel the need to point out a technical fault which is increasingly common in modern publications in general. Modern printing techniques are flexible, and relatively inexpensive, but this can leave the quality of the product at the mercy of the individual printer, as the books are produced by a process of 'print on demand'. In my reviewer's copy I found two general insufficiencies: the text is grey rather than black, making a weak contrast with the background. This should be improved by producing a blacker text as a whole, but it gives special difficulties with some of the diagrams, making them particularly difficult to decipher where the figures and letters are small. In some cases the diagram has been reproduced on too small a scale, which exacerbates this problem. My final comment is that the expense of the book is likely to imply its availability in libraries rather than on the bookshelves of individuals. — John Beckman.

Investigating Art, History, and Literature with Astronomy, by Donald W. Olson (Springer), 2022. Pp. 336, 24 × 16·5 cm. Price £27·99 (paperback; ISBN 978 3 030 95553 3).

The paintings of Johannes Vermeer (1632–75) are widely known and admired, but little is known about the man himself. The novelist Marcel Proust described Vermeer's *View of Delft* as "the most beautiful painting in the world". Donald Olson wondered what astronomical constraints could be put on the date and time when this work was painted, and was able to conclude that it was painted around eight in the morning from the window of a particular inn on a date in early September in 1659 or an earlier year. All done by analysing shadows and Sun angles and consulting old pictures and maps from the period.

These are by no means the only tools at Olson's disposal, as he makes clear in the first three chapters of this unusual book. He uses modern planetarium software for many of his calculations, but he also delves back into old postcards, guidebooks, maps, almanacs, railway timetables, tide tables, and even weather archives. He uses letters by, or about, the artist in question, which often need to be translated. He and his group from Texas State University make regular research trips to particular sites where artists worked, mostly in Europe, and take modern photographs on what he calls "corresponding days" when the astronomical and weather conditions are closely similar to those on a particular date of historical interest. He is also very aware of the issue of timekeeping, distinguishing the Julian and Gregorian calendars and noting that times used to be quoted as local mean solar time rather than related to a time zone.

Although I have given Vermeer as an example, in fact only two chapters relate to paintings, one on Vermeer, Claude Monet, and J. M. W. Turner, and the other on the US artist Georgia O'Keeffe and the Japanese print-maker Kawase Hasui. These two chapters are followed by three on historical events, ranging from Alexander the Great in India and Mont Saint-Michel in the Hundred Years War to Roosevelt and Churchill in Marrakech (dating one of Churchill's paintings) and the Dam Busters raids in the same wartime period (where moonlight was important).

The penultimate chapter looks at the appearance of astronomy in literature, in particular identifying two eclipses (one lunar, one solar) mentioned in Act 1 of Shakespeare's *King Lear* and using them to date when the play was written (late 1605 or early 1606). The final chapter disproves a common statement that from a viewpoint on the edge of Death Valley one can see both the lowest point in the USA and the highest at the same time.

This is a common theme of the book. In all cases he studies, he asks what the published sources say about where and when something happened, and whether that widely accepted view is compatible with the astronomical clues. He finds that in surprisingly many cases the accepted view is incompatible with the various astronomical constraints.

With the art, I found myself thinking that this was all very clever and interesting — but did it add anything to my appreciation of the painting? Probably not. I had similar but lesser misgivings about the value of the other sections. Nonetheless, I found myself marvelling at just how much Olson and his team were able to add to the information about the work of art or the historical event, and I read every word of this book.

Would I recommend it? Well, it is lavishly-illustrated (175 illustrations, mostly in full-colour, so on average every page either has a photo or is facing one) and is almost worth having for the photos alone. But sadly the writing style, especially in the first three chapters describing his methods, is over-long, with unnecessary detail, and a bit repetitive, so only the intrinsic interest of the subject matter carries one on. It is not entirely clear what his target readership is, and he doesn't say, but I think he is probably aiming more at the arts community than at scientists. However, perhaps astronomers might see more point in the whole exercise than your average art-lover, historian, or expert in literature.

All I can say is that I'm glad to have read it and will be happy to have it on my bookshelves. — ROBERT CONNON SMITH.

Our Celestial Clockwork: From Ancient Origins to Modern Astronomy of the Solar System, by Richard Kerner (World Scientific), 2022. Pp. 476, 23·5 × 16 cm. Price £85 (hardbound; ISBN 978 981 121 459 2).

This is an odd book. Its stated aim is to give students beginning a physics course a knowledge of the way in which astronomical concepts have been developed, and providing them with the chance to use mathematical techniques in calculating phenomena. In this respect, students are encouraged to calculate details, although the methods are all explained in detail and use modern techniques. The Preface explains that the examples use elementary mathematics, but that more sophisticated proofs are marked with asterisks that "readers less acquainted with mathematical tools ... can easily skip ...".

Most of the historical material will be familiar to any astronomer versed in the history of the subject, but although comprehensive, the book is a difficult read. Unfortunately, the author seems to have written the book in English, although that is obviously not his mother tongue. It has been poorly edited, presumably in Hackensack, New Jersey, by an American editor (although his name, Ng Kah Fee, suggests that he is Vietnamese). It has American spelling such as 'color', 'meter', *etc.*, throughout, and some very odd sentence constructions and usages. Articles (definite and indefinite) are often missing. Only by reading some sentences again, or translating them into French, have I realized the meaning and why some sentences have been constructed in such strange ways. The editorial process appears to have been minimal. We humans are 'vertebrae', not 'vertebrates' (page 4), and there are words (such as 'wherefrom') that are even archaic or of non-standard construction ('criterions'), according to the great *Oxford English Dictionary*. And where do the terms 'right-screw' (page 28), and 'majestuous' (page 61), and others come from?

There are some surprising statements, such as the one that it is Neptune that has its rotation axis nearly in the plane of the ecliptic (page *xxiv*). It is Uranus, of course, although the actual inclination of the axis (–97°·77) is not mentioned. On page 28 a footnote informs us that the constellation of Ursa Major is called the Big Dipper in Britain and the USA, whereas, of course, the asterism is known as the Plough in Britain and the Big Dipper in the USA. (Not 'the Great Dipper' as the caption to diagram 2.1 has it.) On page 249 we have the statement that 'The distance of the Sun was based on Aristarchus' measurement of 87°, which gives the result 750 000 km, 20 times smaller than the real distance.' Errors such as these do not inspire confidence in the book.

Table 2.3 gives the translation of 'Aquarius' as 'Water Bear'. Figure 6.5 (page 185) purports to show the graduations on a sundial for three orientations, whereas in reality those for south-facing are duplicated. There are so many incorrect spellings and other errors: 'booth' for 'both', 'hunred' for 'hundred'; 'Persaeus' for 'Perseus'; 'belocities' for 'velocities', 'tally' for 'tallow', 'centure' for 'century', 'relying' ('relating'?, page 222), 'saught' for 'sought', 'enthousiast', *etc.*, that one wonders if the text has ever been proof-read. Apart from the poor spelling, some of the names are odd, or unfamiliar. We have 'Byzance' for' 'Byzantium', 'Mesopotamy' for 'Mesopotamia', 'Syena' for 'Syene', 'Magellan's Clouds' for 'the Magellanic Clouds', 'Açcores' for 'Azores', *etc.* I must admit, in my ignorance, to being puzzled by the reference on page 134 to 'the famous theorem of Ptolemy', but this turns out to be the theorem devised by Ptolemy (relating the lengths of diagonals of a rectangle inscribed in a circle) and described in detail on page 220.

But does the book do what it is supposed to do? The answer, I fear, is 'No'. The confusion of the text is often found within the descriptions of the methods to be used to solve the problems. The discussions in the text carry out all the calculations, using modern methods. The calculations are not left to the students as exercises.

The very first calculation that readers are supposed to follow concerns the commensurability of synodic and sidereal months. This is illustrated by the hoary old story of the paradox of Achilles and the tortoise ('turtle' in this book). Was the poet and dramatist Aeschylus then killed by a turtle being dropped on his head? I think not. This may seem an irrelevance, but it is symptomatic of the problems affecting the whole book. This particular problem involves solving an infinite sum. This is calculated using modern methods, with no mention of how it may have been tackled by ancient astronomers.

There is a long discussion of various calendric systems: Egyptian, Babylonian, *etc.*, but again all calculations are carried out with modern values of (say) the tropical year and the lunar synodic month, with no indication of what values were used by ancient astronomers nor how they were derived.

When we come to the work of Kepler, and especially Newton, and the discussion of tides, the calculations are quite complex, many set off with the asterisks, and I do wonder how many readers will follow them. The descriptions and calculations are beset with the spelling and grammatical errors found throughout the book, so the task is made all the more difficult.

The details of the biographies and achievements of some of the 'minor' astronomers Cassini, Römer, *etc.*, are of interest. There is a lengthy discussion of the form of rotating bodies as calculated by Newton, but no mention of the fact that Cassini believed the Earth to be prolate and instigated the expeditions to Lapland and Peru to clarify the issue. — Storm Dunlop.

The Alien Communication Handbook: So We Received a Signal — Now What?, by Brian S. McConnell (Springer), 2021. Pp. 299, 23·5 × 15·5 cm. Price £22·99/$29·99 (paperback; ISBN 978 3 030 74844 9).

Brian S. McConnell's book addresses the question of what would happen if scientists detected an artificial signal that was not only evidence of a technically advanced civilization located beyond the Earth but was also information rich. The book is written from the perspective of a communications expert, and it focusses on the technical aspects of interstellar communication, including our current ability to sample the content of any such signal and the methods that might be used to decipher its meaning. The author does a very thorough job of introducing the reader to the relevant concepts of communication theory, signal-modulation techniques, data representation, computing, and the processing effort required to comprehend fully the data received. Along the way, we learn about animal communication, language, and algorithmic communication systems. The book is very comprehensive on these topics but it might also have addressed the intense astronomical campaign that would follow any initial detection — these would help us understand something about the nature of the sender — revealing their precise location in the Milky Way, their physical dynamics (rotating planet, free-flyer, *etc.*), and some hints on the conditions of their local (stellar/planetary) environment.

McConnell makes the interesting argument that aliens might well communicate using a combination of remote electromagnetic signalling and locally deposited 'inscribed matter' — in the latter case, think of something similar to but much more advanced than the *Voyager 1 & 2* golden records of the 1970s. In principle, this approach permits the recipient to access large amounts of recorded data in a short time, but the author does not comment too much on how the inscribed matter would be made available to the receiver locally, or the fact that the inscribed data is likely to be very outdated due to physical travel times. The book contains several exciting ideas that I had personally not encountered before — in particular, the possibility of participating in pseudo real-time conversations with the sending civilization *via* artificial-intelligence (AI) code embedded in the transmitted signal — an interesting prospect, although also a little frightening if the AI code were also to be nefarious.

McConnell envisages the sampled signal data being pipeline processed and then made publicly available to "anyone with a computer and an internet connection". In this scientific utopia, large teams would be assembled from around the world, bringing a wide-range of different expertise to bear on the signal content. There is a naivety here that is in some senses admirable but probably not very realistic — I'm afraid a more likely scenario is that after the initial discovery, access to any data from an information-rich signal would be heavily restricted, as governments and their commercial partners were mobilized to capitalize on this resource. There is no discussion of the information war that might be unleashed on a regional and global scale. The author does note the scientific progress that such a signal might furnish but avoids discussion of the ways this might be exploited for good and bad causes. There is a particularly interesting discussion of how an advanced but ancient civilisation with sophisticated remote-sensing capabilities, might provide us with a scientific archive of observations of planet Earth made over many millennia, including the first evidence of human activity, *e.g.*, agriculture, megalithic structures, the establishment of large settlements, *etc.*

This is an interesting book with many important insights. It addresses a well-defined but limited technical subset of 'what's next?' after the detection of an information-rich signal. But I have to say, I felt a little cheated from the title, not to see some discussion of the profound cultural, political, and societal impact such a signal would have on us all. — Michael A. Garrett.

An Introduction to Stellar Magnetic Activity, by Gibor Basri (IoP Publishing), 2022. Pp. 141, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 2130 3).

This is an excellent book that will be extremely useful to many young researchers starting out in the fields of stars and exoplanets (and also to some more experienced ones who might enjoy a quick reminder). A broad knowledge of stellar magnetic activity is becoming increasingly more important to the exoplanet community and this book is perfectly pitched to provide a sound basis in the subject without becoming too caught up in details.

It is a book designed to inspire as well as educate. Its strength lies in the clarity of the writing that avoids the need for extended mathematical derivations. The choice of topics reflects the broad experience and expertise of the author. It is not intended to be entirely comprehensive nor to provide a complete historical introduction, but it supplies just enough background to place current research in context. It is this current (and future) research that is the main focus of this book.

This of course cannot be tackled without first laying some sort of foundation. The first few chapters are the most pedagogical, introducing the reader to the physics of the various layers of the solar atmosphere. The section on chromospheres is probably the most technical in the book, but it is supported by a very good appendix on radiative transfer and sufficient references to satisfy any reader who might be encouraged to dig a little bit more deeply into the topic. These early chapters give the reader a good preparation for the second half of the book. This describes current research into the evolution of magnetic activity and the various manifestations of stellar magnetic fields (and the methods by which they are detected). The treatment here is knowledgeable and insightful, and there is a good balance between topics, although with more of an emphasis on observational rather than theoretical advances.

If I have a criticism of this book, it is that the last section is not long enough. It enhances the scope of the book by touching on a selection of topics, including exoplanets, but without a detailed treatment. There is a virtue, however, in keeping this type of book to a manageable length and it is already quite expensive for its intended readership. This last chapter will no doubt pique the interest of many readers and provide a window onto the broad scope of stellar magnetic activity. — MOIRA JARDINE.

Modern Special Relativity: A Student's Guide with Discussions and Examples, by Johann Rafelski (Springer), 2022. Pp. 468, 23·5 × 15·5 cm. Price £49·99/$64·99 (hardbound; ISBN 978 3 030 54351 8).

My first impression was that this book goes beyond standard books on Special Relativity (SR) by including more historical context and clearing up some confusion which exists among some readers (though not among experts) regarding the difference between relative effects (A sees B's clock run more slowly and *vice versa*) and physical effects (the travelling twin really does age less) as well as the difference between the quantities normally considered in SR and what, due to the finite speed of light, an observer actually sees. There is some historical background, but it is used to add to the confusion rather than clear it up. Rafelski is apparently reasonably well known in the heavy-ion community and the book is from what should be a serious publisher, so I was surprised at the extent to which a non-standard exposition of SR is offered to the reader, especially in a book aimed at students. I'm also sure that the confusion is not on my part, as Rafelski claims that anyone who disagrees with his unorthodox interpretations (*i.e.*, almost everyone else) is wrong. Personal communications with relativity experts confirm my interpretation.

A few examples: Rafelski claims that length contraction is something which actually physically happens, rather than being an apparent effect. (As to how two observers can each see the other as contracted, he claims that the one which has accelerated is really contracted, not answering the question what happens if both or neither accelerated.) Related to that, the sand grains in a sand storm would be contracted, but not the distances between them. He claims that acceleration cannot be handled within SR (though he does discuss acceleration in some cases, claiming that his arguments are valid in the limit of "gentle acceleration"), and insists that GR should stand for "gravity relativity". Despite his unorthodox views, most or all things actually calculated have the same result as in mainstream expositions. At the same time, at least in this case, I think that there is a right and wrong interpretation, even if the results are the same. He does, though, indicate some cases in which he claims that his physical effects could actually be measured. It appears that Rafelski believes in the existence of the æther, though conceding that one could never detect it, even in principle. Particularly bizarre is his claim that SR is related to electromagnetic radiation *via* the speed of light (and not just some maximum speed), leading him to speculate that dark matter might not be subject to relativistic effects! (At least he doesn't call the Lorenz gauge the Lorentz gauge.) There are other examples. The book is thus very confusing to read, which is not helped by the fact that Rafelski is obviously not a native speaker of English and apparently there has been no editing to correct for that.

The book has many explanations, useful diagrams, and many worked examples, also involving real-world applications (though the conversations in the style of Galileo's *Dialogues* are not really needed, at least in the form in which they are presented); there is a need for a detailed book on SR, but, due to the problems mentioned above, this isn't it. All the usual topics, and then some, are here, but anyone who could actually learn something from the book would have trouble distinguishing the unorthodox elements from others, even though Rafelski often points out where he thinks that he is wrong and others are right. There are a few footnotes, most of which are references; a six-page index ends the book. As in some other books I've reviewed in these pages, Springer's mysteriously variable bottom margins and missing full stops in captions (fine for short captions, but not for multi-sentence ones with the full stop missing after the last sentence) are on display here.

Obviously, I can't recommend the book. More worrying than a bad book are perhaps the facts that it was written by an otherwise serious scientist and published by what should be a reputable publisher. — Phillip Helbig.

Collins 2023 Guide to the Night Sky, by Storm Dunlop & Wil Tirion (Collins), 2022. Pp. 112, 21 × 15 cm. Price £6·99 (paperback; ISBN 978 0 00 839354 0).

Night Sky Almanac. A Stargazer's Guide to 2023, by Storm Dunlop & Wil Tirion (Collins), 2022. Pp. 272, 18·5 × 12 cm. Price £9·99 (hardbound; ISBN 978 0 00 853259 8).

Weather Almanac. A Guide to 2023, by Storm Dunlop (Collins), 2022. Pp. 272, 18·5 × 12 cm. Price £9·99 (hardbound; ISBN 978 0 00 853260 4).

These three books arrived too late to be included in the 2022 December issue and thus promoted to the list of stocking fillers for Christmas; perhaps the present issue will enable them to be considered by keen sky watchers for the remainder of 2023.

The *Guide to the Night Sky* has been a popular and inexpensive pocket book for years and the 2021 edition was enthusiastically received in these pages (**140**, 284, 2020). It contains all that the layman might require in a month-by-month programme of observing.

Similarly, the 2021 edition of the *Night Sky Almanac* was welcomed in the *Magazine* (**141**, 39, 2021 — again late for the Christmas market!) as a delightful pocket companion with information for world-wide observers in the Victorian style loved by the Managing Editor of *The Observatory*.

The *Weather Almanac* appears to be a new venture, but surely one that will be appreciated by any astronomer; it is again an inexpensive but delightfully produced Victorian-style pocket book. After an informative introduction to the subject, we go on a month-by-month journey in which we discover not only the expected weather in Britain but also the extremes that have been witnessed. Each chapter is seasoned with fascinating snippets of weather history, to make the whole a fascinating read.

All three are highly recommended. — David Stickland.

More From The Library

Astronomy of the Bible (with a biographical sketch), by Ormsby McKnight Mitchel (Blakeman & Mason, 21 Murray Street, New York), 1863. Pp. 322, 18 × 12 cm. Price $1·25 (at the time of publication). No ISBN number, but was "Entered according to Act of Congress, in the year 1863, by E. W. Mitchel in the Clerk's Office of the District Court of the United States for the Southern District of New York." Purchased at auction from the American Association of Variable Star Observers, originally the property of William Tyler Olcott (1873–1936).

Some time ago (meaning more than one year but fewer than 30), a colleague (with apologies to our readers if it was either one of you) asked what I knew about Ormsby M. Mitchel besides what was in the *Biographical Encyclopedia of Astronomy*. First thought, "What's an Ormsby?" Second thought, "Mitchel? Not Michell, John of binary star and black-hole fame. Not Mitchell, Maria, initially her father's assistant and from a Quaker family." Apologies, I guess nothing, was my eventual response.

As a result of acquiring this volume and reading portions of it, I now know several things slightly different from what is in the *BEA*, where his middle name is given as MacKnight and his date of birth as 28 July 1809, in Morganfield, Kentucky. The anonymous *Biographical Notice* says McKnight and the 28th of August 1810, in Union County, Kentucky. The precise date has some bearing on just how young he was at the time of entering the US Military Academy at West Point in 1825 — younger than the present norm, in any case.

The 34 pages of biography end with a summary, which I quote verbatim, being reasonably sure the words are out of copyright: "A graduate of West Point, he was a lieutenant of artillery, a lawyer, a railway engineer, an astronomer; the founder of one observatory (Cincinnati); the director of two (Cincinnati and Dudley); a Doctor of Laws from more than one institution; a Fellow of the Royal Astronomical Society, and of several other foreign societies; a Major-General of Volunteers. In 1841 he was a member of the Board of Visitors at the Military Academy. In 1847 and 1848 he was Adjutant-General of the State of Ohio. He was elected a member of the American Philosophical Society in 1853."

What is not clear from the *BEA* article but radiates from the *Biographical Notice* and the contents of this book (the text version of a series of lectures he gave in 1862 and published posthumously) is that he was for most of his life a devout Christian. The core of the volume is Lectures III and IV, in which he concludes that there is no contradiction between the astronomical understanding of the Universe and its early history (with, for instance, the nebular hypothesis for the origin of the Solar System) and the proper understanding of the version in the book of Genesis. This, he asserts, does not claim six or sixty thousand years, nor six natural days prior to the creation of Adam, nor millions of years ("as the Hindoos assert"), but "In the beginning, God created the heavens and the earth."

Chapters V and VI deal with passages in the Book of Job and elsewhere with some apparent astronomical content. Mitchel is prepared to maintain consistency between those and the science of 1860 by allowing both some non-Divinely-inspired intrusions into the narrative and alternative methods of creating the appearance of miracles, for instance, the injection of a refractive medium between Earth and Sun to give the impression that the Sun stood still in the sky or even moved backwards.

Along the way, Mitchel reminds readers (or auditors of the original lectures) that the founders of Western astronomy (Copernicus, Kepler, Newton, and all) were also believers, and he expresses confidence that there are other milky ways, outside our own, with even more stars.

Am I going to read all six lectures beginning to end? No, but I'm not sorry to have acquired the book. — VIRGINIA TRIMBLE.

OBITUARY NOTICE

Jay Pasachoff (1943–2022)

The Editors are saddened to report that Professor Jay Pasachoff, a long-time subscriber to this *Magazine* and recent contributor to our book reviews, passed away on 2022 November 20. Well known as an eclipse-chaser, Pasachoff was a noted researcher — particularly with respect to the Sun — educator, and passionate enthusiast for outreach. He started his career at Harvard but soon moved to Williams College (in Williamstown, Massachusetts) where he spent most of the rest of his time and became the Field Memorial Professor of Astronomy and Director of the Hopkins Observatory.

Here and There

ONLY ON URANUS

Its entrance was reoriented to the south-southwest, where the planet Venus rises in the summer. — *Archaeology*, **75**, no. 5, 42, 2022.