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A REVIEW OF ASTRONOMY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2025 January 10 at $16^h 00^m$
in the Geological Society Lecture Theatre, Burlington House

Mike Lockwood, *President*
in the Chair

The President. Welcome everybody and thanks for braving the cold weather today. This is a hybrid meeting. Questions can be asked at the end of the meeting by putting them in the Q and A, and then they will be read out by Dr. Pam Rowell.

I now move on to the announcement of the winners of the RAS awards for 2025. The Gold Medal (A) goes to Professor James Binney, Oxford University, and the Gold Medal (G) to Professor Jonathan Tennyson, University College London. The Eddington Medal is awarded to Emeritus Professor Douglas Heggie, University of Edinburgh, and the Chapman Medal goes to Dr. Nigel Meredith, British Antarctic Survey. The Herschel Medal is awarded to Emeritus Professor Ian Smail, Durham University, and the Price Medal to Dr. Paola Pinilla, University College London. The Jackson-Gwilt Medal goes to Professor Anna Moore, Australian National University. The Fowler Award (A) is awarded to Dr. Hannah Wakeford, University of Bristol, and the Fowler Award (G) goes to Dr. John Coxon, Northumbria University. An Early Career Award (A) is awarded to Dr. Steve Cunnington, University of Manchester, and Dr. Niall Jeffrey, University College London. The Early Career Award (G) goes to Dr. Giulia Magnarini, Natural History Museum, London. The Group Achievement Award (A) goes to the European Pulsar Timing Array, and the (G) Award has been given to the Met. Office Space Weather Operations Centre. The Service Award (A) goes to Professor Francis Keenan, Queen's University Belfast, and the (G) Award goes to Dr. Dmitry Storchak, International Seismological Centre. The Secondary Education Award goes to Dr. Alex Calverley, Surbiton High School, whilst the Higher Education Award is given to Professor Andrew Norton, The Open University. The Annie Maunder Medal is awarded to Amelia Jane Piper. The following 'named' lectures will be delivered at a meeting of the Society: The George Darwin Lectureship goes to Dr. Dimitri Veras, University of Warwick, whilst the James Dungey Lecture will be given by Dr. Ryan Milligan, Queen's University Belfast. The Harold Jeffreys Lectureship goes to Dr. Andrew Valentine, Durham University. Honorary Fellowships have been awarded to Professor Caitriona Jackman, DIAS Dunsink Observatory, and Professor Francesca Matteucci of the University of Trieste. Many congratulations to all the award winners [applause].

BepiColombo has arrived at Mercury and the separation of the craft into two will take place later this week. It was launched in 2018 and has already generated a lot of scientific data.

Moving on to today's programme. Nilanjan Choudhury is a Bangalore-based theatremaker and novelist. He has written two plays on science history, *The Square Root of a Sonnet* and *The Trial of Abdus Salam*, which have received wide critical acclaim and have been staged across several cities in India, the UK, and the USA. He is currently working on a new play about India's first woman particle physicist, Bibha Chowdhuri. He has been a part of over 300 stage performances with Bangalore's leading theatre companies including the Centre for Film and Drama and others. Mr. Choudhury's most recent novel is *Song of the Golden Sparrow* — a fictional retelling of the story of free India. His previous novel *Shillong Times* is a coming-of-age story set against the ethnic conflict in the hill town of Shillong during the 1980s and was nominated for the Indian Sahitya Akademi Award in 2023. His earlier novels include a mythological thriller and a contemporary detective caper set in Bangalore. Mr. Choudhury is a postgraduate in Physics from the Indian Institute of Technology, Kanpur.

Mr. Nilanjan Choudhury. I should explain what *The Square Root of a Sonnet* is all about. It is a play which we performed at the Royal Institution, London, in July last year. It is about two giants of modern astrophysics: Sir Arthur Eddington and Subramanyan Chandrasekhar. Eddington, of course, was the most renowned astronomer of his time in the early to mid-1900s and Chandrasekhar was awarded the Nobel Prize for Physics in 1983 along with William Fowler for his work on white-dwarf stars. I believe that the reason that I have been asked to present this today is because of a significant date. Tomorrow is the 90th anniversary of a fairly remarkable incident that happened at the RAS on 1935 January 11. Chandra presented his paper called 'The maximum mass of ideal white dwarfs'. The audience included Jeans, Hardy, R. H. Fowler, Stratton, who was in the Presidential chair, as well as Eddington.

While he was travelling from Bombay to Dover to take up a research studentship at Cambridge under the guidance of Eddington and R. H. Fowler, Chandra spent the three months of the voyage working on the evolution of white dwarfs. He found that white dwarfs nearing the end of their lives, those which have a mass greater than 1·44 solar masses would start contracting and collapsing under their own gravitational forces, becoming very small, and eventually they turned into neutron stars and, in some cases, black holes. This was a remarkable piece of work for a 19-year-old as it involved analysing theories of quantum dynamics, along with Special Relativity. It had to do with electron degeneracy as the star shrinks into a small volume. The idea that a star with the mass of the Sun could become such a tiny thing was something that his mentor could not quite grasp. There was a conflict between the young Chandra and the eminent Eddington at the RAS AGM in 1935, and this was a brutal public humiliation of the younger man. It not only took Chandra by complete surprise, because Eddington had been encouraging him all the while, but it affected him deeply for several years and he left the study of gravitational collapse of stars and worked on other topics. It was only when he was 63 that Chandra returned to the study of black holes.

However, during that period despite the opposition and conflict with Eddington, there was a strange relationship between the two of them especially from Chandra's side. This was a form of hero worship which lasted throughout Chandra's life although the hero turned out, in certain ways, to have feet of clay, by completely dismissing a theory which later on became known as explaining the first critical step to the formation of a black hole.

The title of the play *The Square Root of a Sonnet* is actually paraphrased from one of Eddington's own statements where he says "human personalities are not measurable by symbols, equations, or logic, any more than you can extract the square root of a sonnet", which means we don't often act in rational ways when we are doing rational work in science and mathematics. The interface of the rational world of science and mathematics with the irrational world of the human mind comes together in this play. What follows is a brief seven-minute scene from the play and it enacts a scene at the 1935 January RAS meeting when Chandra was presenting his paper on the maximum mass of ideal white-dwarf stars. Many of the words and sentences used in the clip are quoted verbatim in the sense in that they represent what Eddington said. They are not what Chandra said because this is an imaginary setting. He did not retaliate against some of the things said at the meeting itself but many of the words that you hear Eddington speaking I am quoting verbatim from the meeting report [Ed. — see these pages **58**, 33, 1935].

[There followed a seven-minute extract from the play in which Chandrasekhar was played by Nilanjan Choudhury and the part of Eddington was taken by Sal Yusuf.]

The President. Would you take some questions?

Mr. Choudhury. If you have the time I have the inclination [laughter].

Professor Steve Miller. Are there plans for bringing the play back to the UK? I think you are in discussion with the Murty Trust about doing something in Cambridge that maybe the RAS can be involved with as well.

Mr. Choudhury. First of all Steve, if you are in the room, I am glad to see you up and about. Yes, we would love to come back and we are in talks with the Murty Trust. They have an interest in maybe doing something with the RAS. We will try and see how we can make this financially feasible.

The President. I must just make the point that what made Eddington's behaviour all the more remarkable was that the man was a Quaker and had been known for his kindness, and I just don't understand where it came from. I do know that a lot of people wrote to Chandra afterwards saying that he (Eddington) had got this wrong. The reality and the truth came out in the end but it was a remarkable outburst.

Ms. Gail Campbell. Thank you very much indeed for that wonderful play, and if it does come to Cambridge I will certainly come and see it. There is a huge interest in the lives of scientists and as you know, for example, Srinivasan Ramanujan had a wonderful play about him turned into a film. Do you have any plans to address any other scientists in your artistic work?

Mr. Choudhury. As we speak we have started rehearsals on my second science play. It is called *The Trial of Abdus Salam*. He was the first Pakistani and, in fact, the first Muslim to win a Nobel Prize in Science. This play involves his complex relationship with his country, and that also has a very strong British connection because he did a lot of his work at Imperial College London. We open on March 29 and as mentioned before I have also finished the first draft of a third play I wanted to call *Invisible Particles* which concerns India's first woman particle physicist, a lady called Bibha Chowdhuri who has been completely lost from history, and her life intertwines very closely with another woman physicist, Marietta Blau, whose work on nuclear emulsions finally led to the discovery of the meson.

The President. Thank you very much, Nilanjan. Briefly, do you think that the reference to 'the square root of a sonnet' was by way of some sort of apology from Eddington?

Mr. Choudhury. Not really. As you know Eddington was a very gifted writer and orator and was very fluent with his language and words. This statement had nothing to do with Chandra. In fact, he never apologised. If I may, there is one quote worth repeating — in 1939 Chandra wrote a book which summarized all his work; Eddington had read it and said "How nice to get everything wrong in one place".

The President. Sometimes one can be cursed by having a good wit.

Mr. Choudhury. If someone wants to read the play I would be happy to share a script with them. Please contact me *via* nilanjanpc@gmail.com or www.nilanjan.net. The play really explores the potential reasons why this thing happened. This is Eddington's very strong view on how nature should work, how God should have constructed the world.

The President. Thank you very much, Nilanjan [applause].

We now move on to the Harold Jeffreys Lecture. It will be given by Jessica Irving and the title is 'Hearing planetary hearts: seismology of the cores of Earth and Mars'. Jessica Irving received her MSci in 2005 and PhD in 2009 from the University of Cambridge, where she was also a Postdoctoral Researcher. She was an Assistant Professor at Princeton University and is now Associate Professor in Global Seismology at the University of Bristol. Her research encompasses Earth's core, mantle, and oceans, as well as Mars and other planetary bodies.

[The Harold Jeffreys Lecture explored what seismology has revealed about the structure of the cores of Earth and Mars — a topic on which Jeffreys spent considerable time. A full account is expected to appear in *A&G*.]

Dr. Jessica Irvine. Our understanding of Earth's core has evolved from early ideas of an inaccessible central kernel of seismically slow material, through the discovery and measurement of the inner core, to present investigations into the properties of the dynamic heart of our planet. Seismological data from the *InSight* (*INterior exploration using Seismic Investigation Geodesy and Heat Transfer*) geophysical mission were the first to probe the deep Martian interior, which is now the second planetary core to be seismically detected.

The President. Thank you very much, that was beautifully clear.

Reverend Garth Barber. One of the first surface features on Mars is the apparent appearance of ocean features and yet where has all the water gone? Is there any seismic evidence that there may be sub-surface water in the Martian structure?

Dr. Irving. There are certainly people who could speak better to the surface-related story than I as a seismologist could. I would say, first of all, that there are a number of models about what might be happening directly under the *InSight* lander — some relatively short-scale structure. Some of these models have a small amount of hydrated material present, others do not. The history of Mars is very different to the history of our planet, primarily due to the absence of whole-planet plate tectonics as we understand it. What we do see from the seismic results, and it doesn't directly answer your question, is that we have some small amount of hydrogen and oxygen in the core, and I want to be clear that these are primordial features. That is not where the ocean would have drained to. That water would not have gone the whole way through the mantle of the planet although people may have sometimes suggested it. We have a really complex body that we are seeing, where clearly the nature of water storage must be different to that on the Earth because on Earth we do believe it could be possible for the hydrated material to travel very deep. Indeed, on Mars, we think that is slightly different.

Professor John Zarnecki. I did not understand how, in the case of the Mars event, you were able to locate the origin except in the case of the impact, of course.

Dr. Irving. If you take an undergraduate class in seismology then they will tell you that you need multiple seismic stations to detect the location of an event and I just told you that it was done with one. What you can do is actually use the polarization of the energy to try and determine its back azimuth, *i.e.*, the direction from which the energy is coming. We know that the P wave is a compression and we understand the polarization of those. You can use these P waves to tell you the direction the energy is coming in from and you can use the time separation seismic phases to tell you the distance. We do this by looking at the vertical motion, the east–west and north–south motion of each individual seismic phase and then you can have a go at estimating back azimuth and get a full location, contrary to what any undergraduate lectures might have taught you. This is not easy but only for a few events was the amazing Mars Quake service able to do this sort of work. There are many more events where a full location could not be developed because it was not possible to do the technical calculations. The short answer is that it is super-hard but with a lot of seismic processing you can get a decent idea.

The President. I can see other hands up, but we are beginning to overstay our tenure of the room so please ask your questions to Jessica at the wine reception afterwards. Thank you very much [applause].

Dr. Christopher Lovell is a Dennis Sciama Fellow at the University of Portsmouth. His research focusses on numerical simulations of galaxy evolution, in particular how to model the electromagnetic emission from galaxies, whilst also leveraging the latest statistical and machine-learning methods. He received a PhD in Astronomy from the University of Sussex in 2019, supervised by Professor Peter Thomas and Dr. Stephen Wilkins. He has held postdoctoral roles at the University of Hertfordshire and the University of Tokyo. Recently he was awarded the 2024 Winton Award from the Royal Astronomical Society for his work on forward-modelling extreme-star-forming galaxies. He is a member of the *Euclid*, Learning the Universe, CAMELS (Cosmology and Astrophysics with MachinE Learning Simulations), and FLARES (First Light And Reionization Epoch Simulation) international collaborations. His talk is entitled 'Accelerated modelling of the entire observable Universe'.

Dr. Christopher Lovell. [The latest space-based telescopes, such as the *James Webb Space Telescope* and *Euclid*, are now regularly probing the earliest galaxy populations, formed less than a billion years after the Universe formed. Numerical simulations are a key tool in the astrophysicists' toolbox that allow us to understand the complex processes occurring in those distant galaxies. But how do we compare our theoretical models to actual observations? And what can we learn about both galaxies and cosmology from these sophisticated models?

The talk also reviewed how we model galaxies using numerical simulations, with a particular focus on how we model the light they emit across the whole electromagnetic spectrum. Some of the exciting new methods from statistics and machine learning that are helping to accelerate our models, and provide new insights into both astrophysics and cosmology, were described.]

The President. I'm sorry to hurry you there, but that was absolutely fascinating. We can take a couple of quick questions.

Dr. Q. Stanley. You are taking one of the larger models as the initial conditions for FLARES and that is where you are looking at. Are you finding that it is certain assumptions that you are taking that lead to errors in the areas that you are looking for, or is it other assumptions that you are finding through SPI which leads to those things? It is a very complex situation.

Dr. Lovell. To first order it is the environment. These FLARES regions are large enough that they are capturing cosmological representatives of populations of galaxies. They are rare enough that they are producing rare galaxies but you are right, for a given over-density there is still a lot of scatter in the predicted properties when you add in the galaxy attributes. For certain regions that you think will be very rare there is actually a spread in the rarity of these objects. Otherwise, as you add in the forward modelling that also increases the variance as well so it's not a case of a very simple one-to-one mapping on just the over-density.

The President. One more question.

Reverend Barber. Can you model the very early objects we see with the *James Webb Space Telescope* — the massive black holes, *etc.*?

Dr. Lovell. Yes, is the short answer. We essentially stop the simulations at a redshift of five, so FLARES is very much focussed on *JWST* and early galaxies and it has already been used to explore and place some limits on those very early galaxies. FLARES seems to do quite well at matching some of these early results that suggested attention with our previous understanding of abundances and masses of galaxies. FLARES does slightly better than some other models and we believe that part of that is due to our simulation approach — we are actually catching these rare objects that *JWST* is seeing and other models are able to probe but they don't have the volume to do it. With that said, there have been a few papers in the past few weeks where FLARES is still struggling to produce enough of these very massive things. FLARES is not the end of the story but it is an important contribution.

The President. With that I fear I have to wrap up. Everything you have heard today was beautifully presented and absolutely fascinating and I think we should give a big round of applause to all our speakers [applause]. I should say that Dr. Siân Prosser has produced an exhibition in the Library about Chandrasekhar and Eddington. The next meeting will be on the second Friday of February (14th).

REDISCUSSION OF ECLIPSING BINARIES. PAPER 25: THE CHEMICALLY-PECULIAR SYSTEM AR AURIGAE

By John Southworth

Astrophysics Group, Keele University

AR Aur is a detached eclipsing binary containing two late-B stars which are chemically peculiar, on a circular orbit of period 4·135 d. The primary is a HgMn star which shows temporal changes in its chemical abundances and spectral-line profiles, whilst the secondary is a likely weak Am star. Published analyses of the system have used spectroscopic light ratios to constrain the eclipse models and found that the secondary star is larger than the primary. This unexpected outcome has been taken as an indication that the system is young and the secondary has yet to reach the main sequence. In this work we present the first analysis of the light-curve of the system obtained by the *Transiting Exoplanet Survey Satellite* (*TESS*), whose quality allows us to avoid using a spectroscopic light ratio to constrain the solution. When combined with literature spectroscopic results we obtain highly precise masses of $2{\cdot}544 \pm 0{\cdot}009\ M_\odot$ and $2{\cdot}366 \pm 0{\cdot}009\ M_\odot$ and radii of $1{\cdot}843 \pm 0{\cdot}002\ R_\odot$ and $1{\cdot}766 \pm 0{\cdot}003\ R_\odot$. The light ratio is inconsistent with spectroscopic determinations, confirming the suggestion of Takeda[1] that spectroscopic light ratios of the system are unreliable due the chemical peculiarity of the stars. The properties of the system are matched by theoretical predictions for a slightly super-solar metallicity and an age of 33 ± 3 Myr: both components are young main-sequence stars.

Introduction

The detached eclipsing binary system (dEB) AR Aurigae has been suggested to be a young object in which the secondary component is still a pre-main-sequence star[2]. This claim was based on the less-massive star having a larger radius and lower surface gravity, caused by using a spectroscopic light ratio (SLR) as a constraint in the eclipse modelling. A recent work by Takeda[1] questioned this claim because at least one of the stars is chemically peculiar, making light ratios from spectroscopic absorption lines unreliable. In this work we present an analysis of a new space-based light-curve which does not use an SLR as a constraint, confirms the suggestion by Takeda, and yields improved measurements of the physical properties of the AR Aur system.

The current work is presented in the context of our series of papers which revisit known dEBs[3] for which higher-quality light-curves are now available[4]. The ultimate aim is to measure the masses and radii of the component stars to 2% precision[5,6] and enable their inclusion in the *Detached Eclipsing Binary Catalogue*[7] (*DEBCat*★).

AR Aurigae

AR Aur (Table I) has a long observational history, and was the first dEB known in which one component is a chemically-peculiar star of the HgMn type. The discovery of eclipses was made in 1931 by Pedersen & Steengaard[16], who subsequently measured an orbital period of $P_{\rm orb} = 2{\cdot}076$ d[17]. It was named AR Aurigae in Prager's Katalog of 1936. Spectroscopic observations by Harper[18] and Wyse[19] showed that the $P_{\rm orb}$ is double this, provided the first measurements of the velocity amplitudes of the two stars ($K_{\rm A}$ and $K_{\rm B}$), and yielded an SLR of approximately 0·9 from the 4481-Å and 4549-Å spectral lines. Nassau[20] confirmed that the primary and secondary eclipses have a slightly different depth, and obtained $P_{\rm orb} = 4{\cdot}134581$ d.

Photoelectric photometric studies were made by Huffer & Eggen[21], who adopted an SLR of $0{\cdot}86 \pm 0{\cdot}04$ in their analysis, and Johansen[22] using filters similar to the Strömgren *uvby* system. The data from these two papers were

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

modelled by Cester *et al.*[23] and similar results obtained. O'Connell[24] presented *UBV* photometry and found a change in P_{orb}. Adelman[25] obtained *uvby* photometry mostly outside eclipse and found no additional variability.

Nordström & Johansen[2] (hereafter NJ94) presented a detailed analysis of AR Aur using a precise SLR and the EBOP code to model the light-curves from O'Connell[24] and Johansen[22]. Radial-velocity (RV) measurements were taken from Harper[18] and Wyse[19]. The SLR was obtained by Dr. Graham Hill using the Mg II 4481-Å lines and based on seven spectra taken around quadrature phases. When corrected for the slow change of line strength with effective temperature (T_{eff}), an SLR of 0·866 ± 0·018 was found which gave the ratio of the radii to be $k = R_B/R_A = 1{\cdot}020 \pm 0{\cdot}015$. One outcome of their analysis was that the surface gravity of the secondary star (star B) was lower than that of the primary (star A); this was (with caveats) interpreted as indicating the system was young and star B was still in the final stages of contracting onto the zero-age main sequence.

TABLE I

Basic information on AR Aurigae. The BV magnitudes are each the mean of 111 individual measurements[8] distributed approximately randomly in orbital phase. The JHK$_s$ magnitudes are from 2MASS[9] and were obtained at an orbital phase of 0·23.

Property	*Value*	*Reference*
Right ascension (J2000)	$08^h18^m18^s.896$	10
Declination (J2000)	+33°46′02″·52	10
Bright Star Catalogue	HR 1728	11
Henry Draper designation	HD 34364	12
Hipparcos designation	HIP 24740	13
Tycho designation	TYC 2398-1311-1	8
Gaia DR3 designation	181983575426242944	14
Gaia DR3 parallax (mas)	7·0735 ± 0·0461	14
TESS Input Catalog designation	TIC 144085463	15
B magnitude	6·102 ± 0·014	8
V magnitude	6·144 ± 0·010	8
J magnitude	6·190 ± 0·019	9
H magnitude	6·254 ± 0·017	9
K_s magnitude	6·265 ± 0·023	9
Spectral type	B9 V + B9·5 V	2

Spectral characteristics

The chemical peculiarity of AR Aur was first shown by Wolff & Wolff[26] on the basis of an enhanced Hg II 3984-Å line in star A. More detailed analysis by Wolff & Preston[26] confirmed that star A is a HgMn star and found that star B did not show spectral peculiarities. Takeda *et al.*[27] found changes in the strength and profile of the 3984-Å line of star A and noted that star B appeared normal in their spectra. However, Stickland & Weatherby[28] found enhanced Hg II in *both* components. Khokhlova *et al.*[29] described star A as a typical HgMn star and found that star B showed a different type of chemical peculiarity. Zverko *et al.*[30] found Mn, Ba, and Pt to be overabundant in both stars.

Hubrig *et al.*[31] found line-profile variability for many chemical elements in star A, but none in star B. The projected rotational velocities for both components were measured as $V \sin i = 22 \pm 1$ km s^{-1}. In a subsequent analysis, Hubrig *et al.*[32] found both stars to have a weak magnetic field from spectropolarimetric observations. Those authors also used Doppler tomography to detect strong enhancements of Fe and Y in spots on the surface of star A. The presence of magnetic fields in HgMn stars has been controversial but several detections now exist[33,34].

Folsom *et al.*[35] presented an extensive analysis of atmospheric properties of AR Aur. They (re)confirmed the HgMn nature of star A and that star B shows weak features of being an Am star. They measured the $T_{\rm eff}$ values of the stars, an SLR consistent with that from NJ94, and precise $K_{\rm A}$ and $K_{\rm B}$ values.

Similar conclusions were obtained by Takeda *et al.*[36]. The detailed abundance measurements in this and papers mentioned above typically disagree by more than their uncertainties, suggesting that the measured abundances are variable over time. Takeda[1] presented further abundance measurements, obtained precise $T_{\rm eff}$ values, and pointed out that the SLRs found in previous work may be unreliable as both stars are chemically peculiar; it was this work that prompted the current analysis.

Nearby stars

The multiplicity of AR Aur is of interest. Firstly, it is a member of the Auriga OB1 association[37]. Secondly, it forms a common-proper-motion pair with the A0p star HR 1732 (IQ Aur). This was originally found by W. P. Bidelman, reported by Hoffleit[37] in the Third Revised Edition of her *Catalogue of Bright Stars*, and confirmed by Sargent & Eggen[38]. Thirdly, there is a third component on a wider orbit in the system which manifests as changes in the observed $P_{\rm orb}$ of the inner binary.

Guarnieri *et al.*[39] found $P_{\rm orb}$ to be variable from an $O-C$ (observed minus calculated) diagram which showed a parabolic trend of the residuals of a linear fit to the times of mid-eclipse. Zverko *et al.*[40] suggested this was due to the light-time-travel effect caused by a third star in a wider orbit. Chochol *et al.*[41] found the period of this third body, P_3, to be between 24·75 and 27·09 yr. NJ94 fitted the times of minimum light to obtain $P_3 = 24{\cdot}18 \pm 0{\cdot}21$ yr, with an amplitude of 0·0094 d and a probable small eccentricity of $e_3 = 0{\cdot}17$. Albayrak *et al.*[42] and Zasche[43] have progressively refined the orbital properties of the third body.

Wilson & Van Hamme[44] presented a detailed reanalysis of the AR Aur system. Aside from measuring masses to (a questionable) 0·2% and radii to 0·5%, they obtained $P_3 = 23{\cdot}452 \pm 0{\cdot}096$ yr and $e_3 = 0{\cdot}262 \pm 0{\cdot}023$. They also found the minimum mass of the third body to be $0{\cdot}5122 \pm 0{\cdot}0087\ M_\odot$ — a single main-sequence star of this mass would be much fainter than either of the eclipsing stars, and if it were a binary or a white dwarf it would be fainter still.

Photometric observations

AR Aur was observed in eight sectors (19, 43, 44, 45, 59, 71, 73, and 86) by the NASA *Transiting Exoplanet Survey Satellite*[45] (*TESS*). In all cases data are available at 120-s cadence and were used for our analysis below. Lower-cadence observations (200, 600, and/or 1800 s) are also available for all sectors but were not used due to their lower time resolution. The data were downloaded from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[46].

*https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

We adopted the simple aperture photometry (SAP) light-curves from the SPOC data-reduction pipeline[47] for our analysis, and rejected low-quality data using the quality flag "hard". Additional data points from sectors 73 and 86 were rejected manually due to gaps and increased scatter. The remaining data were converted into differential magnitudes and the median magnitude was subtracted from each sector for convenience. Fig. 1 shows the light-curve from sector 19; the remaining sectors are similar but for clarity are not plotted.

We queried the *Gaia* DR3 database* for all sources within 2 arcmin of AR Aur. A lot of sources were returned — 147 — due to the proximity of the Galactic plane. All are fainter by at least 4·2 mag in the *Gaia* G_{RP} band, so the contamination of the *TESS* light-curve should be small. This is backed up by the CROWDSAP parameter from *TESS*, which depends on the sector but is typically in the region of 0·98.

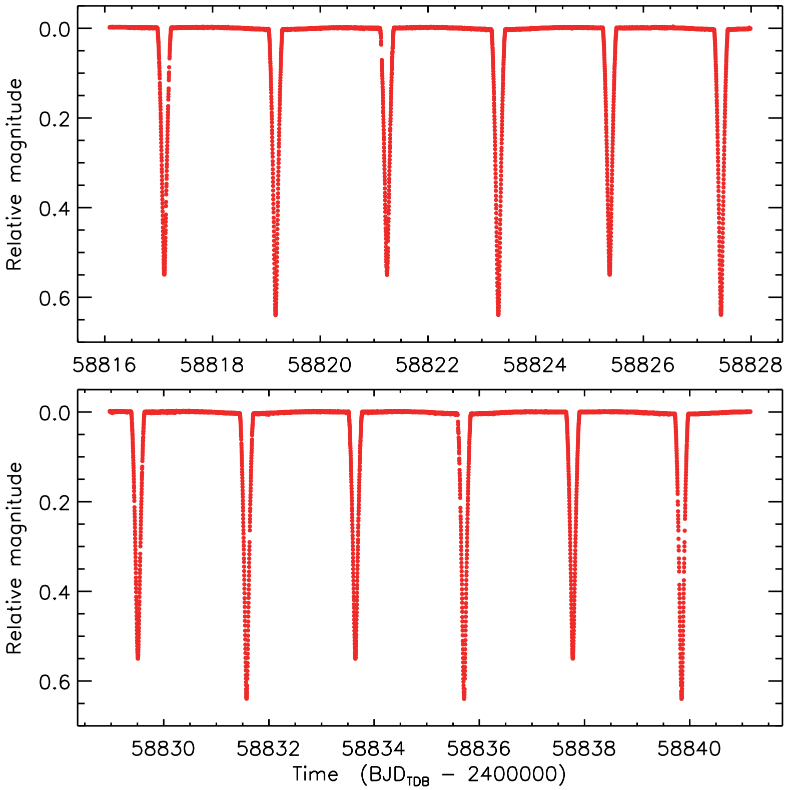

Fig. 1

TESS sector-19 photometry of AR Aur. The flux measurements have been converted to magnitude units after which the median was subtracted. The other seven sectors used in this work are similar but are not plotted for reasons of space.

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

Light-curve analysis

The components of AR Aur are well-detached and almost spherical, so the light-curve is suitable for analysis using the JKTEBOP* code[48,49]. We modelled the light-curves from each sector individually to check for consistency and to guard against small changes in the amount of contaminating light between sectors. We defined star A to be the star eclipsed at the primary (deeper) eclipse, and star B to be its companion. These identities are consistent with the literature discussed above.

The fitted parameters were the fractional radii of the stars (r_A and r_B), expressed as their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$), the central-surface-brightness ratio (J), third light (L_3), orbital inclination (i), orbital period (P), and a reference time of primary minimum (T_0). A circular orbit was assumed as there is no evidence for orbital eccentricity. Limb darkening (LD) was accounted for using the power-2 law[50–52] and we required both stars to have the same LD coefficients. The linear coefficient (c) was fitted and the non-linear coefficient (α) fixed at a theoretical value[53,54]. The observational uncertainties supplied with the *TESS* flux measurements were scaled to force a reduced χ^2 of $\chi^2_\nu = 1{\cdot}0$.

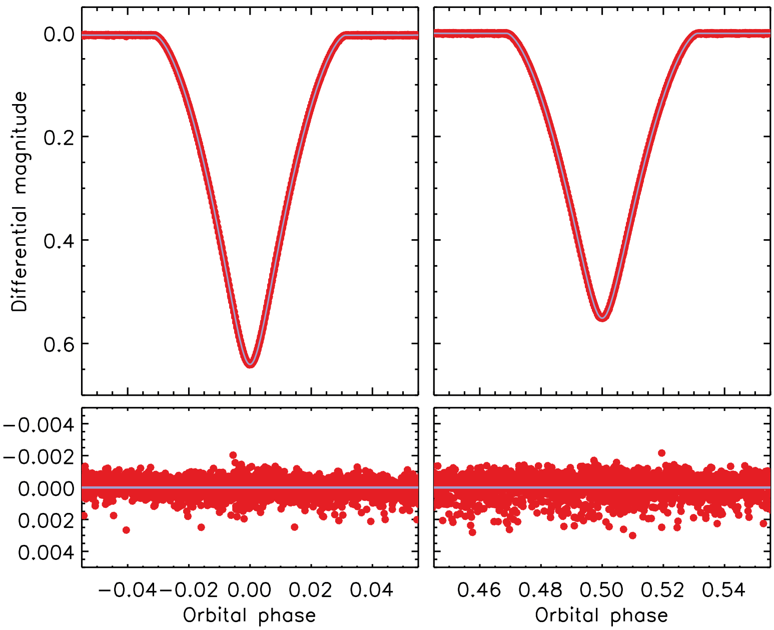

FIG. 2

JKTEBOP best fit to the light-curves of AR Aur from *TESS* sector 19 for the primary eclipse (left panels) and secondary eclipse (right panels). The data are shown as filled red circles and the best fit as a light-blue solid line. The residuals are shown on an enlarged scale in the lower panels.

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

TABLE II

Photometric parameters of AR Aur measured using JKTEBOP *from the light-curves from all eight TESS sectors. The error bars are 1σ and were obtained from the scatter of the results for individual sectors.*

Parameter	*Value*
Fitted parameters:	
Orbital inclination (°)	88·6000 ± 0·0072
Sum of the fractional radii	0·19596 ± 0·00007
Ratio of the radii	0·9578 ± 0·0013
Central-surface-brightness ratio	0·89939 ± 0·00032
Third light	0·0152 ± 0·0027
LD coefficient c	0·553 ± 0·014
LD coefficient α	0·4318 (fixed)
Derived parameters:	
Fractional radius of star A	0·100089 ± 0·000052
Fractional radius of star B	0·095870 ± 0·000092
Light ratio ℓ_B/ℓ_A	0·8249 ± 0·0023

We found that the fits to all sectors were excellent; an example for sector 19 is shown in Fig. 2. The parameters were also highly consistent between sectors, inspiring confidence in the results. In Table II we report the adopted values of the photometric parameters and their uncertainties. We calculated these by taking the unweighted mean and standard deviation of the values for the eight sectors. We did not divide by $\sqrt{8}$ to convert the latter to the standard error as the standard deviations are already very small. We also calculated uncertainties using Monte Carlo and residual-permutation algorithms (tasks 8 and 9 in JKTEBOP) and found that their mean values were similar to each other and to the standard deviation.

Our results differ significantly compared to previous analyses in that we find star B to be definitively fainter and smaller than star A. The radius ratio we find, 0·9578 ± 0·0013, is very different to published spectroscopic values (1·020 ± 0·015 from NJ94 and 1·033 ± 0·005 from ref. 35), and supports the assertion of Takeda[1] that SLRs are not reliable if one or both stars is chemically peculiar. The implications of this result are discussed below.

TABLE III

Times of minimum light measured for AR Aur. Each time is calculated from the data for a whole sector and corresponds to a midpoint of primary eclipse. The final two columns give the uncertainties calculated via the Monte Carlo and residual-permutation analyses, respectively.

Sector	T_0 (*BJD*$_{\rm TDB}$)	*MC error* (*d*)	*RP error* (*d*)
19	2458827·440864	0·000003	0·000004
43	2459484·849830	0·000002	0·000003
44	2459513·792354	0·000002	0·000004
45	2459534·465589	0·000002	0·000003
59	2459923·122341	0·000002	0·000004
71	2460245·624785	0·000003	0·000006
73	2460299·375195	0·000003	0·000007
86	2460650·820263	0·000004	0·000008

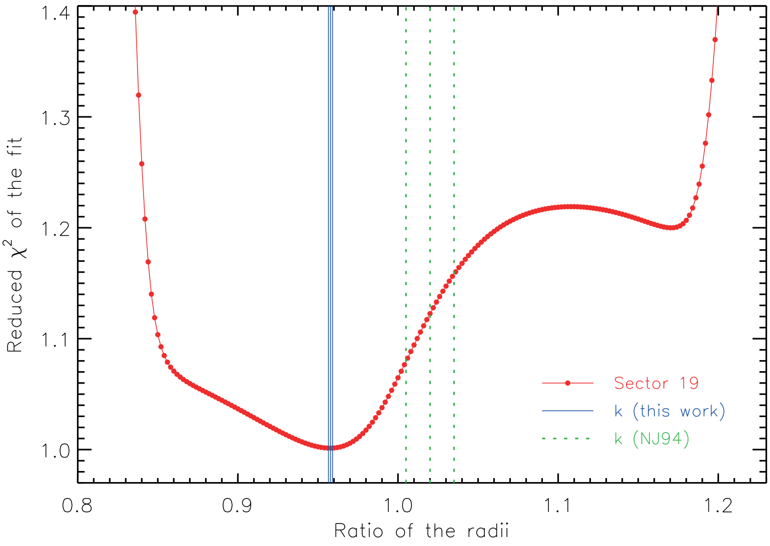

FIG. 3

Variation of χ^2_ν of the JKTEBOP fit to the light-curve from *TESS* sector 19 as a function of the ratio of the radii k (red line with points). Our overall best value and its uncertainty are shown with blue vertical lines, which are very close together. The k from NJ94 is shown with vertical green dotted lines.

To visualize this further we refitted the light-curve from sector 19 in the same way as above, but with k fixed at values from 0·8 and 1·2 at intervals of 0·002. The data uncertainties were scaled to give $\chi^2_\nu = 1{\cdot}0$ for the overall best fit. The result is shown in Fig. 3, where there is a clear minimum χ^2_ν corresponding to the adopted value of k in Table II. This k is significantly different to that found by NJ94 and supports our approach of not including an SLR in our light-curve fit.

It is beyond the scope of the current work to perform an analysis of the times of minimum light. In Table III we report the times of primary mid-eclipse we obtained — one per sector — for use by anyone who wishes to do so.

Physical properties and distance to AR Aur

We calculated the physical properties of AR Aur using the JKTABSDIM code[56] with the photometric properties from Table II and the $P_{\rm orb}$ from ref. 44. We adopted $K_{\rm A} = 108{\cdot}36 \pm 0{\cdot}18$ km s^{-1} and $K_{\rm B} = 116{\cdot}92 \pm 0{\cdot}17$ km s^{-1} from Hubrig *et al.*[33], and the $T_{\rm eff}$ values from Folsom *et al.*[35]. The resulting physical properties are given in Table IV. The synchronous rotational velocities are consistent with the measured values[31].

Fig. 4 shows measurements of the masses and radii of the components of AR Aur from this work (squares) and from the literature (triangles and circles). Our use of the new *TESS* data and precise velocity amplitudes from ref. 33 allows us to reach a new level of precision in our measurements. Not using an SLR to constrain the ratio of the radii causes us to find a steeper mass–radius relation than previous measurements.

TABLE IV

Physical properties of AR Aur defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 55).

Parameter	*Star A*	*Star B*
Mass ratio M_B/M_A	0·9268 ± 0·0020	
Semi-major axis of relative orbit ($R^N_\odot$)	18·416 ± 0·020	
Mass ($M^N_\odot$)	2·5444 ± 0·0086	2·3658 ± 0·0085
Radius ($R^N_\odot$)	1·8433 ± 0·0022	1·7658 ± 0·0026
Surface gravity (log[cgs])	4·3125 ± 0·0008	4·3169 ± 0·0011
Density ($\rho_\odot$)	0·4063 ± 0·0007	0·4285 ± 0·0013
Synchronous rotational velocity (km s^{-1})	22·555 ± 0·027	21·604 ± 0·031
Effective temperature (K)	10950 ± 150	10350 ± 150
Luminosity log($L/L^N_\odot$)	1·644 ± 0·024	1·508 ± 0·025
M_{bol} (mag)	0·631 ± 0·060	0·969 ± 0·063
Interstellar reddening $E(B-V)$ (mag)	0·01 ± 0·01	
Distance (pc)	136·4 ± 1·7	

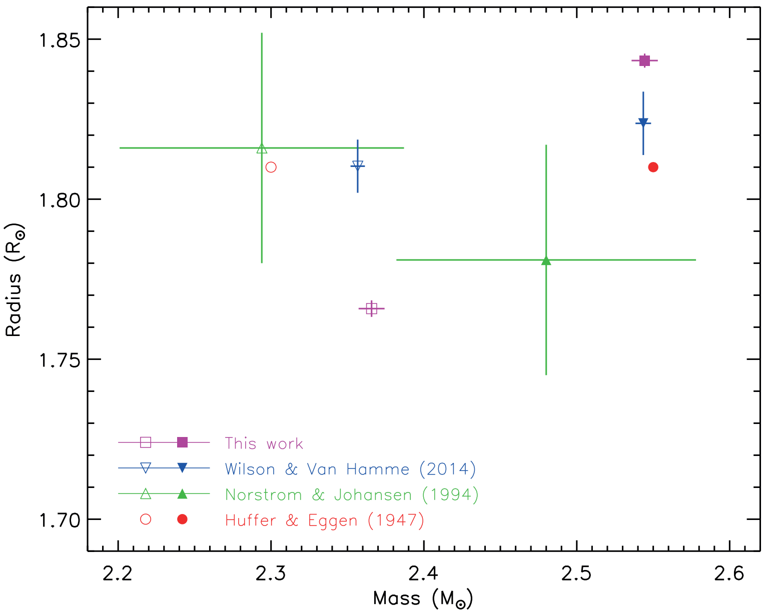

FIG. 4

Mass–radius plot for the components of AR Aur showing the results from the current work and from the literature. Star A is shown with filled symbols and star B with open symbols. No uncertainties were given by Huffer & Eggen[21].

We determined the distance to the system using the *BV* magnitudes from *Tycho*[8], *JHK*$_s$ magnitudes from 2MASS[9], and bolometric corrections from Girardi *et al.*[57]. An interstellar reddening of $E(B-V) = 0{\cdot}01 \pm 0{\cdot}01$ satisfactorily equalizes the distance measurements in the optical and infrared. The resulting distance to the system in the K_s band is $136{\cdot}4 \pm 1{\cdot}7$ pc, which is $2{\cdot}6\sigma$ shorter than the *Gaia* DR3[10] value of $141{\cdot}4 \pm 0{\cdot}9$ pc.

A comparison with the theoretical predictions of the PARSEC 1·2 theoretical stellar evolutionary models[58] finds a good agreement for a metal abundance of $Z = 0{\cdot}020$ and an age of 33 ± 3 Myr after the zero-age main sequence. A lower Z of 0·017 and an age of 59 Myr predicts a mass–radius relation steeper than observed so is disfavoured. A higher Z of 0·030 can be ruled out as its zero-age main sequence predicts radii over 20σ larger than we have measured. The $T_{\rm eff}$ values proposed by Takeda[1] are higher by 200 K for star A and 300 K for star B, and do not match the theoretical predictions as well as the $T_{\rm eff}$ values we have adopted. This analysis confirms that the system contains two young main-sequence stars, and disproves earlier claims that star B is pre-main-sequence.

Summary and conclusions

AR Aur is a system containing a dEB of two late-B stars in an orbit of period 4·135 d, and a lower-mass outer component with a period of 23·5 yr around the inner binary. Star A is established as a HgMn star and star B has been found to show abundances characteristic of a weak Am star. These chemical peculiarities appear to have led to erroneous radius measurements in the past, caused by the use of a spectroscopic light ratio to help specify the ratio of the radii of the stars.

We have modelled eight sectors of data from the *TESS* mission using the JKTEBOP code, and found that the radii of the stars are very well-determined by these exceptionally good data. Combined with published spectroscopic velocity amplitudes we have determined the stars' masses to 0·35% and their radii to 0·15%. The properties of the system match theoretical predictions for a metallicity of $Z = 0{\cdot}020$ and an age of 33 ± 3 Myr, indicating that both components are young main-sequence stars. The distance we determine to the system is $2{\cdot}6\sigma$ shorter than the *Gaia* DR3 value; this moderate discrepancy may be due to the photospheric chemical peculiarity of the system.

We searched for pulsations by feeding the residuals of the fits to the light-curves from *TESS* sectors 43, 44, and 45 to the PERIOD04 code[59]. We found two significant frequencies, corresponding to once and twice the orbital frequency and thus explicable by slight imperfections in the light-curve model. No other significant frequencies were detected up to the Nyquist limit of 359 d^{-1}. Brightness variations on the surface caused by chemical peculiarity are a plausible reason for the signals at once and twice the orbital frequency, but if so are very weak.

Our work on AR Aur therefore yields extremely precise parameter measurements which are consistent with theoretical predictions. The measured values are inconsistent with the hypothesis that star B is a pre-main-sequence star, but do support the assertion by Takeda[1] that spectroscopic light ratios of this system are not reliable due to the chemical peculiarity of both stars. We are left in the unusual and encouraging position of stating that no further work is needed on this system, perhaps save for a refined third-body orbit and a systematic monitoring of the photospheric abundances of the stars to search for temporal changes.

Acknowledgements

We thank Yoichi Takeda for useful discussions. This paper includes data collected by the *TESS* mission and obtained from the MAST data archive at the Space Telescope Science Institute (STScI). Funding for the *TESS* mission is provided by the NASA's Science Mission Directorate. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555. This work has made use of data from the European Space Agency (ESA) mission *Gaia*⋆, processed by the *Gaia* Data Processing and Analysis Consortium (DPAC†). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arχiv scientific paper preprint service operated by Cornell University.

References

(1) Y. Takeda, *Research in Astronomy and Astrophysics*, **25**, 025016, 2025.
(2) B. Nordstrom & K. T. Johansen, *A&A*, **282**, 787, 1994.
(3) J. Southworth, *The Observatory*, **140**, 247, 2020.
(4) J. Southworth, *Universe*, **7**, 369, 2021.
(5) J. Andersen, *A&ARv*, **3**, 91, 1991.
(6) G. Torres, J. Andersen & A. Giménez, *A&ARv*, **18**, 67, 2010.
(7) J. Southworth, in *Living Together: Planets, Host Stars and Binaries* (S. M. Rucinski, G. Torres & M. Zejda, eds.), 2015, *Astronomical Society of the Pacific Conference Series,* vol. 496, p. 321.
(8) E. Høg *et al.*, *A&A*, **355**, L27, 2000.
(9) R. M. Cutri *et al.*, *2MASS All Sky Catalogue of Point Sources* (NASA/IPAC Infrared Science Archive, Caltech, US), 2003.
(10) Gaia Collaboration, *A&A*, **674**, A1, 2023.
(11) D. Hoffleit & C. Jaschek, *The Bright Star Catalogue* (Yale University Observatory, 5th ed.), 1991.
(12) A. J. Cannon & E. C. Pickering, *Annals of Harvard College Observatory*, **92**, 1, 1918.
(13) ESA (ed.), *The Hipparcos and Tycho Catalogues, ESA Special Publication*, vol. 1200, 1997.
(14) Gaia Collaboration, *A&A*, **649**, A1, 2021.
(15) K. G. Stassun *et al.*, *AJ*, **158**, 138, 2019.
(16) H. N. Pedersen & J. C. Steengaard, *Beobachtungs-Zirkulare der Astronomischen Nachrichten*, **13**, 70, 1931.
(17) H. N. Pedersen & J. C. Steengaard, *Beobachtungs-Zirkulare der Astronomischen Nachrichten*, **13**, 72, 1931.
(18) W. E. Harper *et al.*, *Journal of the Royal Astronomical Society of Canada*, **29**, 411, 1935.
(19) A. B. Wyse, *PASP*, **48**, 24, 1936.
(20) J. J. Nassau, *AJ*, **45**, 137, 1936.
(21) C. M. Huffer & O. J. Eggen, *ApJ*, **106**, 106, 1947.
(22) K. T. Johansen, *A&A*, **4**, 1, 1970.
(23) B. Cester *et al.*, *A&A*, **33**, 91, 1978.
(24) D. J. K. O'Connell, *Ricerche Astronomiche*, **8**, 563, 1979.
(25) S. J. Adelman, *A&AS*, **128**, 245, 1998.
(26) S. C. Wolff & R. J. Wolff, in *IAU Colloq. 32: Physics of Ap Stars* (W. W. Weiss, H. Jenkner & H. J. Wood, eds.), 1976, p. 503.
(27) Y. Takeda, M. Takada & M. Kitamura, *PASJ*, **31**, 821, 1979.
(28) D. J. Stickland & J. Weatherby, *A&AS*, **57**, 55, 1984.
(29) V. L. Khokhlova *et al.*, *Astronomy Letters*, **21**, 818, 1995.
(30) J. Zverko, J. Ziznovsky & V. L. Khokhlova, *Contributions of the Astronomical Observatory Skalnate Pleso*, **27**, 41, 1997.

⋆https://www.cosmos.esa.int/gaia

†https://www.cosmos.esa.int/web/gaia/dpac/consortium

(31) S. Hubrig *et al.*, *MNRAS*, **371**, 1953, 2006.
(32) S. Hubrig *et al.*, *MNRAS*, **408**, L61, 2010.
(33) S. Hubrig *et al.*, *A&A*, **547**, A90, 2012.
(34) S. Hubrig *et al.*, *MNRAS*, **495**, L97, 2020.
(35) C. P. Folsom *et al.*, *MNRAS*, **407**, 2383, 2010.
(36) Y. Takeda *et al.*, *MNRAS*, **485**, 1067, 2019.
(37) D. Hoffleit, *Catalogue of Bright Stars*, 1964.
(38) W. L. W. Sargent & O. J. Eggen, *PASP*, **77**, 461, 1965.
(39) A. Guarnieri, A. Bonifazi & P. Battistini, *A&AS*, **20**, 199, 1975.
(40) J. Zverko *et al.*, *IBVS*, **1997**, 1, 1981.
(41) D. Chochol *et al.*, *Bulletin of the Astronomical Institutes of Czechoslovakia*, **39**, 69, 1988.
(42) B. Albayrak, T. Ak & A. Elmasli, *AN*, **324**, 523, 2003.
(43) P. Zasche, *Ap&SS*, **296**, 127, 2005.
(44) R. E. Wilson & W. Van Hamme, *ApJ*, **780**, 151, 2014.
(45) G. R. Ricker *et al.*, *Journal of Astronomical Telescopes, Instruments, and Systems*, **1**, 014003, 2015.
(46) Lightkurve Collaboration, 'Lightkurve: Kepler and TESS time series analysis in Python', Astrophysics Source Code Library, 2018.
(47) J. M. Jenkins *et al.*, in *Proc. SPIE*, 2016, *Society of Photo-Optical Instrumentation Engineers* (*SPIE*) *Conference Series*, vol. 9913, p. 99133E.
(48) J. Southworth, P. F. L. Maxted & B. Smalley, *MNRAS*, **351**, 1277, 2004.
(49) J. Southworth, *A&A*, **557**, A119, 2013.
(50) D. Hestroffer, *A&A*, **327**, 199, 1997.
(51) P. F. L. Maxted, *A&A*, **616**, A39, 2018.
(52) J. Southworth, *The Observatory*, **143**, 71, 2023.
(53) A. Claret & J. Southworth, *A&A*, **664**, A128, 2022.
(54) A. Claret & J. Southworth, *A&A*, **674**, A63, 2023.
(55) A. Prša *et al.*, *AJ*, **152**, 41, 2016.
(56) J. Southworth, P. F. L. Maxted & B. Smalley, *A&A*, **429**, 645, 2005.
(57) L. Girardi *et al.*, *A&A*, **391**, 195, 2002.
(58) A. Bressan *et al.*, *MNRAS*, **427**, 127, 2012.
(59) P. Lenz & M. Breger, *Communications in Asteroseismology*, **146**, 53, 2005.

REVIEWS

General Post-Newtonian Orbital Effects. From Earth's Satellites to the Galactic Centre, by Lorenzo Iorio (Cambridge University Press), 2025. Pp. 282, 25 × 17·5 cm. Price £125/$160 (hardbound; ISBN 978 1 009 56287 4).

The title of this book neatly summarizes both it and many of the author's numerous papers, which have made his name well known. The book deals with many subtle issues which can, in principle, be examined by careful perturbative analysis of two-body motions in the Universe. Thus it is packed with formulae providing the effects on orbital elements (mainly) of perturbations from a wide variety of sources. Actually, while 'post-Newtonian' might to many readers mean 'relativistic' or, more widely, non-classical, the book actually also includes quite classical topics, such as the J2 perturbation of an oblate body, though these are often included as nuisance terms which, if omitted, might mimic the non-Newtonian effects of interest. Little is said of the effects of gravitational waves.

The kinds of effects under discussion are divided into about eight chapters, dealing separately with first- and second-order effects, gravitoelectric and gravitomagnetic relativistic effects, perturbations in non-standard dynamical theories, and so on. Each one of these chapters begins with a short introduction to the physical context of the effects covered, and, having only a nodding acquaintance with some of them myself, I found these interesting. That apart, the text is full of formulae, usually with no more than outline derivations, which the reader has to fill out from the cited literature or provide for himself. The references to the literature are apparently very comprehensive, and the citations and the formulae themselves are presented with a lot of care; the longest ones are hived off to separate appendices.

The author's main application of such results is observational, but almost nothing is said of the statistical methods which such work requires. He does, however, point out the danger of searching for an effect by fitting the residuals from an existing incomplete theory, if one does not repeat the entire fitting with the augmented theory. And when no natural binary motion exists for examining some effect, it can sometimes be done with a suitably designed probe. Some of these are described in a separate chapter at the end, and include proposals with amusingly quirky names, including IORIO (In-Orbit Relativity Iupiter [*sic*] Observatory). The entire text is lightened with etymological and other notes. — Douglas C. Heggie.

Hidden in the Heavens. How the Kepler Mission's Quest For New Planets Changed How We View Our Own, by Jason Steffen (Princeton University Press), 2024. Pp. 253, 24·5 × 16·5 cm. Price £25/$29·95 (hardbound; ISBN 978 0 691 24248 4).

This fascinating book tells the story of *Kepler*, one of the most significant space-science missions ever launched. It is a tale of imagination, innovation, perseverance, technological wizardry, and human ingenuity, described in graphic detail by one of the members of the science team who made the mission such a resounding success.

Until the 1990s, the only family of planets available for astronomers to study was our own Solar System, populated by nine planets (now eight, after the demotion of Pluto), hundreds of satellites, and countless chunks of icy or rocky debris. There seemed little reason to expect any other planetary systems — if they existed — to be very different. Then, in 1992, the first planets confirmed to exist beyond our Solar System were discovered in orbit around a dense, dying star — a pulsar. Three years later, a planet (51 Peg b) was found in orbit around a distant, Sun-like star for the first time. Furthermore, 51 Peg b turned out to be something most unexpected — a searingly hot gas giant that circled its star once every four days, the first example of what came to be known as a 'hot Jupiter'. According to the theories of the time, such a world should not exist. In the years that followed, a steady stream of exoplanet discoveries was recorded, but progress was very slow. However, a group of scientists, led by William Borucki of NASA's Ames Research Center, envisaged a revolutionary space observatory, equipped with a highly sensitive photometer, that would be able to study minute changes in brightness caused by planets transiting in front of distant stars. After years of trying to convince NASA that such a mission was viable, the *Kepler* planet-finding mission was given the go-ahead in 2001 December.

Kepler's primary objective was to spend up to four years staring at more than 100 000 pre-selected stars in order to detect variations in light with an accuracy of 20 parts per million. So much data came pouring in that the science analysts were in danger of being swamped, but the introduction of computer simulations helped to speed up the process. Today, more than 5800 exoplanets have been confirmed, and about half of these were discovered by the *Kepler* team. Jason Steffen, recruited to the *Kepler* science team before it was launched in 2009, gives a compelling account of this groundbreaking mission, including how the mission was conceived, the success of the primary mission that was cut short after four years by a hardware malfunction, and the redesign of the mission (dubbed K2) so that it was able to continue until 2018. He also describes the remarkable variety of worlds that *Kepler* brought to light, including the first super-Earths and sub-Neptunes, the first Earth-sized planets in the habitable zones of their stars, the first planets orbiting in a binary system, systems with seven and eight planets, and astrometric observations that enabled unprecedented photometric studies of numerous stars. The remarkable conclusions are that there are more planets than stars in the Milky Way galaxy, and that many of these worlds are comparable in size to our Earth. Perhaps we are not alone after all! — Peter Bond.

Starbound, by Ed Regis (Cambridge University Press), 2025. Pp. 240, 22·5 × 14·5 cm. Price £25/$29·95 (hardbound; ISBN 978 1 009 45759 0).

There are several versions of a painting under various titles commonly known as *The Fall of Icarus*. The painting, possibly by the Flemish painter Pieter Bruegel (the elder) from perhaps around 1558, shows a coastal landscape in which a horse-drawn plough is guided by a farmer across a field. In the middle distance, in the sea beyond the farm, Icarus, his wings having disintegrated, plunges to his death. Only his flailing legs are visible in the large splash. The farmer doesn't notice. The painting is said to be an allegory about both the dangers of excess ambition and the security to be had from humble toil. The story of Icarus and his father Daedalus, the maker of the wings, is said to originate with the Roman poet Ovid — the dream to fly is very old, and to fly to the stars is a desire possibly as old as humanity itself. In other versions of the Icarus painting the fate of Daedalus is also depicted; he is seen to have continued his flight to land safely on the shore.

Ed Regis is a thoughtful and amusing commentator but his exasperation with wilder extrapolations from reality seems to increase through the 12 chapters of this book, and by the last he has had enough and reveals his inner dream-shattering grouch. But it is in one of the early chapters about three 'Icons of Star Travel' that he lays out his stall. Describing the Bernal sphere, the Bussard Interstellar Ramjet, and Project Daedalus thus: "... each concept was a blend of unrealistic assumptions about what was possible or practical in an indefinite future", which he believes reflects the view that since an object had a name it also has an existence, even though "none of the designs obeyed general principles of standard engineering practice".

We need not trouble ourselves with the details of those projects to see clearly what Regis thinks is important about most of the schemes and plans to deliver humanity to the stars. He would like to see some standard engineering practice, and indeed some real existing physical objects. In 12 chapters he carefully unpicks and assesses the stories and the technology of proposed interstellar travel. He begins by leading us through the origins of the dream — and to be clear the dream is for the transport of humans to a suitable Earth-like planet in orbit around a star other than the Sun. He is not discussing manned excursions to Solar System locations: Mars, Europa, or wherever. The subject of discussion in this book is interstellar starships. Regis takes in turn each of the proposed engineering and social topics involved in the project and applies a healthy dose of reality. For example, simply pointing out that the stars are actually very far away and that human lifespans are comparatively short, makes the proposed task very difficult. To reach the nearest stars at 4·5 light-years distant using something like current propulsion technology would require thousands of years. Enhancing the technology by some means to approach around a tenth of the speed of light, using chemical energy sources, would require more chemical energy than is available on the entire Earth.

With such plain-speaking factual information, garnered from numerous sources, Regis addresses propulsion systems from the almost near-future fusion reactors to drives powered by multiple nuclear explosions, to Earth-based lasers pushing distant space sails, to far-future ideas of space warping and antimatter drives. All fail either to deliver the necessary drive or require the development of solar-system-scale fabrication capabilities. At the end of each topic chapter Regis tries to be positive and says something along the lines of "let's assume that in the future such a system becomes possible" what then? Because individual human life is short he examines the potential for gigantic interstellar spacecraft containing perhaps thousands of travellers on multigenerational voyages. He discusses the morality of such a trip where only the first generation are volunteers. Are the crew on such a ship, particularly second-generation crew, in any worse situation than the current population of the Earth by being on board a sphere enclosed in a life-support system travelling through space with no possibility of escape?

Crew psychology is tricky and has been examined, with far fewer numbers than proposed for a starship, in the self-sustaining, enclosed experimental conditions of *Biosphere 2.0* in Arizona in the 1990s. Over the two years of the project, factions quickly emerged among the eight participants — exacerbated by lack of food and low oxygen levels, both clothes and tempers became frayed. All such crew problems could in principle be neatly circumvented if the crew were asleep, placed into hibernation or suspended animation during the voyage. Long-duration hibernation has not been experimentally verified and problems abound — not least the continued growth of hair and fingernails during sleep.

As well as the host of technical problem associated with interstellar star ships there remains the overriding question — "Why Go?". Regis addresses this in his usual direct manner. He requires logical, rational answers to this challenge, which, even if the voyage is planned to take place a couple of thousand years or so in the future, would still require an unbelievably vast expenditure of resources. What benefit would it be to mankind to go wandering among the stars? Well, the obvious answer is that at some time in the future the Sun will expand and die and in the process incinerate all the planets at least as far out as Mars. Earth and humanity will be no more. But this is billions of years in the future and not one species of Earth-based complex life has lasted more than a small fraction of that time, a few hundred-million years at most. Humans with their uniquely susceptible, almost uniformly identical, DNA are more likely than most to face earlier rather than later extinction. Many commentators think it unlikely that we will last the next 1000 years. The usual answers that are given to the 'why go' question involve poetic feelings of the sort 'our future lies in the stars' or 'exploring is human nature, it is in our DNA'. Regis quite reasonably points out that the vast majority of people do not go exploring but quite contentedly sit on the sofa drinking beer and eating crisps — so it is clearly not a universal component of our DNA. The technocrats answer that a far-reaching technical endeavour such as a multigenerational starship will provide focus to such lives — a focus for human ambition. Well maybe, but again Regis notes that there are equally ambitious projects like universal health care, clean water, or contented fruitful lives for most of the Earth's human population which are also capable of providing focus and with a much more likely chance of success.

The British journalist and political commentator Marina Hyde describes a rhetorical technique used to oppose any piece of proposed government legislation or planning — a technique she calls "Whataboutery". Whataboutery describes an argument which highlights, and places penny-pinching obstacles, real or imagined, in the path that may inhibit the smooth acceptance of the proposal. "What about the financial markets?", "What about the housing stock?", "What about the farmers?". Whataboutery is particularly effective against the more ambitious proposals — what about the parking, for example, when discussing the development of a major power station. Whataboutery appears wise and thoughtful without the effort of having to argue an alternative approach, merely to point out potential difficulties. But Regis is not indulging in Whataboutery, or necessarily criticising ambition, but simply pointing out some hard facts. His discussion is not in the minutiae of small details but addresses the overwhelmingly vast lack of potentially capable technology.

The science-fiction writer Kurt Vonnegut says of *The Star Spangled Banner* that in a Universe of a gazillion civilisations no other has chosen an anthem of "gibberish sprinkled with question marks". Gibberish or not, to loyal patriots the song is inspiring and deeply meaningful. Poetry and dreams matter. As Ed Regis points out in the preface to this book, dreams have been responsible for scientific breakthroughs — he quotes the example of Kekulé and the structure of the benzene ring. There is a Flemish proverb, perhaps in relation to Bruegel's painting "and still the farmer ploughs" — perhaps we could add to that "and while he ploughs he dreams".

Perhaps the choice isn't necessarily between the hubris of ambition or the humility of the *status quo*, there is a middle way, as Daedalus discovered, to use tried-and-tested and carefully calibrated technology within the bounds of its capabilities. This excellent and thoroughly readable book guides our thinking and starship imaginings to follow Regis's ideal of not letting our dreams outrun what is possible and as he says, and delivers, in the final chapter: "What is needed is a severe and sober calculation of the odds". — Barry Kent.

Target Earth, by Govert Schilling (translated by Marilyn Hedges) (MIT Press), 2025. Pp. 120, 21 × 14 cm. Price $21·95 (about £17) (hardbound; ISBN 978 0 262 55134 2).

There is a story that Eric Clapton was given his first guitar, a metal-strung acoustic, at a very early age — perhaps five or seven years old. It had a particularly high action and the metal strings hurt his young fingers so he found it difficult to play and he gave up. Later and a bit older he tried again with a different guitar and the rest is musical legend. Many people have also given up playing music when their first instrument has been difficult and perhaps badly made. In spite of the lyrics by one-time Bristol-based singer Fred 'Leadbelly' Wedlock who claimed to have made his name singing "the folk tradition" — "With a yard of Spanish plywood and a capo" — a poor introductory instrument can be off-putting. I imagine there are generations of budding astronomers who have also been dissuaded by poor-quality beginner telescopes. Beginners' instruments and beginners' introductory books need to be of sufficient quality that they do not discourage, but rather inspire learning while also being affordable so that the cost is not off-putting.

This book is not a detailed study of asteroids, comets, *etc.*, but rather a fast-paced romp through all such pieces of naturally occurring space debris that may come crashing down on Earth. As Schilling himself says "this slim book is not the place to discuss at length all the newest knowledge" — he was describing knowledge of the Solar System's origins in that sentence — but it applies generally to the entire book. This book is not a scientific treatise but a brisk scamper through the headline information about falling space rocks. I should also say that it is very comprehensive in that it addresses most of the issues and is certainly bang up to date. It is in that, not necessarily pejorative, sense that the book may be described as superficial. In just 96 pages of text Schilling describes the objects that have struck the Earth with minor or severe consequences. He lists the sizes, composition, and impact velocity of these objects and also describes their potential sources and possible disaster-mitigating actions.

Although there is certainly a place for this low-in-detail but all-encompassing account, it is a pity that Schilling doesn't help the more inquisitive reader by adding more references to the bits of space gossip that he uses. There are a few references scattered through the text, the odd web page, a list of six other books for further reading, and there is a brief index. Few of the named space rocks are included in it. I did find interesting and surprising pieces of information in the text, such as the eight-yard-diameter rock $2020VT_4$ which zoomed between the surface of the Earth and the *ISS* in 2020 November, or that *Philae*, the *Rosetta* lander investigating Comet Churyumov–Gerasimenko, lasted a few months after its unplanned hopping over the comet's surface and crashing under a cliff face. The existence of the *ATLAS* last-alert telescope system which spots potentially hazardous asteroids was also new information to me.

There is no doubt that Schilling provides a very clear account of the real hazards of space rocks to human civilisation and the measures being taken to guard against the consequence of impact — which in an emergency might involve evacuating the population of target sites. He also outlines the benefits, for example, that our civilisations, indeed our very existence, can be attributed to the catastrophic collisions of Earth with asteroids.

My overwhelming feeling is of a book executed within time and space constraints. It seems like a rush job, as if the instructions to the author may have been to write down everything you know about asteroids in under 100 pages. The author is very well informed — so he knows a lot and thus in such limited space everything is necessarily lacking a bit of depth. To some extent this works well with his easy conversational style of writing — although some things jar. I found the use of yards to describe the sizes of meteorites as rather strange. I feel that yards are primarily used for agricultural or sports-ground dimensions — vaguely technical things are usually described in popular science in miles, feet, and inches — even when there are hundreds or thousands of feet. Yards seem particularly odd when used for the depth of a bore hole. There are also some curious sentences that are just baffling: the Antarctic meteorite hunt which is described as "success assured" — why? Or that the triceratops and tyrannosaurus demise is with "no coincidence" at a geological boundary — again why "no coincidence"? Could these be issues of translation from the original Dutch to American English or is it just that lack of a bit more explanatory detail?

To come back to my first paragraph, could this book be described as a beginners' introduction as I suspect is its aim? It is certainly well made but at just under £20 for around 100 pages of text it probably isn't great value. But does it inspire and encourage? On balance — maybe. It is full of factual snippets without much 'how' or 'why' science. This strange brew might make a great gift for a fact-loving young person — maybe one of the same age as Clapton when he finally got around to enjoying the guitar. — Barry Kent.

The Whole Truth: A Cosmologist's Reflections on the Search for Objective Reality, by P. J. E. Peebles (Princeton University Press), 2022. Pp. 264, 22·7 × 14·7 cm. Price £18·99 (paperback; ISBN 978 0 691 23137 2).

This is a 'paperback review' of a book already reviewed in hardcover; as such I mention only some things related to the physical book and some matters not mentioned by Trimble in her review[1] of the hardback version, which I intentionally did not re-read before drafting this review. Peebles of course needs no introduction, but the cover reminds the reader that he won the Nobel Prize in Physics (in 2019). Like another book[2] from the same publisher that I reviewed[3] in these pages, the first thing I noticed were the unorthodox (though different) page headings; in that book, the chapter numbers and names are at the bottom of the page; this one follows the usual convention in that respect, though the page number is in square brackets and at a fixed distance from the name of the chapter or section, rather than from the edge of the page. There is a long preface explaining the motivation for the book, no figures, more than sixteen pages of references (including article titles; unusual but useful for a book of this type are author/year references in the text), and a six-and-one-half-page small-print index; there are a few, sometimes long, footnotes in the main text.

This book covers much of the same ground as his previous book[4] (reviewed by both Trimble[5] and me[6]), though the emphasis is different, something which is sometimes explicitly mentioned (p. 166): "Let us pass over the details entered in Cosmology's Century.... We are interested in the big picture." That holds for Chapters 3–6; the first two and Chapter 7 are relevant summaries of the history and philosophy of physics from the point of view of a physicist; my guess is that most working physicists agree with Peebles when he concludes, in spite of or perhaps because of knowledge of other ideas among philosophers, that something like objective reality exists and it is the job of physicists to study it. As always, I am happy when a real scientist is critical of Kuhn's idea of paradigm shifts (pp. 30–32), which I see as at best a caricature of the way science actually works. In several recent reviews I've complained about authors who should know better getting basic concepts in cosmology wrong; I can recommend Peebles' clear and detailed explanation of the Hubble–Lemaître law (pp. 92–93). In my review[6] of *Cosmology's Century*, I wrote that Peebles only briefly mentioned the flatness problem, although he did much to popularize it[7]. There is an entire section (6.4) on that and closely related topics here, presenting, in my view, a much more balanced approach. "You win some, you lose some."

Discussion of a 'fourth neutrino' might be confusing to those who are certain that there are only three; 'neutrino' is often used in a more general sense (*e.g.*, 'effective number of neutrinos') in cosmology, and in 1977 it wasn't yet clear that there could not be a fourth generation of elementary particles. For some reason, the unit 'Volt' is always capitalized, and "fact on the ground" — a phrase which I had never encountered before — or a variant of it occurs ten times towards the end of the book. But those items are more interesting than annoying.

Of course I second Trimble's recommendation: "Please read the book." And read her review. — PHILLIP HELBIG.

References

(1) V. Trimble, *The Observatory*, **143**, 142, 2023.
(2) L. Page, *The Little Book of Cosmology* (Princeton University Press), 2020.
(3) P. Helbig, *The Observatory*, **140**, 281, 2020.
(4) P. J. E. Peebles, *Cosmology's Century: An Inside History of Our Modern Understanding of the Universe* (Princeton University Press), 2020.
(5) V. Trimble, *The Observatory*, **141**, 41, 2021.
(6) P. Helbig, *The Observatory*, **141**, 43, 2021.
(7) R. H. Dicke & P. J. E. Peebles, in S. W. Hawking and W. Israel (eds.), *General Relativity: An Einstein Centenary Survey* (Cambridge University Press), 1979, p. 504.

An Introduction to General Relativity and Cosmology, 2nd Edition, by Jerzy Plebański and Andrzej Krasiński (Cambridge University Press), 2024. Pp. 577, 17·5 × 24 cm. Price £69·99 (hardbound; 978 1 00 941562 0).

Both authors are well known for their highly mathematical approach to General Relativity (GR), which had a strong tradition in the former Soviet Union (Sakharov, Zel'dovich, Novikov, *et al.*) and many neighbouring countries (both authors are Polish, though the first author spent a substantial fraction of his life in Mexico). Some might quibble with the title; of the many books I've read covering both GR and cosmology, this book is both one of the longest and the most mathematical. The second author (the first died in 2005) is aware of the tension between the title and the contents, mentioning it in the preface to this second edition, and justifies calling it an 'introduction' because not all topics are covered* and because no prior knowledge of GR or differential geometry is assumed, though knowledge of calculus, Special Relativity, classical mechanics, and electrodynamics is assumed (thus one could start learning GR and cosmology with this book, though the author notes that "[it] takes a careful reader to some height of advancement"). This is very much a 'maths first' book which, despite the author's caveat, covers a large range of topics; that it also does so to a significant depth while 'showing much of the work' explains the length. The first part of eleven chapters (at only a bit more than a hundred pages) covers 'Elements of differential geometry' while the second, with thirteen chapters (but about four-hundred pages), 'The theory of gravitation'. The first part is rather standard, though it does mention Bianchi models and the Petrov classification (though that chapter, like several sections, is marked with an asterisk as being less relevant and more advanced, sort of like 'track two' in *MTW*[1]). The second part includes chapters on standard topics such as the Einstein equations, relativistic cosmology, and the Kerr and Schwarzschild

*Missing topics which are mentioned are gravitational waves, the Cauchy problem, generating new stationary-axisymmetric solutions out of known solutions, the Penrose transform, cosmic censorship, experimental tests, spinor methods, relativistic astrophysics, history of relativity, and Special Relativity.

metrics, but also topics which obviously reflect the interests of the authors, such as the Kaluza–Klein theory, Lemaître–Tolman[–Bondi] models, and Szekeres geometries; a short chapter on relativistic hydrodynamics and thermodynamics and one on the Global Positioning System are more of an attempt to include at least a brief overview of topics which are obviously important in a practical context or currently hot topics*, as opposed to more specialized topics, many of which are covered in some detail.

So it doesn't cover everything. However, it does cover a lot of ground, though of course it is necessarily restricted in the discussion of the various individual topics, about many of which books of similar length have been written. So what is the attraction of a book which covers several topics in a fair amount of detail, as opposed to a *really* introductory book then additional in-depth books for more specific topics? One possibility is that it is a good book if one wants to learn GR in some detail with applications to many fields presented in a uniform notation (different notation schemes, especially regarding signs, are a constant concern when studying GR); apart from worked examples in the main text, there are exercises at the end of most chapters (no solutions, but the last chapter is entitled 'Comments to selected exercises and calculations'). Another is that it is very well written, perhaps surprising since neither the second nor (as far as I know) the first author is a native speaker of English. (Krasiński mentions on his website that his only native language is Polish. I strongly doubt that Plebański was a native speaker of English. However, I know of an astronomer from a non-English-speaking country with a name typical for that country and who grew up there who nevertheless is a native speaker of English as well.) Indeed, the language is better than in many books written by native speakers: there are few typos, and I even have fewer complaints about style than I normally do when reading a book. Other useful features are eighteen pages of somewhat smaller-print references, including titles and the page(s) on which each is cited in the text, and a thirteen-page index (in the usual small print often used for indices). I also enjoyed the footnotes, which are often comments on the history of the topic. Occasionally, there are such remarks in the main text, or gems such as the description of the Bergmann–Wagoner theory: "... a curiosity because it is far from being well understood". From others, it is obvious that the authors are very familiar with the literature: "But this is where most textbooks make a mistake....."; "This second condition was found by Hellaby and Lake (1984), but in their paper it is hidden as two humble numbers in tables and a one-line comment and seems to have been overlooked by all later authors." There are a few black-and-white figures scattered throughout the book; except for two pictures of gravitational-lens systems, they are diagrams of the sort one expects in such books.

Some things were also a bit surprising. As mentioned, sign conventions always need to be kept in mind when studying GR, but I don't think I've ever come across Λ accelerating the expansion of the Universe when negative; when

*For example, a huge amount of work involving numerical relativistic hydrodynamical simulations has been done in order to interpret what is seen by the *Event Horizon Telescope*.

discussing cosmology in more detail, though, "[f]ollowing Friedmann we denote $\Lambda = -\lambda$".* (Note that these days, usually λ is the 'dimensionless cosmological constant' equal to $\Lambda/(3H^2)$.) Even apart from my own interest in the flatness problem, the discussion here certainly deserves special mention, starting out with a warning that "The views expressed in this section are A. K.'s. J. P. bears no responsibility for them." I basically agree with his discussion of the flatness problem itself, but instead of considering arguments claiming that it is not really a problem even within the context of the Friedmann models[6], he points out that it is "completely transformed if we consider the Lemaître–Tolman (L–T) and Szekeres models" — while that is true, it is probably irrelevant to our Universe.

Electrically charged black holes (Kerr–Newman if they are spinning, Reissner–Nordström if not) often get short shrift because they are thought to be rare. This book, though, has a fair amount of discussion on them, highlighting many interesting and unexpected (at least for me) aspects. That is true in general: although Lemaître–Tolman[–Bondi] and Szekeres models are more general than the Friedmann models usually used in discussing cosmology, it seems doubtful that they apply to our Universe, but they are discussed in great detail (not only within the context of the flatness problem as mentioned above). (To be sure, the second author has used them to try to explain the acceleration without dark energy, but I'm sure that they would have been included even if the Universe were not believed to be accelerating.) Of course, there are other topics once thought to be interesting but irrelevant — an example is redshift drift (sect. 17.10); however, due to advances in technology it can now be studied in detail[7].

Apart from the claim that one needs to know H_0 in order to measure q_0 from the magnitude–redshift relation†, I noticed no real mistakes, at least not if we can forgive the authors (both Polish, the second associated with the Copernicus Astronomical Center) for claiming that "Copernicus was the first astronomer who noted that the Earth is not at the centre of the Universe". (Copernicus is introduced in connection with the Copernican Principle that we are not located at a special place in the Universe.) However, I do think that their claim "that virtually the whole of observational cosmology is based on

*At first I thought that it was a typo rather than an unusual sign convention. Almost 30 years ago I corresponded with the late Steven Weinberg regarding a sign error in his famous textbook[2] which covers ground similar to the one reviewed here; that also involved an unexpected minus sign accompanying the cosmological constant. I sent him an email after I had convinced myself that it was actually inconsistent and not some unusual convention. We eventually found out that it was an actual typo in some printings of his book. I was surprised that he invested so much time tracking down a typo in a book written decades earlier. A few weeks ago, while listening to a seminar talk I learned that there is a more serious error in that same book, which is due to the propagation of a typo from Messiah's textbook[3]; undoubtedly many have also quoted Weinberg's expression without noticing the typo. I'm sure that that explains his dedication and attention to detail. Many years later, I reviewed[4] another[5] of his books and sent him a list of minor mistakes. Again, I was surprised about how concerned he was with them.

†While important historically[8], observational cosmology has moved beyond trying to measure only H_0 and q_0. The latter is the first non-linear term in a Taylor expansion, and thus was important when redshifts were small and distance calculation for general Friedmann models was difficult; neither is the case today.

the Friedmann–Lemaître models is a consequence of inertia in thinking and of emotional attachment to the doctrine of equivalence of all positions in the Universe" is exaggerated. Certainly a hundred years ago simple models were assumed because, with practically no data, they were as good an approximation as any and calculations are easier in them. But even before the first edition was written (2006), the idea that the Universe is homogeneous on large scales had become an observational fact (see the discussion in a book[9] by an expert in the field reviewed in these pages[10] a few years ago). Probably related to that is a sceptical attitude towards the standard ΛCDM model of the Universe and the hope of the authors that alternative explanations for the claim that acceleration has been observed might prove to be right. In another context, the authors note that one of their ideas (an attempt to explain gamma-ray bursts *via* blueshifted radiation from a non-standard Big Bang) has "met a violent opposition from astrophysically minded referees and will likely not be further pursued". There is a good discussion of the definitions of cosmological distances, but I was somewhat surprised that the simplest generalization to a more realistic universe[11,12] is not mentioned, though more complicated effects such as the position drift of light sources (due to moving matter sweeping along light rays passing through it) are.

This book has a very different balance among the various topics than that of otherwise broadly similar books. More detailed discussion of those related to our Universe can be found elsewhere, but this book is the place to go for interesting if not necessarily relevant details which are hard to find elsewhere, in addition to those reasons mentioned in the second paragraph above. After I had written this review, I came across a link[13] on Krasiński's personal web page to the review in this *Magazine* by Alan Heavens of the first edition[14]. His review is rather similar, but as expected shorter than mine. I can't improve on his recommendation: "For anyone looking for a thorough mathematical treatment of General Relativity, or for a supplement to existing books, this is highly recommended. It is not a standard text by any means, but I would be surprised if there was anyone who didn't find in it something new, interesting, and enlightening". — PHILLIP HELBIG.

References

(1) C. W. Misner, K. S. Thorne & J. A. Wheeler, *Gravitation* (Freeman), 1973.
(2) S. Weinberg, *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity* (John Wiley & Sons), 1972.
(3) A. Messiah, *Quantum Mechanics* (translated from the French by G. M. Temmer) (North-Holland Publishing Company), 1961.
(4) P. Helbig, *The Observatory*, **136**, 82, 2016.
(5) S. Weinberg, *To Explain the World: The Discovery of Modern Science* (Allen Lane), 2015.
(6) P. Helbig, *European Physical Journal H*, **46**, 1, 2021.
(7) P. Helbig, *The Observatory*, **145**, 116, 2025.
(8) A. Sandage, *Physics Today*, **23**, 34, 1970.
(9) P. J. E. Peebles, *Cosmology's Century: An Inside History of Our Modern Understanding of the Universe* (Princeton University Press), 2020.
(10) V. Trimble & P. Helbig, *The Observatory*, **141**, 41 & 43, 2021.
(11) P. Helbig, *The Open Journal of Astrophysics*, **3**, 1, 2020.
(12) P. Helbig, *The Observatory*, **140**, 128, 2020.
(13) https://users.camk.edu.pl/akr/obsreview.pdf
(14) A. Heavens, *The Observatory*, **127**, 200, 2007.

Triton and Pluto. The Long Lost Twins of Active Worlds, edited by Adrienn Luspay-Kuti & Kathleen Mandt (IoP Publishing), 2025. Pp. 292, 26 × 18·5 cm. Price £120 (hardbound; ISBN 978 0 7503 5616 9).

The icy worlds of Triton and Pluto are remarkably similar and yet their evolutionary paths have diverged. Both are technically dwarf planets and share many properties with Kuiper Belt objects. This reference book is both a synthesis of what was known about them up to and including 2023 as well as an exploration of where future studies may usefully lead. It comprises 12 chapters authored by 48 contributors, each chapter being a stand-alone account of the subject area it covers. The book is one of the latest publications in the AAS–IoP Astronomy series, which now number 59 texts, all available on-line as e-books.

The book has been edited to a high standard with relatively few errors given the complexity of some sections. Although e-books are searchable and indexable, regrettably the physical books do not have an index. There is some repetition between the various chapters — unsurprising, especially given the paucity of information available for Triton. Chapter topics include origins, interiors, cryovolcanism, morphology and geology, atmospheres and their interactions with the surface, the ionosphere and magnetosphere, and subsurface oceans (especially Triton). Three of the latter chapters deal with open questions needing answers and future measurement, but need referencing outcomes of recent decadal surveys. Interestingly, the chapter on 'Planning for Long-Lived Missions' includes human considerations and has wider relevance for the astronomical community. A cross-disciplinary chapter on the chemistry of cosmic ices of relevance to Triton and Pluto and their overlap with TNOs and comets would have been a useful addition. Currently there are no active space missions targeting Triton, Pluto, or TNOs. Hopefully this publication will serve as a focus improving the chance that a future such mission proposal will be accepted. —Richard Miles.

OBITUARY NOTICE

Sir Francis Graham-Smith FRS (*1923–2025*)

Known to his friends at the Royal Greenwich Observatory (RGO, for many years home of this *Magazine*) as Graham Smith, he was a pioneer in radio astronomy, beginning with wartime work in telecommunications — as did many in that nascent field — becoming a professor at the University of Manchester in 1964. From 1976 to 1981 he was the Director of RGO with the principal task of creating the Northern Hemisphere Observatory on La Palma in the Canary Islands. (While at Herstmonceux he enjoyed playing badminton with two of the present Editors of this *Magazine* — RWA & DJS!) He was Astronomer Royal from 1982 (ironically the post that was once held *automatically* by the head of the RGO) until 1990, but remained active in astronomy until very recently. He was born on 1923 April 25 and died peacefully on 2025 June 20. A full obituary may be expected in *Astronomy & Geophysics* since Graham was President of the RAS from 1975 to 1977.

Advice to Contributors

The Observatory magazine is an independent, on-line only, journal, owned and managed by its Editors (although the views expressed in published contributions are not necessarily shared by them). The Editors are therefore free to accept, at their discretion, original material of general interest to astronomers which might be difficult to accommodate within the more restricted remit of most other journals. Published contributions usually take one of the following forms: summaries of meetings; papers and short contributions (sometimes printed as *Notes from Observatories*); correspondence; reviews; or thesis abstracts.

All papers and *Notes* are subject to peer review by the normal refereeing process. Other material may be reviewed solely by the Editors, in order to expedite processing. The nominal publication date is the first day of the month shown on the cover of a given issue, which will normally contain material accepted no later than four months before that date. There are no page charges.

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(No.) Authors, journal, volume, page, year.

and for books:

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where the items in square brackets are required only when citing an article in a book. Authors are listed with initials followed by surname; where there are four or more authors only the first author '*et al.*' is listed. For example:

(1) G. H. Darwin, *The Observatory*, **1**, 13, 1877.
(2) D. Mihalas, *Stellar Atmospheres (2nd Edn.)* (Freeman, San Francisco), 1978.
(3) R. Kudritzki *et al.*, in C. Leitherer *et al.* (eds.), *Massive Stars in Starbursts* (Cambridge University Press), 1991, p. 59.

Journals are identified with the system of terse abbreviations used (with minor modifications) in this *Magazine* for many years, and adopted in the other major journals by 1993 (see recent issues or, *e.g.*, *MNRAS*, **206**, 1, 1993; *ApJ*, **402**, i, 1993; *A&A*, **267**, A5, 1993; *A&A Abstracts*, §**001**).

UNITS & NOMENCLATURE: Authors may use whichever units they wish, within reason, but the Editors encourage the use of SI where appropriate. They also endorse IAU recommendations in respect of nomenclature of astronomical objects (see *A&AS*, **52**, no. 4, 1983; **64**, 329, 1986; and **68**, 75, 1987).

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