THE OBSERVATORY

A REVIEW OF ASTRONOMY

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EDITORIAL

In the 2023 December issue, an editorial outlined the predicament in which this *Magazine* found itself, mainly as a result of a dramatic increase in the cost of postage. The action that the Editors took then was to raise the price of subscriptions substantially for 2024. That action has resulted in a marked decline in the number of subscribers, particularly among Fellows of the RAS; it is surmised that the same fall-off in the number of libraries taking *The Observatory* did not occur due to some inertia among institutions that have been subscribing for a much longer period.

Whatever the case, the Editors have agreed that a new approach is required. So from the start of Volume 145 in 2025, the *Magazine* will be provided *without charge* in the form of a PDF file that can be found on our web site:

http://www.obsmag.org/

That PDF can be downloaded and, for users wishing to avoid reading material from a screen (as is the case with most of the Editors!), it can be easily printed. Indeed, especially with the aid of a printer capable of double-sided printing, and using the 'Actual size' facility, a copy of the *Magazine* can be produced which merely needs to be trimmed to the familiar size to resemble a traditional issue. The cover pages can also be made available, so that anyone with a supply of light-blue paper can complete the process in full.

We hope that this offer of a free, open-access journal will continue to be of interest to both individuals and institutions who, we trust, will appreciate the financial and environmental benefits. And to help expedite this process, the present Editors will be pleased to welcome Phillip Helbig to their number; his enthusiasm for *The Observatory* is perhaps the main reason that we are not 'calling it a day'.

In addition to having the latest PDFs available on-line, it is intended that PDFs of recent issues will be available in the same way. Furthermore, it is also planned to enable the Astrophysics Data System to connect to each issue on-line as soon as it becomes available, so there will be no delay as there is at present. Indices for the last 20 years or so, again in PDF form, will appear on our website too.

October Page 2024.indd 217 19/09/2024 14:33

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 March 9 at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

MIKE EDMUNDS, *President*
in the Chair

President. Good afternoon. This is a hybrid meeting. Questions can be asked at the end of the lectures, but you will be muted so please use the chat facility. The questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. I hope that many of you will have had an e-mail today or seen the headlines in the press — I'm really pleased to announce that we have obtained a new deal on the accommodation arrangements at Burlington House. Last week, with the other courtyard Societies, we signed a 999-year lease at a peppercorn rent, which means that we don't have to pay rent in future. It basically transfers ownership of Burlington House from the Government to the Societies. It does mean that we have to pay money to look after the building in return, but we can afford this from our reserves. We can now plan for the future and work more closely with the other courtyard Societies to plan outreach events and so on [applause].

On to today's programme. I'm very pleased to welcome Dr. Ravindra Desai. He is an Assistant Professor at the University of Warwick. His research into astrophysical plasmas incorporates both particle-scale kinetic physics and system-scale phenomena, to pursue blue-skies research into how plasma dynamics govern astrophysical systems across the Solar System and beyond. He is also interested in how astrophysical plasma processes can intersect with, and pose dangers to, our increasingly technology-dependent society through the phenomenon collectively known as space weather, and, no doubt, particularly bad in the UK as it always is [laughter]. The title of his talk is 'Extreme space-weather events'.

Dr. Ravindra Desai. Space weather is influenced by phenomena operating across a multitude of scales, from the large-scale expulsion and evolution of coronal mass ejections from the solar corona, to particle-scale interactions within the radiation belts. My interests within plasma simulations focus on both large-scale fluid physics and kinetic processes and the interplay between them to try to understand holistically space weather and the extreme physical regimes that this can produce. I want to start with Sun-to-Earth studies of coronal mass ejections and review some of the largest geomagnetic storms on record and examine under what conditions 'Carrington-scale' events are possible.

Coronal mass ejections (CMEs) are eruptions of vast amounts of magnetized material which erupt from the Sun at high velocities, and are the primary cause of severe space weather. When they reach Earth, these solar storms trigger amazing auroral displays, but can disrupt power grids, satellites, and communications. I first introduce the large CME that occurred on 2012 July 23 and which narrowly missed Earth by just two weeks. The CME was estimated to travel at around 2250 km s^{-1}, and is thought to be comparable to the Carrington event in 1859. We used a state-of-the-art magnetohydrodynamic model of the inner heliosphere, driven by time-dependent boundary conditions at the solar surface, to model this event and examine whether a prior CME on July 19 might have influenced this CME and enhanced its characteristics. We found that by the time of the July 23 event the solar wind had largely recovered from the July 19 event, so the previous event had little impact. However, our model showed that if the latter CME had occurred earlier, closer to the 19 July event, then it would have been even more extreme — reaching speeds of up to 2750 km s^{-1}. Hopefully here I have shown how two CMEs can combine to produce an even more severe space-weather event.

I then discuss a following study where we examined the interaction of two magnetized CMEs between the Sun and the Earth to see how these can combine to enhance their impacts at Earth, their 'geo-effectiveness'. We used magnetohydrodynamic flux-rope models to simulate pairs of CMEs and determine the strength of the resultant storm. For idealized conditions we explored three factors: the tilt of the CMEs with respect to Earth's magnetic field, the twist of the magnetic fields, and the delay time between two successive erupting CMEs. To quantify the strength of the storms, we used a measure of how compressed Earth's simulated magnetic field was and calculated the commonly used Disturbance Storm Time (DST) index. A significant finding here was that the handedness of the CME had a significant effect on the geo-effectiveness of the resultant storm through magnetic reconnection, or lack thereof, between the two interacting CMEs.

How do these impulsive injections of energy flow through the coupled Sun–Earth system and present an imminent danger to our increasingly technology-reliant society? In 1991 March, a large interplanetary shock struck the magnetosphere, at the leading edge of a CME. This rapidly accelerated a new radiation belt into the normally depleted slot region — a region considered safe by many satellite operators. To model this we use ensembles of test-particles embedded within global magnetohydrodynamic simulations which are able to reproduce this rapid energization process for radiation-belt electrons. We consequently examine a variety of shock impacts and examine the results and find that shocks of greater than 1000 km s^{-1} pose a significant space-weather risk. We are taking these results forward to be implemented at the UK Met Office for space-weather-forecasting purposes.

In summary, I have shown using a series of Sun-to-Earth simulation studies how severe and extreme space weather events can unfold. Thank you for your attention.

The President. Thank you very much. Questions?

Reverend Garth Barber. Is it possible to compare these recent extreme events with the Carrington event? Was that similar to or greater than these?

Dr. Desai. That is something that I am interested in. So far the modelling capabilities have extended Sun to Earth at the radiation belts. If you want to compare to the Carrington event the only data we have is from magnetometers on the ground. For that there is too much detail — we need a model of the Earth's ring current. If you have a model like that you can reproduce the signatures on the graph, so yes, I think there is a lot of potential for going back, and that is something that is on the agenda.

Dr. Paul Wheat. Is there any impact at all on the pressure waves in the atmosphere when these things hit? Is there anything that came back down and you get a bounce either in pressure or density changes in the physical atmosphere? As a rider to that is there much we can do either with satellites or on the ground if we know what is coming, because we don't get a lot of warning, do we?

Dr. Desai. In answer to the first part of your question, absolutely. There is an effect on the neutral atmosphere. When you compress the magnetosphere you get all those velocity shears, you get currents, which close along the field lines and these produce a phenomenon called Joule heating which heats the whole atmosphere. The ions collide with the neutrals which heats the whole atmosphere and modifies satellite drag. It's a big problem for satellite operators and for producing conjunction warnings between satellites and satellite debris. For extreme events there might not be too much warning. You might see something on the Sun that will arrive a day later. That is probably enough time to galvanize observations on the ground. There are lots of facilities on the ground that are constantly observing, such as radar systems and ground magnetometers which are perfectly active and provide a valuable resource. Space-weather forecasting requires ten or 100 times more observations from stations before it can compete with terrestrial forecasting.

The President. One last question.

Professor Mike Cruise. You mention the 'f' word a few times in the talk, *i.e.*, forecasting. Do you see a really big improvement in the ability to forecast the trigger event or will we always be just waiting for the front edge of this and then you will forecast what's going to happen next?

Dr. Desai. At the moment I think it is a case of watching the Sun, and if you see a large active region rotating on the solar disc there is an increased likelihood that something will erupt from that. It is very difficult to predict whether active regions are about to erupt. In the last few days there has been a very large active region which is pointed towards the Earth and has produced loads of flares but hasn't produced CMEs and people don't know why.

The President. Thank you very much indeed. [Applause.]

We now move on to a talk entitled 'Massive black holes during the first billion years with the *JWST*' and I'm delighted to welcome Dr. Hannah Übler who is currently a Newton-Kavli Fellow at the Kavli Institute for Cosmology and the Cavendish Laboratory at the University of Cambridge. She obtained her Doctorate (PhD in Astronomy) in 2019 from the University of Munich, Germany, working at the Max Planck Institute for Extraterrestrial Physics in Garching on galaxy kinematics during the peak epoch of cosmic star formation. Hannah also holds a Magister Artium in Philosophy from the University of Munich. Her research focusses on the formation and evolution of galaxies and massive black holes, most recently using the *NIRSpec* instrument on board *JWST*, as part of the *NIRSpec* GTO team and as co-lead of the *NIRSpec-IFS* GTO survey.

Dr. Übler. It is my pleasure to present to you today results about massive black holes in the first billion years detected with the *James Webb Space Telescope* (*JWST*). The majority of the work I will present has been done in collaboration with the *NIRSpec* Guaranteed Time Observations (GTO) team surveys GA-NIFS and JADES, the latter a joint effort with the *NIRCam* GTO team.

We have learned much about the properties of distant galaxies through large survey efforts over the past decades. We know that there has been a peak epoch of cosmic star formation around redshifts $z \sim 1-3$, leading to a build-up of stellar mass, while the winding-down of star formation has been accompanied by a decline in molecular gas in galaxies. Much of the spatially-resolved properties of these galaxies have been revealed through ground-based spectroscopy. However, ground-based studies of the rest-frame optical properties of galaxies are limited to $z \sim 4$ due to the Earth's atmosphere. With *JWST*, we can observe these wavelengths at $z > 4$ for the first time, facilitating detailed studies of galaxies during the first few billion years of cosmic history, and of course also of their black holes.

Supermassive black holes have been observed in all massive galaxies in the

October Page 2024.indd 220 19/09/2024 14:33

local Universe, and the experimental proof for a supermassive black hole at the centre of our own galaxy, the Milky Way, has been awarded with the Nobel Prize in Physics in 2020. Observational evidence suggests that there exists a tight link between the growth and properties of galaxies and their supermassive black holes. Yet, we still do not understand how these black holes managed to grow so massive so quickly, even though the key pathways for forming massive black holes were identified already 40 years ago. Through *JWST*'s ability to push observational studies of galaxy evolution into the first billion years, we may now start to constrain some of these predicted formation pathways for the first time.

Before I discuss some of our exciting results on this topic, a few more words about the telescope. *JWST* has been developed over several decades, and is the largest telescope currently in space. It has gold-coated mirrors to reflect infrared light, a large sunshield to keep the instruments cool, and a huge improvement in sensitivity and sharpness compared to previous missions in the infrared. On board *JWST* are four superb instruments, *NIRCam*, *NIRISS*, *NIRSpec*, and *MIRI*, and I will focus mainly on discoveries with the *NIRSpec* instrument. The *NIRSpec* GTO team is following two complementary strategies to study galaxies in the early Universe. The GA-NIFS survey uses the *NIRSpec Integral Field Spectrograph* (*IFS*) to get detailed and spatially-resolved views on carefully-selected individual galaxies. The JADES survey uses the multi-shutter array to observe up to 200 objects at a time through single slits, thus providing statistical information, while *NIRCam* provides imaging.

Through these observing programmes, it became clear early on that there are many more active black holes in the early Universe than previously expected. I show here an example from GA-NIFS of the first spatially-resolved spectroscopic study of a galaxy and its massive black hole one billion years after the Big Bang. In the spectrum of this object, GS 3073, you can appreciate the superb data quality we can achieve with *JWST*. We see clearly the broad-line region associated with gas clouds orbiting at high velocities around the accreting black hole in the helium and hydrogen lines, and we also observe emission lines of highly ionized atoms, indicative of the radiation field from an active galactic nucleus (AGN). This rich spectrum allows a detailed investigation of many important physical properties of the galaxy and its black hole, such as kinematics, dynamical mass, metallicity, excitation, electron density, black-hole mass, and outflow properties. Interestingly, although the AGN lies in the deepest *Chandra* field, it is not detected in X-rays.

Also in JADES we found several of these broad-line AGN. Interestingly, they all appear to be over-massive with respect to the stellar mass of their host galaxies, when compared to galaxies in the local Universe. There is also some indication that we see dual AGN, that is, two broad-line regions within our slit observations. This is not trivial to interpret in the JADES spectra. The spatial resolution of the *IFS* is a great advantage here. I show here another example from the GA-NIFS survey, where we were extremely excited to find an off-centre AGN in the system ZS 7 only 740 million years after the Big Bang. Our observations indicate an on-going galaxy and massive-black-hole merger. The final stages of such massive-black-hole mergers in the early Universe will be detectable with future gravitational-wave missions like *LISA*.

Finally, I want to show you the highest-redshift black hole found to date, in the galaxy GN-z11 at $z = 10{\cdot}6$, identified here through emission lines tracing extremely high ionization, high densities in the broad-line region around the black holes, and fast outflows. With measurements of black-hole masses so early in cosmic history, we can finally start to put constraints on theoretical models of massive-black-hole growth in the early Universe.

I hope I have shown you how *JWST* is pushing the redshift frontier and our understanding of early galaxy evolution. Within the *NIRSpec* GTO team we follow a two-tier approach to get both statistics and very detailed studies of the earliest galaxies and their black holes. We are also very excited for the years to come, just having been awarded an open-time Large Programme to characterize massive black holes and their host galaxies in the first billion years with the *NIRSpec IFS*. And, of course, we are looking forward to many unexpected discoveries that lie ahead. Thank you very much for your attention.

The President. You have two black holes, 600 pc apart — how long would it take for them to merge?

Dr. Übler. We can make back-of-the-envelope calculations on what would be the dynamical-friction time-scale — between 100 and 200 million years. However, if we also consider the stellar-hardening timescale, *etc.*, the real time to merge might be longer. The final stage of the merger will be detectable with *LISA*.

Professor Phil Charles. On that same system you must have some idea of the rough size of the black holes from your data.

Dr. Übler. From the broad-line region we can estimate the mass at about $10^{7 \cdot 7}$ solar masses. This is fairly massive but not as massive as some of the black holes that have been detected at similar redshifts. For the other source we don't see a broad-line region and so we don't have a direct way to estimate the black-hole mass. We can do some estimates but this gets really difficult. We can, of course, use the local relation between the black holes and the host properties so we have an estimate of the stellar mass of the system, but then we also see that many of the sources that are discovered are way off, by two or three orders of magnitude. In our JADES data the secondary black holes are estimated to be less massive by about two orders of magnitude or so.

Dr. Robert Fosbury. The hypothesis of the black hole — is that based solely on the line width or are the emission-line spectra consistent with normal black-hole ionization rules?

Dr. Übler. We see these broad-line regions in the hydrogen line, and also in the helium lines. We have the broad lines but we don't see them in the forbidden lines. This is an indication about the origin of the emission and it's consistent with black holes; however, there are diagnostic diagrams that are used for local AGNs, for instance, the so-called BPT diagram where you compare specific line ratios, and this tells you what the prominent ionization mechanism is in the source — is it star formation or AGN? The issue with these diagrams for the high-z sources is that due to the lower metallicity of these galaxies in the early Universe, galaxies shift their position in this diagram such that at $z = 4$ or so star-forming and AGN-dominated systems start to overlap in these diagnostics. The development of alternative diagnostic diagrams takes a lot of effort, and several groups are working to identify new diagnostic diagrams that can be used to identify, based on narrow lines, what is dominated by black holes and by star-formation feedback. Some promising diagrams are those that include the He II line which requires relatively high ionization. For many sources we don't have deep-enough spectra to detect these lines and so we have people working on alternative diagnostics such as the UV lines. This is also done for galaxies in the local Universe. Also, for the auroral lines, there is a project on which a student is currently engaged to find new diagnostics to help identify, in addition to those features like the broad lines, what could be an AGN or not. In the local Universe, people look for X-ray emission, and also, as I said earlier, in higher-

October Page 2024.indd 222 19/09/2024 14:33

redshift objects. We do not see X-ray emission for the AGN I showed, even in very deep integrations, so this is something that people are trying to understand now.

Mr. Horace Regnart. How does the central Milky Way black hole compare in size to those central black holes for similar-sized galaxies? Is there a hint of anomaly, and if so, is there a hint of an explanation?

Dr. Übler. Regarding the Milky Way, I will refer you to Frank Eisenhauer in the audience who knows everything about the black hole in our own galaxy. In terms of these high-redshift sources, if you remember the diagram showing the black-hole mass *versus* stellar mass, this would suggest to us that actually these black holes are, compared to the galaxy size, bigger than what we have in the Milky Way. There are some uncertainties that we need to take into account both in terms of how the black-hole masses are derived, but also how the stellar masses are measured. If we look at other properties of the galaxies, for instance, the integrated velocity dispersion that can be used as an estimator of the total mass of the system, we see that we are closer to the local relation, and potentially this would suggest that the baryonic mass corresponding to a black hole in the local Universe is already present here, but has not yet converted into stars, and these are things that we try to pin down with the programme that we have upcoming. With these imaging-spectroscopic data we hope to get much more accurate estimates of the stellar masses and also the black-hole masses to understand what the systematics are in the plots I showed, and also measure the kinematics.

The President. Thank you very much [applause].

It is now my pleasure to introduce the Eddington Lecture for this year, to be given by Dr. Stephen Taylor who is a Northern Irish astrophysicist and Assistant Professor at Vanderbilt University in Nashville, Tennessee. He has an undergraduate degree in physics from the University of Oxford in 2010, followed by a PhD from the University of Cambridge in 2014 where he worked with Dr. Jonathan Gair at the Institute of Astronomy. After postdoctoral fellowships at NASA's Jet Propulsion Laboratory and Caltech, he joined Vanderbilt University as faculty in 2019. Stephen Taylor is the recipient of the US National Science Foundation's prestigious CAREER award, and was recently named as the 2024 Kavli Plenary Lecturer by the American Astronomical Society. He co-led the North American Nanohertz Observatory for Gravitational Waves analysis campaign that resulted in the first evidence for an all-sky background of gravitational waves at light-year wavelengths, and currently serves as the Chair and spokesperson of the NANOGrav collaboration. We look forward very much to your talk which is entitled 'The dawn of galaxy-scale gravitational-wave astronomy'.

Dr. Stephen Taylor. Thank you very much for the warm invitation to deliver this year's Eddington Lecture.

The first direct detection of gravitational waves (GWs) was by ground-based instruments like *LIGO* (the *Laser Interferometer GW Observatory*) in 2015. The field has blossomed from that first detection of two black holes coalescing in 2015, to the amazing 2017 multi-messenger observation of two neutron stars merging and radiating not just GWs but pan-spectral electromagnetic (EM) waves, to a growing catalogue of mergers that has recently almost doubled in number with a new on-going observation run. But as we know from the history of EM astronomy, new discoveries await as we expand into heretofore inaccessible or unexplored regions of phase space.

On 2023 June 29, the global pulsar-timing-array community announced strong evidence for an all-sky background of gravitational waves at nanohertz frequencies, almost eleven orders of magnitude lower in frequency than had previously been seen by *LIGO*. This discovery was made with approximately 3·5–4 sigma significance by NANOGrav, a collaboration that I currently chair. But in a remarkable day for the field, the *European Pulsar Timing Array* (*EPTA*), the *Indian Pulsar Timing Array* (*InPTA*), the *Parkes Pulsar Timing Array* (*PPTA*), and the *Chinese Pulsar Timing Array* (*CPTA*), all announced their own evidence with varying levels of significance.

The radio telescopes used by these collaborations are really only the Earth-based portion of the detector, with the crucial other portion being the pulsars themselves. Discovered in 1967 by Dame Jocelyn Bell-Burnell while a graduate student at Cambridge, pulsars are rapidly spinning neutron stars that emit radiation along a magnetic-field axis that may be misaligned from its rotational axis. This creates a lighthouse effect, such that, if we are fortunate to be in its path, we measure a radio pulse from these objects every time they rotate. This allows us to time the arrival of these pulses, and to use their timing accuracy to construct predictive models. Differences between predicted and observed pulse-arrival times can be ascribed to a variety of processes, including some intrinsic and astrophysical sources of noise, and GWs.

When a GW transits between a pulsar and the Earth, it induces a change in the proper separation between those bodies, causing radio pulses to arrive earlier or later than expected. While one may be tempted to try GW detection using only the few best-timed pulsars, the presence of noise due to pulsar rotational instabilities and ionized-interstellar-medium effects makes the confident attribution of timing residuals to GWs impossible. Hence GW detection with pulsar timing is predicated upon the unique correlation signature of timing residuals induced between pairs of pulsars across angular scales by GWs. This correlation signature is called the Hellings & Downs curve, and is predicted under the assumption of an isotropic GW background signal described by GR.

The distinctiveness of this correlation signature, being predominantly quadrupolar in structure, is why it plays a central role in our GW detection statistics. It also underlies the NANOGrav observing strategy since the collaboration's founding in 2007, wherein more pulsars have been added to the array in addition to continued monitoring of the original pulsars. The array has steadily expanded since NANOGrav's earliest work consisting of five years of observations of 17 to the most recent 15-year dataset of 68 pulsars. The timing of many pulsars allows for many distinct cross-correlation values to be measured between pairs across a distribution of angular separations, ensuring that the Hellings & Downs correlation signature is well mapped.

With strong evidence established for a nanohertz-frequency background of gravitational waves, we are now interested in its properties, and ultimately its origins. It certainly appears to have a steep, red spectrum. When the power-spectral density of its induced timing residuals is fitted to a power-law model, the exponent appears to be approximately –3·5 or steeper. This characterization is broadly supported by the independent analyses of NANOGrav, the *EPTA*, *InPTA*, and *PPTA*. However, the posterior probability distribution of the recovered parameters does have some support for a power-law exponent of –13/3, a value that holds special significance. A model with this steepness is the average GW spectrum predicted to derive from a population of inspiralling binary compact objects. Thus our attention turns to a cosmic population of supermassive black-hole binary systems as the most plausible origin for the measured GW background signal. These are the naturally expected by-product

October Page 2024.indd 224 19/09/2024 14:33

of hierarchical galaxy growth, in tandem with most galaxies harbouring a central massive black hole. Yet we do not want simply to assume and fix the shape of the spectrum to analytical expectations; we want to measure it since, at lower frequencies that correspond to wider orbital separations, there are a variety of interactions that these binaries may have with their broader galaxy environments. Whether these be scattering interactions with stars, or coupling to discs of gas, such mechanisms can impart a low-frequency turnover in the shape of the spectrum.

Our analyses show that a population of supermassive black-hole binaries can plausibly produce a background of GWs consistent with what we've found. The constrained amplitude of the GW background is consistent with previous literature, although favouring the high end of the range of those predictions. What is obvious though is that we are sensitive to the very-high-mass tail of the distribution of black holes in the Universe, with typical masses for contributing systems being greater than a billion solar masses, and with redshifts nearer than one. As we look to the future, our next scientific milestone is to resolve individual binary systems out of the confusion of signals from the entire population. One way this may initially be achieved is through measuring anisotropy in the intensity of the GW background (similar to characterizing anisotropy in CMB temperature fluctuations), perhaps observing excess power in a certain direction that indicates the presence of binary signal. While we have no evidence of GW anisotropy yet, we could expect to find anisotropy within the next five years if the origin of the GW background signal is truly a population of binary supermassive black holes, and as further leverage we also expect the level of anisotropy to increase with GW frequency. Yet we do also currently conduct searches for individual binary systems based on modelled templates for the GW signal as it would appear in pulsar-timing residuals. Again, we have no evidence of a single binary system in our GW searches yet, but we have charted the distance out to which we can exclude the presence of a binary, which, for a billion-solar-mass system at a GW frequency of 27 nHz, varies from approximately 160 Mpc where we have the most pulsars on the sky to approximately 30 Mpc in the part of the sky with the sparsest pulsar coverage.

While a population of supermassive black-hole binaries may be the most prosaic origin of the GW background, they are by no means the only one. Processes in the early Universe such as inflation and phase transitions, or topological defects like cosmic-string networks and domain walls, could all produce GWs which may lie within the frequencies to which pulsar-timing arrays are sensitive. This is an area of rapid growth within our field, as new researchers join us in a bid to test their new early-universe models against our data. While there is as yet no evidence of such signals, constraints on some models (*e.g.*, of ultralight dark matter) are competitive with other experiments. This is really only the beginning of the tremendous science to come from this field. There are many questions remaining to answer, among which are the origin of the GW background signal, the time to detection of individual binary signals, and the nature of tests of fundamental physics and early-Universe cosmology that complement other observations. Within the next few years, the key regional pulsar-timing collaborations will be combining their datasets to form an international array with more than 100 pulsars, offering exciting prospects for stronger detection of the all-sky background and perhaps even individual sources. There are also mid-term prospects for new radio facilities in the US such as the proposed *DSA-2000*, an array of 2000 × 5-m dishes that would have a sizable portion of time dedicated to NANOGrav observations.

And of course, the *Square Kilometer Array* will be a huge leap forward in radio astronomy, providing the potential to carry the field of pulsar-timing-array GW searches further into the future.

For now, I would like to conclude by thanking you all for your attention and acknowledging the tremendous efforts of my collaborators in NANOGrav and the International Pulsar Timing Array community in this recent breakthrough.

The President. Thank you very much indeed. I'm sure that Mr. Eddington would have been fascinated by that lecture. Can I invite questions?

Professor Chris Lintott. I just wondered whether there were things that we could learn about pulsars that would improve your measurements.

Professor Taylor. Indeed yes. Something that would help us tremendously with measuring individual supermassive black-hole-binary signals is improving our knowledge of the distance to the pulsars and that is because we have to track back the phase of the gravitational-wave signal to the pulsar, and in order to do that well we would need to know the distance of the pulsar within a gravitational wavelength. That would be sub-parsec precision on the distance and we don't have that at the moment for more than just one or two pulsars. We know the pulsar distances to about 10% and they are at kiloparsec distances. I was talking to some folks yesterday at the IoA, Cambridge, about potential ways to do that, which would help tremendously.

Dr. Guy Morgan. Pulsars glitch. The ones you observe have presumably not glitched yet, but if you get a glitch does that destroy the data from that pulsar?

Professor Taylor. Yes. Milli-second pulsars that we use are less glitchy than the canonical pulsars and so for that reason and several others, we use millisecond pulsars. Some of them have glitched and that shows up in our timing behaviour and something distinctive in a way that could not be explained by GW signals. Obviously it is the sudden change in spin of the pulsars — timing offsets look like a ramp as it's an integrated step function, so that is a very clear signature. Interestingly, if you had some other GR effects, you could have ramp features as well correlated across different pulsars. That's called the GR memory effect — it is very rare and very difficult to find but it would be very clear and easy, we think, to separate from actual glitch behaviour.

Professor Charles. You talk about the individual sources and there are a few known binary-black-hole systems with known recurrence times. I am thinking here of OJ 287 which has something like a ten- or eleven-year outburst time-scale which I think is now fairly well established as its period. Is there any chance of something like that?

Professor Taylor. OJ 287 was one of the candidates on the map that I showed. Unfortunately in the fits to those flares, the theory being that the secondary black hole is plunging through the accretion disc of the primary creating flares, the implied dynamics of the system would give a mass ratio that disfavours GW detection; the secondary black hole is just very light in comparison to the primary which diminishes the chirp mass in the GW signal. We can still search for it but the prospects are slim for that particular candidate.

The President. Can I particularly thank the Eddington Lecturer, and also the other two speakers as well? Interesting that each of them mentioned the other which is indicative of just what these meetings are supposed to do. Thank you very much indeed. [Applause.]

Let me remind you that in the Council Room we will be celebrating the news about the new lease on the premises. I'd like to say that this development has been due to many people in the Society over many years — at least ten years — some might say 30 years. It has involved people such as Phil Diamond, members of his staff, past and present Treasurers of the Society, past Presidents, Council members, and so on. It has been a long haul so a good celebration is certainly called for. I give notice that the next A & G Highlights meeting will be on Friday, April 12th.

Editorial Note: The Editors wish to record their gratitude to Dr. Quentin Stanley for his invaluable help in compiling this report.

THE STRUCTURE OF THE GALAXY AS DESCRIBED IN BRITISH PROFESSIONAL JOURNALS 1820–1920
PART 1: 1820–1905

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When the Royal Astronomical Society was formed in 1820, the prevailing view of the structure of our Galaxy (also known as the Milky Way, the 'sidereal system', or even 'the universe') was that of William Herschel[1], derived from his 'star gauging', counting stars in different telescopic fields of view. As neatly summarized a little later by Alexander von Humboldt in his *Cosmos*, "The cluster of stars, to which our cosmical island [the Solar System] belongs, forms a lens-shaped, flattened stratum, detached on every side, whose major axis is estimated at seven or eight hundred, and its minor one at a hundred and fifty times the distance of Sirius." In addition there were the nebulae, which might be part of the galactic system, in which case it would encompass the entire Universe, or could be external 'island universes', the argument not being settled in favour of the latter until Hubble's work in the 1920s. A previous article[2] considered pre-Hubble papers in British professional journals (primarily *Monthly Notices of the Royal Astronomical Society* and *The Observatory*) which turned out to be about external galaxies (whether the original authors thought so or not). Here we similarly consider papers on the structure of our own Galaxy across approximately the same time period to explore what British readers could discover about the structure of the sidereal system (generally omitting papers merely describing, without interpreting, the appearance of the Milky Way on the sky). We take the end point as 1920 to cover papers up to the culmination of Harlow Shapley's series of contributions[3] from Mount Wilson which demonstrated essentially the modern view of the Galaxy. Given the rush of papers towards the end of the period, we split the time range into two very unequal parts; in this first part we cover the years up to 1905.

The Papers

1820–1877

The first reference to the Milky Way in *Monthly Notices of the* (then) *Astronomical Society of London* came in its first volume in 1829[4], in John Herschel's Presidential Address[5] on the awarding of the Society's Gold Medal to Professor Bessel of Königsberg "for his observations of stars in zones". Herschel noted that "continental astronomers" felt "the necessity of laying a foundation for future sidereal studies as deep and wide as the visible constituents of the universe itself [though to] say that every individual star in the milky way, to the amount of eight or ten millions, is to have its place determined and its motion watched, would be extravagant". Bessel won the Gold Medal again in 1841 for the parallax of 61 Cygni[6], the first step in the quantification of the size of the Galaxy.

In 1848, the Council's Report to the AGM[7] included reviews of two interesting contributions. Thomas Galloway FRS, a secretary of the RAS, had presented "an elaborate memoir" to the Royal Society[8] on 'The Proper Motion of the Solar System' which won him that society's Royal Medal. He correctly found the apex of the Sun's motion to be in the constellation Hercules, as determined using southern stars, in agreement with previous work based on northern stars. Assuming that the Sun's motion was in a circle around the centre of the system (in a plane defined by the Milky Way) he deduced a centre towards Norma, possibly by good fortune, not that far from the actual centre in Sagittarius. [We might note here that different authors used 'Milky Way' to denote either the star clouds as seen on the sky or the whole 3D stellar system.] The previous year, the Council had reported[9] on a related "curious calculation" by Johann Heinrich von Mädler, director of the observatory at Dorpat (now Tartu, in Estonia), which implied that the Sun was orbiting a centre near the Pleiades, 160 pc away, with a period of 18 200 000 years, his so-called 'central sun hypothesis'.

The second review was of the *Étude d'astronomie stellaire* by Wilhelm Struve, director of the Pulkowa (Pulkovo) Observatory, on the distribution of stars. This contained "an epitome of the whole of the author's views on the subject" and demonstrated that naked-eye stars were distributed on the sky in the same way as fainter ones and thus were part of the same Milky Way disc. The relative numbers of stars of different magnitudes were used to suggest that the faintest visible to William Herschel were 228 times further away than typical stars of the first magnitude (which from known parallaxes he took as 5 pc), while the inverse-square law suggested a factor of 664; "M. Struve considers that there is no other way [to account for this difference] than by supposing that light is extinguished in its passage".

In 1850[10], Astronomer Royal George Biddell Airy returned to the question of the Sun's proper motion, using a new method of his devising to obtain an apex position similar to previous estimates but a much larger implied velocity for the Sun.

In 1857, Prof. Secchi sent a letter to Mr. Carrington, the RAS secretary, which was published in *MN*[11]. Amongst other observations, he noted that he was "occupied in examining the brilliant places of the Via Lactea in Sagittarius, and especially in making figures and measures of clusters." He pointed out that "the greatest number of globular stellar clusters lies in this circle [the great circle delineating the maximum density of bright stars] also, or very near it … perhaps instead of a single star, a globular cluster has been formed under circumstances and laws which will remain most probably always a mystery to mankind."

Cleveland Abbe of the US Naval Laboratory presented a paper[12] at the 1867 May RAS meeting 'On the Distribution of the Nebulae in Space'. Given the known shortfall of nebulae in the region of the Milky Way, he had counted the objects from John Herschel's *General Catalogue of Nebulae and Star Clusters* in different areas of the sky and deduced that (*i*) the clusters (and planetary nebulae) were in the Milky Way system but closer than the average of the faint stars, (*ii*) the other nebulae were "in general without" the Milky Way, and (*iii*) "The visible universe is composed of systems, of which the *Via Lactea*, the two *Nubeculae* [Magellanic Clouds], and the *Nebulae*, are the individuals, and which are themselves composed of stars … and gaseous bodies". Suggesting that the low counts of nebulae in the Galactic Plane was because the "visible universe is less extended in that direction" he concluded that the nebulae (including the *Nubeculae*) were distributed throughout a prolate ellipsoid perpendicular to the plane.

In 1869 and 1870 we find four particularly relevant papers from the prolific Richard Proctor in *MN*[13] (he wrote 44 in total, on various topics, in these two years, mostly for the new journal *Nature*). He was a strong opponent of the island-universe theory of nebulae and also disagreed with the standard interpretation of the Milky Way as a more or less uniform disc of stars seen from the inside. The first paper considered the distribution of nebulae in a similar way to Abbe, but with an equal-area projection. He considered that nebulae avoiding the Milky Way was strong evidence for an "intimate association between the stellar and nebular systems", with the different types of nebulae "owing their present constitution to the fact that they are outside the region of most active stellar aggregation". The second concerned the relative distances of stars of different brightness, with Proctor arguing that the 'small' stars in the Milky Way were no further away, and in some cases nearer, than 'lucid' [*i.e.*, bright] stars. In a separate contribution to *Nature*[14] he noted several regions of the sky where stars of different brightness shared "a community of motion", or "star-drift", implying they were grouped together. He expanded on this in 'A New Theory of the Milky Way', where he proposed "that the Milky Way has not a great lateral extension (compared … with its thickness)", thus comprising a "stream of stars amidst the sidereal system", "the condensed part of a spiral of small stars, which has been swayed into its present figure by the influence of large stars". In the fourth he pointed out that it was unreasonable to suppose that the regions where faint stars were apparently more densely packed implied that the system extended further in these directions, as in Herschel's famous diagram, since this would imply spikes sticking out which all happened to point towards the Sun and which "could not result from any conceivable dynamical processes".

Proctor subsequently[15] created a chart on which he plotted 324000 star positions ("at the moderate rate of one minute for ten stars, 32,400 minutes, or 540 hours") as a detailed map of the sidereal system. He summarized his views in a further paper in 1873[16], asserting "without the slightest fear of contradiction … that the … chart of 324,000 stars disposes finally of all theories of the constitution of the sidereal universe which had previously been enunciated". (Note that Proctor used the term 'extra-galactic' for the 'irresolvable nebulae', but only in the sense that they were outside the main plane of the system.)

Also in 1873, Sydney Waters compiled a similar 'isographic' map of Herschel's nebulae and clusters ("both globular and irregular"), again concluding[17] that "the clusters are part of, if not immersed in, the Milky Way itself", that the nebulae (excluding the gaseous ones) "seem to form a distinct scheme", and that "the two schemes are probably subordinate parts of our sidereal system". A few years later[18], Waters produced a chart of the stars in similar fashion to Proctor's but for the southern hemisphere, and generally supported Proctor's views on fainter stars not being more distant.

In 1877, Maxwell Hall produced a lengthy *Memoir*[19] on 'The Sidereal System', looking at proper motions, parallaxes, and the new development of spectroscopic radial velocities. Though using a generally similar solar apex to other authors, he placed the centre of the rotation 150 pc away in the direction of Pisces (roughly similar to Proctor's earlier suggestion of a centre associated with the "great double cluster in Perseus"). He also determined a rotation period of 20 million years and thus a mass interior to the Sun's orbit of 78 million solar masses (consistent with solar-mass stars somewhat less than 1 pc apart on average). He spent many years attempting to refine his result, but without approaching the correct direction for the centre[20]. (A large number of other authors also investigated the solar apex over the next twenty years, but generally without any further implications for the structure of the system, so are not listed below unless of particular interest.)

Again in 1877[21], E. J. Stone presented his work 'On Apparent Brightness as an Indication of Distance in Stellar Masses'. He effectively demonstrated how to calculate the change in number counts with apparent-magnitude limit even if stars varied widely in intrinsic luminosity (and, though not explicitly showing it, if the density was not uniform), and noted that "the average distances of the fainter stars must be greater than those of the brighter stars". He later also reported[22] a group of four stars across a large area of sky with similar, but slightly diverging proper motions that might indicate that they were in a small group in the distant past.

1878–1890

The first volume of this *Magazine* in 1878 carried a review[23] — by the pre-Raphaelite painter and disputatious FRAS John Brett[24] — of a paper on the distribution of stars by Professor Geovanni Celoria of the Osservatorio Reale di Milano in Brera. From his star counts, Celoria is noted as interpreting the structure of the Milky Way as two intersecting rings. Brett himself concludes that "if a few of our hitherto idle astronomers … follow the lead of Prof. Celoria … we might, after a short interval of time, have laid before us a complete systematic survey of the heavens such as would almost inevitably produce a tenable thesis of the shape of the visible universe".

In 1879, *The Observatory* reviewed[25] a contribution 'Photometric Researches' from Harvard College Observatory by Charles S. Peirce, *via* a direct copy of a paper from the US journal *Popular Science Monthly* written by Henry Farquhar. This discussed the relative number of stars of different magnitudes and the implications for whether stars were uniformly distributed in space, suggesting a small peak of density near the Sun and a dense ring further out, rather like the Ring Nebula. Farquhar made a point of disagreeing with some of Proctor's inferences (above).

A further review followed[26], this time a summary of *Uranometria Argentina* by B. A. Gould (the director of the national observatory at Cordoba), which presented uniform measurements of all stars down to the seventh magnitude in the southern hemisphere. While agreeing that stars could have different intrinsic brightnesses, the anonymous reviewer noted that "it cannot be doubted that the average distance of all the 5^{th}-magnitude stars, for instance, is nearer to us than the average of all the 6^{th}-magnitudes". Gould explained the relative excess of

October Page 2024.indd 230 19/09/2024 14:33

bright stars as the effect of a flattened local cluster of stars containing the Sun (now known as Gould's belt). Gould was subsequently awarded the RAS Gold Medal for this work. In a later contribution of his own to *The Observatory*[27] he noted, in passing, plates taken of the "magnificent tract in Sagittarius which is too densely sown with stars to be considered merely a portion of the Milky Way, and yet too large and undefined to be regarded simply as a cluster".

In 1880, J. L. E. Dreyer reviewed[28] a contribution from M. Houzeau — more precisely Jean-Charles-Hippolyte-Joseph Houzeau de Lehaie — director of l'Observatoire de Bruxelles (whose rather fraught career included a hasty escape from Texas in the American Civil War, as he was an outspoken abolitionist). His *Uranométrie Générale* was another star-cataloguing and counting exercise, which agreed with earlier work by Wilhelm Struve "that the density of stellar layers parallel to the plane of the Milky Way decreases very regularly and gradually towards the poles of the latter". Gould's and Houzeau's papers were also summarized in *MN*[29].

Rev. T. H. E. C. Espin joined in with the equal-area projections in 1881, plotting the positions of known variable stars[30]. He found that they preferred a band at an angle to the plane and that the connection to the Galaxy appeared different in different areas of the sky. 'Temporary stars' (*i.e.*, novae) seemed to occur mostly around where this band crossed the Milky Way. (Following work elsewhere, noted in *The Observatory*[31], Espin[32] later found that very red stars congregated in a few regions in the Milky Way.)

E. C. Pickering contributed a lengthy and intriguing paper[33] on the same topic. Pickering proposed that if variability was due to star spots rotating around the star, then stars pole-on to the Earth would vary less (as the same hemisphere was always visible). "If we admit a common origin for the stars of the Milky Way, a general coincidence in their axes of rotation seems not improbable", *e.g.*, perpendicular to the Galactic Plane. In this case, as seen from Earth, the chances of variability would depend on position on the sky, with those in the plane most variable. Pickering found this effect in his data, the variables — the short period ones, especially — lying close to a great circle with its pole about 10° from the Galactic Pole, though he noted that this could just be due to their physical distribution, regardless of their rotation.

In 1885, *The Observatory*[34] reported work by Hugo von Seeliger, the director of the Gotha Observatory, on yet more star counts. From his observation that the counts increased faster towards the Galactic Plane for faint stars than bright ones, Seeliger surmised that the overall structure was spherical but with a higher density of stars close to the equatorial plane.

Another Note[35] the following year described the efforts of Hans Homann in Berlin to determine the velocity of the Sun through the stellar system by consideration of the spectroscopically measured velocities of other stars. (His paper in *Astronomische Nachrichten* appears to be his only contribution to astronomy.) Homann found a speed of around 30 km/sec, with an apex some distance from that found by earlier studies of proper motions, the reviewer (probably Walter Maunder, one of the Editors) being somewhat sceptical of the accuracy. Maunder had concluded[36] from his own compilation that these attempts were premature as there were too few velocities and insufficient coverage of the sky.

An interesting sidelight on many of these studies arose in the form of an International Congress in Paris in 1887 to consider proposals for a 'Photographic Chart of the Heavens' ('la Carte du Ciel'), which was first described in *The Observatory*[37] in a transcript of a Royal Institution lecture by David Gill. A keen

October Page 2024.indd 231 19/09/2024 14:33

proponent, Gill noted that at the agreed depth of magnitude 14 "as at present defined in France" (there was then no uniform scale at faint magnitudes) there would be around 20 million stars. Even he quailed at the thought of going to magnitude 16 as some had suggested, which would be much slower. ("Besides, what are you to do with pictures of 100 millions of stars when you have got them?") Gill suggested another objective was a catalogue of all stars down to 11th magnitude, around two million positions and magnitudes. This (and a technical note by Gill) prompted a response[38] from the Editors of *The Observatory* (A. A. Common and H. H. Turner) decrying Gill's "astounding proposition … to establish a Central Bureau … to take the photographs and *measure* them, and make a catalogue, the work to go on for twenty-five years at a cost of 250,000 franks, or £10,000, per annum" and stating that the Congress had not committed to such a scheme. However, Gill[39], supported[40] by the Congress president Admiral Mouchez and by RAS stalwart E. B. Knobel (even though he had voted against it), demonstrated that a catalogue had indeed been approved at the Congress, though Common and Turner remained unconvinced[41] and the discussion rambled on over future issues of this *Magazine*.

Leading astronomical author and commentator Agnes Mary Clerke wrote[42] a glowing (if in retrospect misguided) 1888 review of work recently reported to the Royal Society by Norman Lockyer. Lockyer's 'meteoric hypothesis' was based on his experiments on the spectra of meteoric samples heated to moderate temperatures, as compared to the spectra of comets and nebulae. The claimed similarities convinced Clerke that "the proof that nebulae … are closely allied to comets may be said to be complete. That comets are formed of meteoric materials is universally admitted". Summarizing, Miss Clerke states that Lockyer's finding is that "All self-luminous bodies in space are composed of meteorites variously aggregated and at various stages of temperature … the existing distinction between stars, comets and nebulae rests on no physical basis". She concluded that it "appears to follow that the Milky Way is a region of condensation for meteor-swarms as well as for stars".

Her review, in *Nature*[43], on 'Photographic Star-gauging' considered the form of star counts, which appeared to differ, at faint magnitudes, between the Milky Way and higher latitudes. She concluded that "the lower margin of the galactic aggregations lies at a distance from us corresponding roughly to the mean distance of a ninth magnitude star", which she set at 1400 light years, and that "the aggregated stars are … neither larger nor smaller than those in our nearer neighbourhood".

She also wrote a summary in *The Observatory*[44] of a paper on the Orion Nebula by William and Margaret Huggins, read at the Royal Society in 1889[45]. From the spectra of the stars and of the nebula, they concluded that "these stars of the trapezium are not merely optically connected with the nebula, but are physically bound up with it, and are very probably condensed out of the gaseous material of the nebula". The following year, roles were reversed, with Mrs. Huggins providing a book review in this *Magazine*[46] for Miss Clerke's *The System of the Stars*, which covered the types of stars (and nebulae, which she was convinced were local) and stellar distances and motions: "the translation of the heavens and their construction".

While the photography was getting under way, the (4th) Earl of Rosse's assistant at Birr Castle, Otto Boeddicker, produced probably the last great hand-drawn rendering of the Milky Way[47,48] the product of five years' continuous work. ("Can the pencil of the draughtsman be any longer profitably employed upon nebulae seen with the 6-foot when photography, to say the least, follows so closely on his heels?"[49])

Photographs did indeed follow, E. E. Barnard presenting to the RAS[50] his plates of Milky Way regions taken at Lick, noting particularly the presence of 'dark holes', the beginnings of his famous catalogue of dark nebulae (though in 1893[51], he still believed they were real gaps between star clouds, rather than due to obscuration). H. C. Russell similarly presented plates from Sydney[52] but noted that the appearance of the Milky Way on those plates differed from that on the Lick plates and from direct telescopic observation, leading to the question as to which to accept.

Isaac Roberts described, in 1890, his photographs of star clusters[53]. He suggested that purely stellar clusters like those in Perseus were the end point of a sequence, starting with largely nebulous objects like Orion or the Pleiades and moving (by way of spiral nebulae) through clusters such as M 5 and M 13 which he thought showed residual nebulosity as well as stars, thus providing "an intelligible classification of some of the stages in the evolution of the universe".

Dedicated amateur observer T. W. Backhouse sent an abstract of his work 'The Structure of the Sidereal Universe' to *MN*[54]. He had tabulated various specific features in an area of the Milky Way, *viz*. straight lines and parallel arrangements of stars and of 'nebulous wisps', which he found to be generally roughly parallel to the Galactic Plane. Backhouse was among those who considered that there was a real connection between bright stars and nebulosity, implying that the Milky Way was nearby and the faint stars were physically very small.

1891–1905

Moving on to 1891, the Council report in *MN*[55] included reference to work on the solar motion by Oscar Stumpe in *Astronomische Nachrichten* (taken from his doctoral thesis in Bonn), the "peculiar feature in the treatment (being) the addition of a term depending on a supposed orbital motion of the stars in the plane of the Milky Way".

Gill[56] presented a picture of 'An Astronomer's Work in a Modern Observatory'. In the concluding part he discussed Pickering's[57] prism survey of the sky which implied that "stars of the Sirius type" (*i.e.*, blue/white ones) "occur chiefly in the Milky Way". He interpreted this to mean "that the Milky Way is a thing apart, and that is has been developed perhaps in a different manner, or more probably at a different and probably later epoch from the rest of the sidereal universe". Gill also reckoned he saw in Isaac Roberts' photograph of Andromeda Laplace's nebular theory of solar-system formation playing out, "a very early stage in the evolution of a star-cluster or sun-system".

Agnes Clerke[58] reviewed photographic work by Max Wolf at Heidelberg, on the Cygnus region, which showed nebulosity around bright stars and apparently connected to the Milky Way. In Clerke's more poetic language "The brilliant orbs shown … to be intertwined by means of sinuous wreaths of nebula with minute clustering objects, must plainly belong to the same scheme of generative activity."

It is worth digressing at this point to note that 1890–1891 saw the formation of the British Astronomical Association (BAA), with its own journal for those seeking something less academic than *Monthly Notices*. Papers and reviews of papers concerned with the structure of the Galaxy were actually quite prevalent during the 1890s, with several members (who were also Fellows of the RAS) making regular appearances. These included W. H. S. Monck, J. Ellard Gore

October Page 2024.indd 233 19/09/2024 14:33

(who suffered an untimely end when run over by a horse-drawn hackney carriage), and A. C. Ranyard, the editor of *Knowledge* (in succession to Richard Proctor).

Returning to *The Observatory*, in 1893[59] there was a review of a translation (which had appeared in *Knowledge*) of a paper by J. C. Kapteyn, originally read at the Amsterdam Academy of Science. Kapteyn assumed that for a group of stars, the mean proper motion was entirely due to solar motion, thus comparing these mean proper motions gave relative distances to the groups. According to the reviewer, the "principal results found seem to be" that distant stars, both bright and faint, grouped themselves in the Milky Way plane, but nearby stars did not, and that the mean distance of stars of a given magnitude range is greater towards the Milky Way than in other directions.

The Observatory next carried a review[60] of J. Ellard Gore's 1893 book *The Invisible Universe: Chapters on the Origin and Construction of the Heavens*, which in turn reviewed theories of the sidereal universe from Kant to Lockyer's meteoric hypothesis. "In the second half of the book Mr Gore deals with [the] stellar distribution in space, and especially with the form of the Milky Way". The reviewer was Annie Scott Dill Russell, the future Mrs. Maunder.

Also noted in *The Observatory*[61] was a meeting of the BAA at which A. C. D. Crommelin reported on a physical model which he and his sister, Miss C. D. Crommelin, had constructed, using beads on strings, to show the 3D distribution of nearby stars.

Sidney Waters[62] mapped the distribution of star clusters, resolvable nebulae, and irresolvable nebulae, again demonstrating that the clusters were closely associated with the Milky Way but the nebulae (planetaries excepted) were distributed centred on the Galactic Poles. He proposed that both clusters and nebulae were part of the 'sidereal universe', but where "the clusters cease the nebulae begin, as though the conditions of the distribution of matter have been favourable to the production of clusters in the Milky Way, and of nebulae elsewhere". In response to Waters exhibiting his charts at the BAA, as reported in *The Observatory*, Dreyer[63] agreed with Pickering, that "the Milky Way was likely to be in an earlier stage of evolution as compared with other regions of the universe". Maunder added that the "various facts all pointed to the conclusion that the visible sidereal universe was … but one single organism".

In 1895 *The Observatory* reviewed[64] a paper 'On the Distribution of Stars in the Milky Way' by Cornelis Easton of Dordrecht which had been in *AN* (and originally published as *La Voie Lactée dans l'hemisphère boréal*). Easton found that the density of visible stars down to 11th magnitude was correlated to the brightness of surrounding diffuse Milky Way light. The previous year, there had been a review[65] by RAS stalwart W. H. Wesley of Easton's hand-drawn maps, which were noted as differing significantly from Boeddicker's (above). Surprisingly, it appears that the only UK mention of Easton's notable paper 'A New Theory of the Milky Way', in which he posited that the Milky Way disc contained a spiral, centred in the direction of the bright region in Cygnus, and with the Sun on the edge of it (but still at the centre of the whole system), came in the *JBAA* in 1898.

Yet another review of the solar-apex question, this time by G. C. Bompas, appeared in 1896[66], where it was noted that the apex appeared to vary with the distance of the comparison stars; the positions moving roughly along the Milky Way suggested to him that the Sun and stars were orbiting in a plane near to that of the Galaxy

An original contribution, by Alice Everett in *MN*[67], explored the orientation of the orbits of binary stars, but found that the poles of the orbits appeared to be randomly distributed on the sky.

At a special meeting of the RAS in 1897[68], Prof. Barnard (that year's Gold Medallist) presented slides of his latest photographs of nebulous regions. Similarly to Wolf (above), he pointed out that the 'great Nebula of Antares', which he had described in a paper in *MN* in 1895[69], and its associated bright stars were seen to be "connected with the vacant lanes and the small stars forming the ground-work of the Milky Way", concluding that "these stars are really small compared to our Sun and not simply more distant than others". H. H. Turner in response, though, "could not help feeling sceptical" about the latter conclusion. (Barnard was also involved in a long-running and fractious argument with Isaac Roberts[70] over whether nebulous regions were best studied with a small refractor — his 'portrait lens' — or Roberts' larger reflector.)

In 1899 *Nature* featured[71] a lengthy transcript of Lockyer's 'Lecture to Working Men' at the Museum of Practical Geology titled 'On the distribution of the various chemical groups of stars'. He added to the earlier result that bright-line stars were associated with the Milky Way, the observation that they nearly all occurred where the Milky Way looks double (around the 'Aquila rift'), noting that "it looks … as if there is something connected with this doubling of the Milky Way which produces the conditions which generate these bright-line stars". He found this was also true of novae, which he believed were due to collisions between his meteoric streams and unseen nebulae, and reiterated the view that nebulae with bright lines (*i.e.*, gaseous) were in the Milky Way but nebulae with continuous spectra were not. He also reviewed, and agreed with, Monck's work (published in the US journal *Astronomy and Astro-Physics*) which found that 'metallic' stars (later spectral types) were typically nearby while 'gaseous' (hotter) stars were further away. Lockyer had illustrated his talk with a clear globe with bands for the Milky Way and circles for the relevant stars stuck on. Lockyer subsequently[72] gave a précis of the part of his own book, *Inorganic Evolution*, which dealt with 'Our Stellar System', covering similar topics to the earlier lecture. He considered that his results disproved the notion that the stellar system was constructed in the same way as spiral nebulae, as these were densest at the centre. As an aside, he noted that the Milky Way was also likely densely populated with 'dark bodies', so that light from beyond was blocked, explaining the preponderance of nebulae towards the pole if they were "other universes", that is, "clusters of stars with which our own system has absolutely no concern or connection".

In passing, we can note that the 1899 RAS Gold Medal[73] went to Frank McClean for what can be regarded as the ancestor of all spectroscopic surveys of the Galaxy. Using instruments at his own observatory in Tunbridge Wells and at the Cape Observatory, he obtained photographic (objective prism) spectra of every star down to magnitude 3·5.

The Observatory of 1900[74] included a note on 'Spiral Nebulae', drawing on Keeler's discussion of the photographs taken at Lick with the *Crossley* reflector. Keeler estimated that 120 000 previously unrecorded nebulae (which he considered were part of the sidereal system) were accessible to the telescope. Most of those he had observed had spiral structure, so if "the spiral is the form normally assumed by a contracting nebulous mass, the idea at once suggests itself that the solar system has been evolved from a spiral nebula".

In 1901, Lord Kelvin, in amongst a discourse to the British Association on the effect of gravity on the ether, as transcribed in *The Observatory*[75], made a calculation of the density of the Galaxy. If a thousand million suns were "at rest thousands of million years ago so distributed that now they were equally spaced throughout the supposed [1 kpc radius] sphere, their mean velocity would now be about 50 kilometres per second … not unlike the measured velocities of stars". This consistency (assuming stars of the same mass as the Sun) implied an average density of $1{\cdot}6 \times 10^{-20}$ kg m^{-3}, not that far from modern estimates for the solar neighbourhood. He also considered that stars would form from atoms spread throughout the Galaxy by gravitational contraction of over dense regions and eventually through particle collisions causing energy to be carried away. Kelvin also commented positively on the suggestion that the rapidly moving nearby star Groombridge 1830 (now identified as a halo star) was from outside the Galaxy and just passing through.

The Observatory[76] twice reviewed M. Stratonoff's *Études sur la Structure de l'Universe*, from the publications of l'Observatoire de Tachkent (Tashkent in Uzbekistan). This was another star-counts paper using the *Bonner Durchmusterung*, Stratonoff concluding that the distribution of stars down to magnitude 9·5 did not follow the details of the Milky Way and that the latter was best described as "an agglomeration of condensations or stellar clouds touching one another all along the galaxy". The first reviewer was Frank Dyson, the second Walter Maunder. In *MN* in 1902, A. M. W. Downing[77] essentially repeated Stratonoff's analysis, but using the *Cape Photographic Durchmusterung*, again finding a flattened stellar system for the fainter stars, but with no further interpretation.

Also in 1902, *The Observatory* carried a review[78] by Henry Hollis of Simon Newcomb's *The Stars: A Study of the Universe*. One point picked out was a calculation of the size of the universe (*i.e.*, Galaxy). Newcomb imagined dividing the universe into concentric spheres of increasing radius and counting the number of stars with corresponding parallaxes. He deduced that there was one star for every eight 'units', where one unit was a sphere of radius 1 pc, so to fit in his estimate of 125 million stars required a radius of 1 kpc (though he actually accepted Herschel's disc-shaped galaxy as a convenient working hypothesis).

This was followed by a Note[79] with a somewhat startling title (given today's usage) 'An Apparent Motion of the Universe', which concerned conclusions published by David Gill in *AN*. Based on the comparison of star positions in different catalogues he had found that "the brighter stars rotate with respect to the fainter stars as a whole about some centre". This was received doubtfully by H. H. Turner[80], in *The Observatory* and *MN*, and by the Greenwich observers in a Note[81] "communicated by the Astronomer Royal" (Sir William Christie) and presented by Dyson at the RAS. Dyson also reviewed[82] 'Prof. Kapteyn's researches on the distances, movements and luminosities of the fixed stars', but with no inferences concerning the overall stellar system. (A further review of Kapteyn's work was presented by Sir David Gill during his presidential address to the British Association, recorded in *The Observatory*[83], a few years later.)

Returning to star distributions, at another RAS meeting, Turner presented[84] a 'Preliminary Note on the possible existence of two Independent Stellar Systems', the Milky Way plus a proposed belt of stars which led to two separate minima in the star density near the North Galactic Pole, but subsequently withdrew the paper before it appeared in *MN*.

In 1904 in *The Observatory*[85], 'Ancient and modern Ideas about the Milky Way' were discussed in a multi-part paper by Puiseux (of Paris Observatory), which essentially summarized all the work noted above but viewed spiral nebulae as external and an indication of what the Milky Way would look like from the outside.

Finally, for this part, the only significant paper in 1905 was Dyson and Thackeray's on the Sun's motion[86], which agreed with earlier work showing that bright and Type II (solar-like) stars generally had larger proper motions than fainter and Type I (bluer) stars, the latter also tending to be in the Milky Way.

The Authors and Reviewers

N.B. The brief biographical notes on those involved are not repeated if they already appeared in recent contributions to this magazine[2,4,87,88].

Thomas Galloway was born in Lanarkshire in 1796 and educated at Edinburgh University, subsequently teaching at the Royal Military College at Sandhurst before becoming an actuary. He wrote astronomical articles for the *Encyclopaedia Britannica* and various magazines.

Father (Pietro) Angelo Secchi S.J. was born in 1818 and ordained in 1847. Already lecturing at Collegio Romano, he was forced into exile with the other Jesuits in the revolution of 1848 and spent some time at Stonyhurst College in Lancashire, which had a major observatory, before emigrating to the USA. He returned to Rome as professor of astronomy in 1850 and shortly afterwards founded an observatory at the Collegio. Said to have contributed 730 papers in all areas of science, his chief astronomical work was to provide the first steps in the classification of stellar spectra.

Maxwell Hall graduated from Cambridge in 1871 and moved to Jamaica the following year, building a notable observatory in Montego Bay, from where he made precise observations of Mars at its favourable opposition in 1877. By profession he was a barrister, but he also served as the Government Meteorologist and found time to publish around 60 papers, 25 in the British astronomy journals.

Edward James Stone FRS was Her Majesty's Astronomer at the Cape Observatory from 1870 until his appointment as Radcliffe Observer in Oxford in 1879. He had been 5th Wrangler in 1859 and shortly afterwards became Chief Assistant at Greenwich, winning the RAS Gold Medal in 1869 for his 'Rediscussion of the Observations of the Transit of Venus, 1769'. In all, he supplied around 150 contributions to the RAS, of which he was president 1881–82, and to the Royal Society.

Henry Hill Farquhar was a member of the US Coast Survey and acted as Charles Sanders Peirce's assistant in the photometric work at Harvard. He published a paper on 'Fundamental Right-Ascensions' in *AJ* in 1890 and later worked for the Census Bureau and other government departments. He was a delegate to the world peace conference at The Hague in 1907.

Though born in the USA, Benjamin Apthorp Gould spent three years gaining experience at European observatories (becoming friends with von Humboldt and Gauss) before working for the US Coast Survey and directing Dudley Observatory. He founded the *Astronomical Journal* in 1849 and edited it until 1861 (as well as when it was restarted in 1885). He moved to Cordoba as observatory director in 1865 and was an early advocate of large-scale stellar photography.

Edward Charles Pickering obtained the post of professor of physics at MIT when only 21 years old and shortly afterwards was responsible for the founding of the first 'physical laboratory' in the USA. He became director of Harvard College Observatory in 1876, remaining in post for over 40 years, and was responsible for instigating multi-epoch photographic surveys of the sky, as well as large-scale prism spectroscopic surveys, twice winning the RAS Gold Medal. He was also prominent in promoting women astronomers to senior positions.

Ernest Amédée Barthélémy Mouchez had entered the French navy at the age of 16, gaining promotion to captain by the time of the Franco–Prussian War in 1870. He spent many years in surveying and was appointed to the Board of Longitude before taking over the Paris Observatory in 1878, subsequently establishing a 'summer observatory' on Pic du Midi.

Edward Ball Knobel worked in several other trades before becoming managing director of the Ilford Photographic Company (who, *inter alia*, produced astronomical plates). A keen planetary and stellar observer, he also had a great interest in historical astronomy and compiled a 'Chronology of Star Catalogues'. He had joined the RAS in 1873 and was on its council continuously from 1876 to 1922 (when he was 80), twice serving as president.

The most famous of Agnes Clerke's many contributions was her *History of Astronomy in the Nineteenth Century*, first published in 1885. She supplied numerous astronomical entries in the *Dictionary of National Biography* and *Encyclopaedia Britannica* and became an Honorary Fellow of the RAS in 1903, well before women were allowed to be elected as Fellows.

The founding editor of *Nature* in 1869, Sir Joseph Norman Lockyer FRS was a civil servant until becoming a professor in the Royal College of Science in 1881. He was director of the Solar Physics Observatory in South Kensington from 1885. His main work was in the field of solar spectroscopy (identifying the new element helium while still an amateur observer) and what would now be termed laboratory astrophysics. His son W. J. S. 'Jim' Lockyer, a wartime major in the RAF, was also an FRAS and took over the running of his father's private observatory in Sidmouth.

Previously a mathematician — he published an application of Gauss' theory of knots to electrodynamics — Otto Boeddicker had been Astronomer at Parsonstown since arriving from Germany in 1880 and initially worked on observing Jupiter with the 36-inch telescope. He worked for the 4th Earl until the latter's death in 1908. He then assisted the 5th Earl on the estate and with opening Birr Castle Dairies and a technical school. He left Britain when classified as an enemy alien during the Great War. Then living in Freiburg, in 1936 he placed the somewhat battered original of his Milky Way drawing in the care of the RAS.

Jacobus Cornelius Kapteyn had started out at Leiden but from 1878 was professor of astronomy and mechanics at Groningen. As Groningen did not have an observatory, from 1896 he worked on the plates taken by Gill at the Cape Observatory to produce the *Cape Photographic Durchmusterung* of over 450 000 stars, winning the RAS Gold Medal in 1902. From 1906, he organized work at around 40 observatories to update William Herschel's old method of counting stars in different directions, and this led to his development of what became known as the Kapteyn Universe. This was essentially an oblate distribution of stars about 10 kpc across and 2 kpc thick, with the Sun about 600 pc from the centre. He published the definitive version of his work as 'First Attempt at the Theory of the Arrangement and Motion of the Sidereal System' in *ApJ* just before his death in 1922.

Annie Scott Dill Maunder (née Russell) had graduated from Girton in 1889 as a Senior Optime in the maths tripos, then became a 'lady computer' at Greenwich, working on Walter Maunder's sunspot programme. Obliged to give up her professional post on marriage, she nevertheless continued to work at the Observatory and went on numerous eclipse expeditions. She was an early member of the BAA, editing its journal for many years, and became one of the first female fellows of the RAS in 1916.

Andrew Claude de la Cherois Crommelin taught at Lancing College before being appointed to a post at the Royal Observatory in 1891. His main areas of expertise were asteroids and comets, making the most precise prediction of the 1910 return of Comet Halley. He was later involved in the eclipse observations from Sobral in Brazil in 1919 which Eddington used to verify Einstein's prediction of light bending. He was RAS president 1929–1930. His sister Constance de la Cherois Crommelin was a graduate of Newnham College, Cambridge, and became a teacher of mathematics and English at boarding schools, first in Brighton and then London. She married the poet John Masefield.

William Henry Wesley was a trained engraver, noted for his drawings of the solar corona and lunar maps. In a paper for *Knowledge*, Wesley carried out an inventive analogue version of a numerical simulation by sprinkling ink dots onto a piece of paper to see if strings and lines of dots appeared in the same way as lines of stars in the Milky Way. He was RAS assistant secretary, the main administrator of the Society, for 47 years.

In 1896 George Cox Bompas was a recently elected FRAS, though in his late sixties. He had been a solicitor in London for many years. He was also a fellow of the Royal Geographical Society, the Geological Society, and the Palaeontological Society.

Like many early female astronomers (Annie Russell was a direct contemporary), Alice Everett took the mathematical tripos at Girton College (her father was a professor of mathematics). Invited to take up a post at Greenwich in 1890, she next moved to Potsdam Observatory (1895) to work on the Carte du Ciel. She was a founder member of the BAA and an early council member. She later worked on optics at the National Physics Laboratory and (after technically retiring) made significant contributions to television broadcasting, still giving her occupation as radio and optical engineering in 1939, when she was 74.

William Henry Stanley Monck trained in theology at Trinity College, Dublin, and was subsequently professor of Moral Philosophy there, writing on logic and metaphysics. He was later a Chief Registrar of the High Court of Ireland. He published widely (over 180 papers) in *The Observatory*, the *JBAA*, *Nature*, *Popular Astronomy*, and the *Publications of the Astronomical Society of the Pacific* among others (but only once in *MN*), on topics ranging from ancient chronology to non-Euclidian geometry.

Frank McClean was a graduate of Trinity College, Cambridge, and followed his father (also an FRAS) in becoming an engineer. However, he was well off enough to retire at the age of 33 to concentrate on his scientific interests, particularly astronomy. Aside from his spectroscopic survey he was most noted for the discovery of oxygen in stellar spectra. He was elected an FRS (again like his father) in 1895 and endowed the Isaac Newton studentships in Cambridge. His father-in-law was John Greg, a Lancashire mill owner who also had his own observatory, while his son (eventually Lt-Col. Sir) Francis Kennedy McClean AFC was a pioneer aviator and also an FRAS, travelling to several solar eclipses.

William Thomson, Lord Kelvin, one of the leading mathematical physicists of his day, was professor of Natural Philosophy in Glasgow for 53 years from 1846, working most famously on thermodynamics. In astronomy, he is most remembered for his time-scale for the Sun to radiate at its present rate purely through gravitational contraction. He was president of the Royal Society 1890–95 and the first scientist awarded a peerage.

Placed second in the tripos at Trinity, Frank Watson Dyson was elected a

October Page 2024.indd 239 19/09/2024 14:33

fellow there and researched in gravitation before becoming Chief Assistant at Greenwich in 1894, leading the work on proper motions. Astronomer Royal for Scotland from 1906, he returned to Greenwich as Astronomer Royal in 1910. He is now best remembered for organizing the 1919 eclipse expeditions which led to the confirmation of the predictions of General Relativity. He was knighted in 1915.

A maths graduate from Trinity College Dublin, Arthur Matthew Weld Downing FRS was an Assistant at the Royal Observatory from 1873, working on star positions, and, from 1892 Superintendent of the Nautical Almanac Office. He communicated 75 papers and notes to *MN* and was a vice-president of the RAS.

Henry Park Hollis was an Assistant at Greenwich from 1881 for nearly 40 years and mainly involved with stellar-position-measurement programmes. He was also astronomical correspondent for *The Times* and an Editor of *The Observatory*.

Pierre Henri Puiseux, the son of a professor of celestial mechanics at the Sorbonne, worked at the Paris Observatory from 1885, primarily on photographic studies of the Moon and on the Carte du Ciel. He won the prestigious Prix Jules Janssen in 1900.

William Grasett Thackeray, a relative of the novelist William Makepeace Thackeray, was appointed to the staff of the Royal Observatory in 1875, spending many years on transit work and later superintending the computational work in Greenwich.

In summary, it is notable that despite the obvious interest in this area (as reflected in the number of review articles), there are only 19 British, or British-based, scientists who made original contributions to the debate on the structure of the Galaxy, across the 85 years covered, and only nine of those could be considered professional astronomers.

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 20: HO TEL CHECKOUT

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We present a detailed analysis of the detached eclipsing binary system HO Telescopii, which contains two A-type stars in a circular orbit of period 1·613 d. We use light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*), which observed HO Tel in three sectors, to determine its photometric properties and a precise orbital ephemeris. We augment these results with radial-velocity measurements from Sürgit *et al.*[1] to determine the masses and radii of the component stars:

$M_{\rm A} = 1{\cdot}906 \pm 0{\cdot}031\ M_{\odot}$, $M_{\rm B} = 1{\cdot}751 \pm 0{\cdot}034\ M_{\odot}$,
$R_{\rm A} = 2{\cdot}296 \pm 0{\cdot}027\ R_{\odot}$ and $R_{\rm B} = 2{\cdot}074 \pm 0{\cdot}028\ R_{\odot}$.

Combined with temperature measurements from Sürgit *et al.*[1] and optical-infrared apparent magnitudes from the literature, we find a distance to the system of $280{\cdot}8 \pm 4{\cdot}6$ pc which agrees well with the distance from the *Gaia* DR3 parallax measurement. Theoretical predictions do not quite match the properties of the system, and there are small discrepancies in measurements of the spectroscopic orbits of the stars. Future observations from *Gaia* will allow further investigation of these issues.

Introduction

In the current series of papers we are performing detailed photometric analyses of a set of known detached eclipsing binaries (dEBs) for which space-based light-curves are available but have not been studied previously, and which have published spectroscopic mass measurements. The aim is to increase the number of stars with precisely-measured masses and radii against which theoretical stellar models can be compared[2–5]. A detailed exposition of these goals can be found in the first paper of the series (ref. 6) and a review of the impact of space telescopes in this scientific area can be found in ref. 7.

In this work we investigate the dEB HO Telescopii (Table I), which contains two late-A type stars in a circular orbit of period 1·613 d. Its variability was discovered by Strohmeier *et al.*[8] under the designation BV 590, and its correct orbital period was determined by Spoelstra & van Houten[9]. Subsequent work on this object has been nicely summarized by Sürgit *et al.*[1] (hereafter S17). These authors presented radial-velocity (RV) measurements from medium-resolution spectra obtained with the *SpUpNIC* spectrograph[10] on the 74-inch *Radcliffe* telescope at the South African Astronomical Observatory. S17 combined these RVs with five-colour (Walraven[11] *VBLUW*) light-curves from Spoelstra & van Houten[9] and the light-curve from the All-Sky Automated Survey (ASAS[12]) to measure the properties of the system. Below we use the same RVs and new space-based data to refine the measurements of the system properties.

October Page 2024.indd 242 19/09/2024 14:33

TABLE I

Basic information on HO Telescopii. The BV magnitudes are each the mean of 110 individual measurements[13].

Property	*Value*	*Reference*
Right ascension (J2000)	$19^{h}51^{m}58^{s}\cdot93$	14
Declination (J2000)	$-46°51'42''\cdot4$	14
Henry Draper designation	HD 187418	15
Gaia DR3 designation	6671501451113955072	14
Gaia DR3 parallax	3·5186 ± 0·0314 mas	14
TESS Input Catalog designation	TIC 80064289	16
B magnitude	8·59 ± 0·03	13
V magnitude	8·31 ± 0·01	13
J magnitude	7·814 ± 0·027	17
H magnitude	7·776 ± 0·029	17
K_s magnitude	7·730 ± 0·018	17
Spectral type	A7V + A8V	1

Photometric observations

HO Tel has been observed in three sectors by the *Transiting Exoplanet Survey Satellite* (*TESS*[18]): sector 13 (2019 July) where the observations were summed into cadences of 1800-s duration; sector 27 with a cadence of 600 s; and sector-67 with a cadence of 200 s. We downloaded the data for all sectors from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[19]. However, we restricted our analysis below to the data from sector 67 due to its better sampling rate. We adopted the simple aperture photometry (SAP) data from the *TESS*-SPOC data reduction[20] with a quality flag of "hard". These were normalized using LIGHTKURVE and converted to differential magnitudes.

The light-curve from sector 67 is shown in Fig. 1. Four regions of data (one of which is outside the figure) were removed from our analysis due to incomplete coverage of eclipses or decreased photometric precision due to scattered light from Earth: we kept 8006 of the original 9332 data points. The primary eclipse is clearly deeper than the secondary. We label the star eclipsed during primary minimum star A and its companion star B.

We queried the *Gaia* DR3 database† and found a total of 75 objects within 2 arcmin of the sky position of HO Tel. Of these, the brightest is fainter than our target by 4·5 mag in the G_{RP} band, and the remainder are fainter by at least 5·7 mag in that band. This suggests that the *TESS* light-curve of HO Tel will be contaminated by light from nearby stars at the level of only a few percent.

Preliminary light-curve analysis

The components of HO Tel are close and significantly distorted from sphericity. However, the number of data points is large enough to make an analysis with a code implementing Roche geometry slow. We have therefore undertaken a preliminary analysis with a simpler code to determine the orbital

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

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

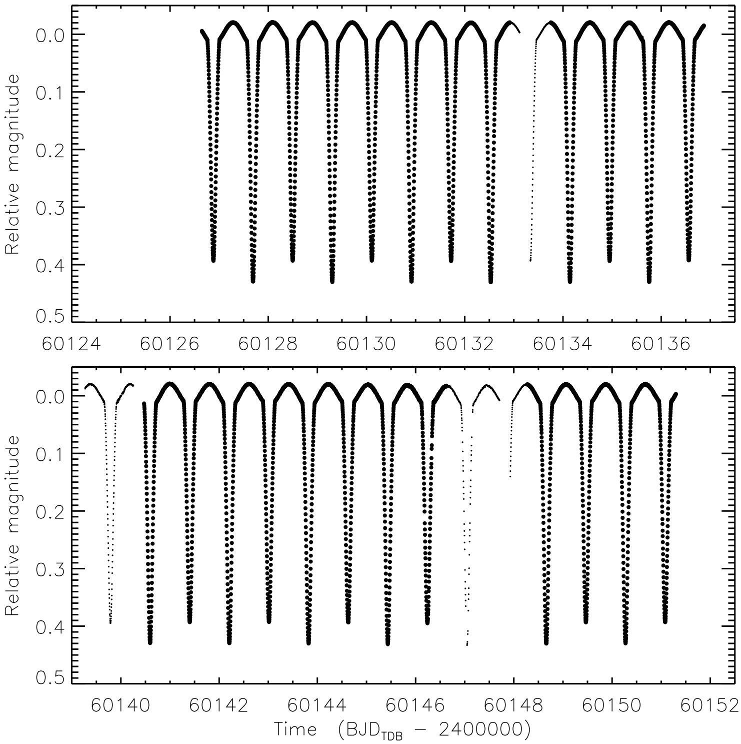

FIG. 1

TESS short-cadence SAP photometry of HO Tel from sector 67. The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median. The two panels show half the sector each. Larger points show the data retained for analysis and smaller points the data rejected due to offsets or increased scatter.

ephemeris and enable the construction of a phase-binned light-curve.

We modelled the *TESS* sector-67 light-curve using version 43 of the JKTEBOP⋆ code[21,22] using a suitable set of adjustable parameters (see previous papers in this series). Once a good fit was achieved, the *TESS* observations were converted to orbital phase and binned into 1000 points equally-spaced in phase. This phase-binned light-curve retains practically all the information of the original data whilst containing a factor of eight fewer data points.

We refined the orbital ephemeris of HO Tel by adding new and published times of mid-eclipse to our JKTEBOP fit. We included the four times from Sistero & Candellero[23], and the four times from Spoelstra & Van Houten[9]. Uncertainties were not quoted for those measurements so we adopted an error bar of ±0·003 d for each. We also measured three additional times of primary eclipse by fitting the *TESS* sectors individually. The precision of these eclipse times is extraordinary (0·3 to 0·9 s) but appears to be justified. The early times were converted to the BJD_{TDB} time-scale[24] to match the *TESS* data.

We also tried to include the timing from table 2 of S17 but found it to deviate from a linear ephemeris by +30·8 min; conversion from the original HJD

⋆http://www.astro.keele.ac.uk/jkt/codes/jktebop.html (presumed UTC) to the BJD_{TDB} time-scale used in the current paper would add a further 65 s to this discrepancy. The issue probably arises from the use of an old time of conjunction combined with a fixed period, which is not a problem for fitting the RV curve but does make the timing unsuitable for determining the orbital period. We therefore excluded it from our analysis.

The ephemeris was obtained as part of our JKTEBOP solution in the preceding section and is

$$\text{Min I} = \text{BJD}_{\text{TDB}}\ 2460135{\cdot}755972(3) + E \times 1{\cdot}613103937(8), \qquad (1)$$

where E is the cycle number and the bracketed quantities represent the uncertainty in the final digit of the preceding number. The individual eclipse times and their residuals *versus* this linear ephemeris are given in Table II. We see no evidence in these data for a deviation from a constant orbital period.

TABLE II

Times of published mid-eclipse for HO Tel and their residuals versus the best fit reported in the current work. Each residual is given as a fraction of the uncertainty. The asterisk indicates the time not included in the final best fit, to avoid double-use of data. The orbital cycle is an integer for primary eclipses and a half-integer for secondary eclipses.

Orbital cycle	*Eclipse time* (BJD_{TDB})	*Uncertainty* (d)	*Best fit* (BJD_{TDB})	*Residual* (σ)	*Source*
−13113·5	2438982·31756	0·003	2438982·31750	1·12	23
−13113	2438986·34984	0·003	2438986·35026	0·28	23
−13108·5	2438990·38244	0·003	2438990·38302	0·34	23
−13087·5	2439024·25888	0·003	2439024·25821	−0·08	23
−11072·5	2442274·65961	0·003	2442274·66264	1·18	9
−11072	2442275·47641	0·003	2442275·46919	−2·24	9
−10886·5	2442574·70254	0·003	2442574·69997	−0·68	9
−10649	2442957·81126	0·003	2442957·81216	0·48	9
−909	2458669·444500	0·000010	2458669·444494	−0·61	This work
−673	2459050·137019	0·000007	2459050·137023	0·57	This work
0*	2460135·755971	0·000003			This work

Analysis with the Wilson-Devinney code

The main analysis of the light-curve was performed using the Wilson-Devinney (WD) code[25,26], which implements Roche geometry to represent accurately the shapes of distorted stars. We used the 2004 version of the code (WD2004), driven by the JKTWD wrapper[27], to fit the phase-binned light-curve from the previous section. Below we describe the adopted solution of the light-curve, followed by the error analysis. The parameters in the WD2004 code are described in its accompanying user manual (ref. 28).

For our adopted solution we fitted for the potentials and light contributions of the two stars, the orbital inclination, and one limb-darkening coefficient per star. Limb darkening was implemented using the logarithmic law with the linear coefficients fitted and the nonlinear coefficients fixed at theoretical values from Van Hamme[29]. We also had to fit for the albedo of both stars and for third light to obtain a good fit to the data. We used mode 0, where the effective temperatures ($T_{\rm eff}$s) and light contributions are decoupled, and fixed the $T_{\rm eff}$s to values from S17. We adopted a circular orbit, the mass ratio from S17, the simple model of reflection, synchronous rotation, gravity-darkening exponents of 1·0 (suitable for radiative atmospheres), the maximum possible numerical precision of N1 = N2 = 60, and the Johnson R passband as representative of the *TESS* passband for stars like those in HO Tel. With this approach we obtained a good fit to the data (Fig. 2) which has residuals that are small but do show a trend with orbital

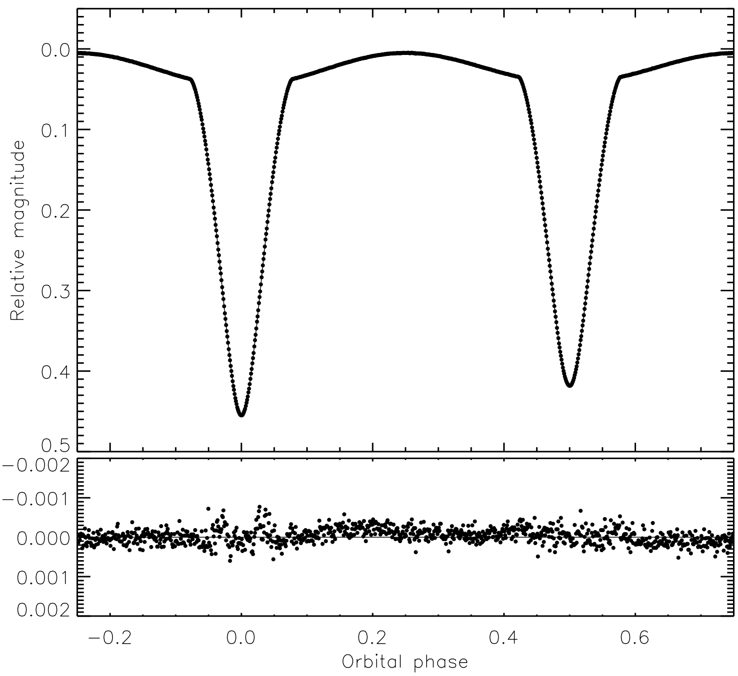

FIG. 2

Best fit to the binned light-curve of HO Tel using WD2004. The phase-binned data are shown using open circles and the best fit with a continuous line. The residuals are shown on an enlarged scale in the lower panel.

phase. The parameters of this fit are given in Table III.

The error bars returned by WD2004 account for the scatter of the data but not for the many choices made during the modelling process, so are far too small. To determine realistic error bars we performed a large number of alternative modelling runs whilst varying the input physics and treatment of the data. These differences were: using mode 2 and fitting for $T_{\rm eff}$ instead of the light contribution of star B; changing the spectroscopic mass ratio by its uncertainty; changing the rotation rates by $\pm 0{\cdot}1$; changing the gravity-darkening exponents by $\pm 0{\cdot}1$; fitting for a phase shift; fixing the limb-darkening coefficients at the theoretically-predicted values; using the square-root limb-darkening law; using the Johnson *I* passband instead of *R*; changing the numerical precision values (N1 and N2) to 59, 58, 57, or 56; using the detailed reflection-effect option; using two instead of one reflection with the detailed reflection treatment; using a light-curve phase-binned into 500 instead of 1000 points; and removing the polynomials from the JKTEBOP fit before binning. This process is basically the same as has been used for numerous systems in the past[30–33].

The result of this process was a large set of different parameter values. The differences for each parameter *versus* the adopted solution were added in quadrature to obtain the final uncertainty for that parameter. These error bars

TABLE III

Summary of the parameters for the WD2004 *solution of the TESS light-curve of HO Tel. Uncertainties are only quoted when they have been assessed by comparison between a full set of alternative solutions.*

Parameter	*Star A*	*Star B*
Control parameters:		
WD2004 operation mode	0	
Treatment of reflection	1	
Number of reflections	1	
Limb-darkening law	2 (logarithmic)	
Numerical grid size normal	60	
Numerical grid size coarse	60	
Fixed parameters:		
Phase shift	0·0	
Mass ratio	0·921	
Rotation rates	1·0	1·0
Gravity darkening	1·0	1·0
$T_{\rm eff}$ values (K)	7872	7627
Bolometric linear LD coefficient	0·6720	0·6799
Bolometric logarithmic LD coefficient	0·1991	0·2043
Passband logarithmic LD coefficient	0·2454	0·2430
Fitted parameters:		
Bolometric albedos	1·20 ± 0·40	1·00 ± 0·24
Potential	4·848 ± 0·048	5·036 ± 0·051
Orbital inclination (°)	81·041 ± 0·067	
Light contributions	6·92 ± 0·19	5·19 ± 0·18
Passband linear LD coefficient	0·579 ± 0·017	0·550 ± 0·017
Third light	0·016 ± 0·013	
Derived parameters:		
Fractional radii	0·2575 ± 0·0026	0·2325 ± 0·0029
Light ratio	0·754 ± 0·036	

TABLE IV

Changes in the measured fractional radii of the stars due to differing model choices. Each is expressed as the percentage change versus the value of the parameter.

Model choice	*Effect* (%) $r_{\rm A}$	*Effect* (%) $r_{\rm B}$
Changing mass ratio	0·38	–0·56
Changing rotation rates by ±0·1	0·28	–0·21
Changing gravity darkening by ±0·1	0·03	–0·02
Fitting for phase shift	0·00	0·00
Fixing limb-darkening coefficients	0·34	–0·18
Using the square-root limb-darkening law	–0·01	–0·04
Using the Johnson *I*-band	0·10	–0·16
Setting the numerical precision to N1=N2=58	0·82	–1·02
Using the detailed treatment of reflection	0·01	0·00
Detailed treatment of reflection with two reflections	0·01	–0·00
Modelling a light-curve of 500 phase-binned data points	0·09	–0·13
Removing the polynomial normalization	0·05	–0·19

are reported in Table III. The albedos and third-light values are quite uncertain: their error bars are dominated by the variation obtained when using the Johnson *I* band instead of the *R* band.

The fractional radii of the stars are determined to 1·0% and 1·3% precision, respectively, but the main source of uncertainty is unexpected. To illustrate

October Page 2024.indd 247 19/09/2024 14:33

this we give in Table IV the individual contributions to the uncertainties in the fractional radii which arise from the various model choices listed above. The largest effect is due to the choice of numerical precision, which sets a limit on how well the fractional radii (r_A and r_B) can be measured. We have previously seen this effect in our analysis of the eclipsing system KIC 4851217 (Jennings *et al.*, submitted) so the current result is not an isolated incident. It is likely that more sophisticated modelling codes[34] will suffer less from this effect and thus allow an increase in the precision achievable in the determination of the properties of distorted stars in eclipsing binary systems.

Radial-velocity analysis

S17 obtained 45 medium-resolution spectra, from each of which they measured RVs for both stars using cross-correlation. These were included in their analysis with the WD code and the resulting parameters were given with 90% confidence intervals. As we universally use standard errors we have reanalysed the RVs to determine our own spectroscopic orbital parameters.

The RVs were obtained from table 1 in S17 and modelled using the JKTEBOP code, with the orbital ephemeris from above but with no other constraints from the *TESS* light-curve. The quoted error bars were scaled so the fit to the RVs of each star had a reduced χ^2 value of unity. We fitted for the velocity amplitudes of the stars and the systemic velocity of the system, obtaining $K_A = 132{\cdot}3 \pm 1{\cdot}2$ km s^{-1}, $K_B = 144{\cdot}0 \pm 1{\cdot}0$ km s^{-1}, and $V_\gamma = -5{\cdot}5 \pm 0{\cdot}6$ km s^{-1}, respectively. The error bars for these quantities were obtained using Monte Carlo simulations[35]. If the systemic velocities of the two stars are fitted separately there is a difference of 3·9 km s^{-1} between the stars, and the K_A and K_B change by –0·4 km s^{-1}.

The best fit to the RVs is shown in Fig. 3. It can be seen that there are three spectra which give large residuals, around phases 0·13 and 0·59. If these are rejected the measured properties become $K_A = 133{\cdot}9 \pm 1{\cdot}2$ km s^{-1}, $K_B = 145{\cdot}5 \pm 0{\cdot}8$ km s^{-1}, and $V_\gamma = -4{\cdot}4 \pm 0{\cdot}5$ km s^{-1}. We chose not to adopt these values, because there were no clear reasons to reject those data, but report them for completeness.

The spectroscopic orbital parameters given by S17 agree with our own results, and are $K_A = 131{\cdot}5 \pm 1{\cdot}2$ km s^{-1}, $K_B = 142{\cdot}8 \pm 1{\cdot}2$ km s^{-1}, and $V_\gamma = -5{\cdot}9 \pm 0{\cdot}7$ km s^{-1}. A cross-check of these numbers is also available using the *Gaia*[36] DR3[37] tbosb2 catalogue*[38], which includes the parameters of a double-lined spectroscopic orbit for the system. Based on 12 RVs for each star the orbit is $K_A = 136{\cdot}8 \pm 1{\cdot}2$ km s^{-1}, $K_B = 144{\cdot}5 \pm 1{\cdot}2$ km s^{-1}, and $V_\gamma = -7{\cdot}5 \pm 0{\cdot}6$ km s^{-1}. The velocity amplitude of star A is somewhat higher than that found from the RVs of S17, but this cannot have been investigated further because the individual RVs from *Gaia* have not be made publicly available. A small disagreement was also found in our analysis of V570 Per[39], and other issues have been noted in the literature[40–42], so we look forward to the RV measurements and individual spectra becoming available in future.

Physical properties and distance to HO Tel

The physical properties of HO Tel were determined from the results of the WD2004 code and RV analyses given above, using the JKTABSDIM code[44] (Table V). The masses and radii of the component stars are now known to 2% or better, matching the minimum requirements for a useful comparison with theoretical models[2,45]. Our results agree well with those from S17, but the availability of the *TESS* data has allowed us to improve the measurement precision of the radii

*https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=I/357/tbosb2

October Page 2024.indd 248 19/09/2024 14:33

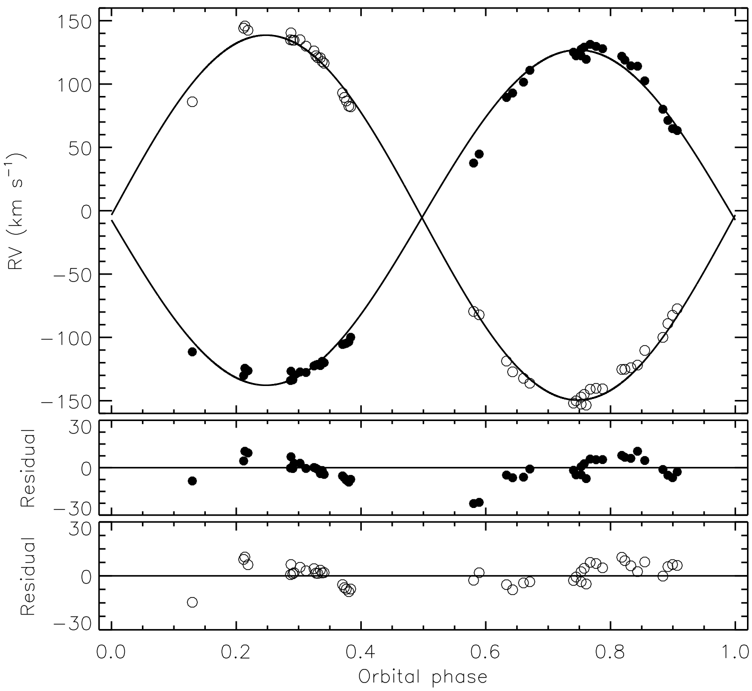

Fig. 3

RVs of HO Tel from S17 (filled circles for star A and open circles for star B), compared to the best fit from JKTEBOP (solid lines). The residuals are given in the lower panels separately for the two components.

Table V

Physical properties of HO Tel defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 43).

Parameter	*Star A*	*Star B*
Mass ratio $M_{\rm B}/M_{\rm A}$	0·919 ± 0·010	
Semi-major axis of relative orbit ($\mathcal{R}^{\rm N}_{\odot}$)	8·918 ± 0·050	
Mass ($\mathcal{M}^{\rm N}_{\odot}$)	1·906 ± 0·031	1·751 ± 0·034
Radius ($\mathcal{R}^{\rm N}_{\odot}$)	2·296 ± 0·027	2·074 ± 0·028
Surface gravity (log[cgs])	3·996 ± 0·009	4·048 ± 0·012
Density ($\rho_{\odot}$)	0·1574 ± 0·0048	0·1965 ± 0·0075
Synchronous rotational velocity (km s^{-1})	72·03 ± 0·83	65·03 ± 0·89
Effective temperature (K)	7872 ± 200	7627 ± 201
Luminosity log($L/\mathcal{L}^{\rm N}_{\odot}$)	1·261 ± 0·045	1·118 ± 0·047
$M_{\rm bol}$ (mag)	1·59 ± 0·11	1·95 ± 0·12
Interstellar reddening $E(B-V)$ (mag)	0·04 ± 0·02	
Distance (pc)	280·8 ± 4·6	

from 7% to 1%.

To determine the distance to the system we adopted the $T_{\rm eff}$ measurements from S17, the *BV* and *JHK*$_{\rm s}$ magnitudes from Table I, the surface-brightness calibrations from Kervella *et al.*[46], and the method from Southworth *et al.*[44]. The 2MASS *JHK*$_{\rm s}$ magnitudes were obtained at orbital phase 0·796. A small interstellar reddening of $E(B-V)$ = 0·04 ± 0·02 was needed to bring the

October Page 2024.indd 249 19/09/2024 14:33

distances from the BV bands into agreement with those from the JHK_s bands. The resulting distance of 280·8 ± 4·6 pc agrees with the value of 284·2 ± 3·2 pc from the *Gaia* DR3 parallax.

Conclusion

The dEB HO Tel contains two A-type stars in a short-period orbit which causes them to be tidally deformed. We have determined their masses and radii using photometry from the *TESS* mission and published ground-based RVs from S17. The measurements are to 1·6% and 1·9% precision in mass, and 1·2% and 1·0% precision in radius. The mass measurements are limited by the scatter in the available RVs, and the radius measurements by the numerical precision of the modelling code used. Adding published $T_{\rm eff}$s and apparent magnitudes to the analysis allowed a measurement of the distance to the system of 281 ± 5 pc, in agreement with the distance from *Gaia* DR3.

We have compared the measured properties of the component stars to the predictions of the PARSEC theoretical stellar-evolutionary models[47]. We confirm the discrepancy found by S17 in that a good fit to both stars cannot be obtained for a single age, and that star B matches predictions for older ages (1030 ± 70 Myr) than star A (880 ± 60 Myr) for a solar metal abundance (Z = 0·017). The improved agreement seen by S17 in the Hertzsprung–Russell diagram suggests the discrepancy is related to the measured masses of the stars. To test this we used the K_A and K_B values from *Gaia* to obtain slightly higher masses and a good fit in the mass–radius diagram for an age of 800 ± 50 Myr. However, this results in an increase in the predicted $T_{\rm eff}$s, which must then be brought down by adopting a higher metallicity of at least Z = 0·03.

HO Tel would benefit from more detailed spectroscopic study. Forthcoming data releases from *Gaia* will contain more epochs of spectroscopy, and the individual RV measurements from the *RVS* spectrometer, so will help in this work. Ground-based spectra would also be useful in determining the $T_{\rm eff}$s and photospheric chemical compositions of the stars to better precision and accuracy.

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[*]https://www.cosmos.esa.int/gaia

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

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CORRESPONDENCE

To the Editors of 'The Observatory'

Lunar Dust Clouds and Space Missions

The high accident rate of space probes, when attempting to land on the lunar surface, is still a surprising phenomenon. Thus, in the period 2019–2023 the following landers were lost at low (<15 km) altitudes: *Beresheet*, *Vikram 1*, *OMOTENASHI*, *Hakuto-R Mission 1*, and *Luna 25*. The 'successful' lander *SLIM* had losses of an engine nozzle and communication with the Earth during descent. It had landed at a 90-degree angle. The next lunar module to have 'survived', *Odysseus IN-1*, tipped over during landing. Perhaps such incidents are partly a manifestation of an unaccounted risk factor.

In this regard, the problem of levitating lunar dust deserves attention[1]. Apparently, the effects of absorption and scattering of light by lunar dust clouds were first noticed during the occultation of Saturn on 1762 June 17[2]. Despite numerous reports[3] of Earth-based observations of similar effects, dust clouds on the Moon were recognized by the planetary community only after they were recorded *in situ* as a lunar horizon glow by the *Surveyors 5–7* and *Apollo 10, 15, 17* missions[4,5]. Although the later *Clementine* and *LRO* missions found that the concentration of lunar dust above the lunar surface appears 10^4 times lower than that suggested by the *Apollo* estimates, a specialized lunar mission, *LADEE*, registered five dust clouds which had a density comparable to the estimates based on *Apollo* data[6]. Hence, the dust concentration varies greatly and its *in-situ* measurement over a limited space-mission time span is unrepresentative. At the same time, the information on lunar dust clouds, provided by Earth-based monitoring, is apparently forgotten. It makes sense to fill this gap in data analysis.

Really, ground-based observations of lunar horizon glow (*i.e.*, the forward scattering of sunlight by electrostatically levitating dust particles) are described in astronomical literature[3] (21 cases) in the form of light strips along the dark limb of the crescent Moon, or as light ledges near cusps of the solar crescent during an eclipse[7,8]. Sometimes (23 events), the lunar horns' prolongations close the crescent, and turn it into a ring[9–11]. The images of such an annular Moon can be found in ancient artifacts[12] as well as in modern Earth-based photos[13]. Moreover, the dust clouds were manifested sometimes in the form of a dark band of light extinction parallel to the lunar limb on the discs of Jupiter[14], Saturn[2], and Mars[15] during their occultations. There is a photo of such a dark stripe[16], which was parallel to the lunar limb but perpendicular to the Jovian cloud bands. The analysis of all nine such anomalous planetary occultations shows that the dust clouds extended from the lunar surface up to the height of between 4 and 66 km.

In the Lunar Occultation Archive (cdsarc.cds.unistra.fr/viz-bin/cat/VI/132C), among 849 occultations during the period 1967–2022, in which the duration, τ, of a star's appearance/disappearance was measured, in 419 cases (49%) the event duration was anomalously long ($0{\cdot}1 \le \Delta t \le 8{\cdot}6$ s). These values are significantly longer then the predicted timescale $\Delta t \approx 0{\cdot}05$ s of stellar occultations. Obviously, binary systems cannot explain the gradual fading of a star as reported by observers[3]. However, the anomalous duration of occultation, converted into the space-scale $0{\cdot}1 < \Delta t\ V_M < 8{\cdot}4$ km (here $V_M = 1{\cdot}02$ km/s is the average orbital speed of the Moon), is comparable with the scale height $5 < H < 20$ km of lunar levitating dust according to *Apollo*[17] data.

The effective light extinction during an anomalous occultation means the sufficient optical thickness of a dust cloud: $\tau = N_d\sigma \sim 1$. Here N_d is the dust column density, and $\sigma = \pi r_d^2$ is the cross section of a dust particle of r_d radius. For rough estimates, one can use the cloud model in the form of a homogeneous layer of thickness H. The path length of the starlight ray inside the dust layer is $L = 2\ [(R+H)^2 - R^2]^{1/2}$, where R is the lunar radius. Hence, $N_d = n_d L$, where n_d is the average dust concentration in the layer, which could be estimated using the condition $\tau \sim 1$: $n_d \sim (\pi L r_d^2)^{-1}$. Assuming realistic[17] values of $H = 10$ km and $r_d = 1$ μm, one can estimate $n_d \sim 10^6$ m^{-3} and the mass of a dust particle $m_d = \rho(4/3)\pi\, r_d^3 = 1{\cdot}26\times10^{-14}$ kg for the lunar density $\rho = 3\times10^3$ kg m^{-3}. Now let's estimate the time, T_c, during which a spacecraft with a mass $M_{sc} = 100$ kg and cross-section $S = 1$ m^2, flying at a circular orbit of altitude $Z_o \leq 10$ km with velocity $V \approx 1{\cdot}68$ km/s inside a circumlunar dust cloud, would crash on the Moon. The spacecraft's energy-loss rate due to collisions with the dust is $\varepsilon = (0{\cdot}5\ m_d\ V^2)\ (n_d SV) \approx 30$ W. The work needed for vehicle descent is $\Delta E = g\, M_{sc}\, Z_o \leq 1{\cdot}6\times10^6$ J, where $g = 1{\cdot}622$ m s^{-2} is the lunar surface gravity. Hence, the time-scale of the fall is $T_c \sim \Delta E/\varepsilon \leq 15$ hours. Note that this estimate is on the order of the orbital period ($2\pi R/V = 1{\cdot}8$ h). By adding the factor $(S/1\text{ m}^2)^{1/2}$, one can transform the resulting T_c to the case of a different cross-section. Correspondingly, a femtosatellite ($S < 0{\cdot}01$ m^2) could drop during one orbit. Analogously, the factor 1 μm/r_d transforms the model value T_c to the case of a different dust size. Hence, the case of $r_d \geq 10$ μm is fatal for small satellites.

The estimates obtained demonstrate the danger of the dust factor, which needs to be taken into account, especially when planning manned flights to the Moon.

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2024 February 28

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October Page 2024.indd 253 19/09/2024 14:33

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On the Value of Conference Proceedings

Upon returning from some recent travel, I found the April issue of *The Observatory* in my letterbox. In a book review[1], the question was raised as to the on-going value of printed books of conference proceedings in light of the fact that many contributions had been published in journals before the proceedings, or even before the conference. Another question was whether printed books are needed with many journals becoming on-line-only. The second question is really unrelated; also, the arguments for and against conventional printed and on-line-only versions of journals and conference proceedings are essentially the same. The third question was whether anyone still seeks them out and searches them for new work*. I know for a fact that some people still seek them out for *old* work. Most of my recent travel was to the Moriond cosmology conference[2], and during that conference I got a message from a colleague saying that he had recently looked up a reference from a 1981 Moriond conference, praising the fact that each contribution had a photo of the author (a tradition which still continues to this day). Sometimes something needs to be cited but there is no journal reference; for example, I've cited a conference proceeding for the source redshift of the gravitational-lens system 0218+357[3].

In the old days, there were three main reasons to go to conferences: to hear about the latest results, to get an overview of work outside of one's own field, and to meet old and new friends and colleagues. Electronic communication has made the first obsolete to some extent (thus leaving more time for the other two), though not entirely. Sometimes results, especially involving strong claims, take a while to be refereed, and will appear long after the conference, perhaps even after the publication of the proceedings — or they might not appear at all if found wanting. Those are exactly the type of results which should be checked and confirmed or refuted, and the conference proceedings might be the only source one can cite, at least initially.

While it might just be possible to keep up with the literature in one's own field, it is impossible to do so in all fields. One might hear an interesting talk in a field different from one's own; the proceedings provide a starting point for looking up further references. I tend to present topics at conferences before submitting them to journals, in order to get feedback. But even if the work has appeared elsewhere before the conference, the conference proceeding is usually shorter and more digestible, and there can be value in a collection of such contributions on a common theme, especially if the proceedings are well produced (examples are reviewed in refs. 4 and 5).

Conference proceedings are also useful for historians of science. I'm writing this while reading a book[6,7] which mentions the 1927 Solvay conference. As with the 1957 Chapel Hill conference on the role of gravitation in physics, we should be grateful that there is a written record. Even if the written record differs somewhat from what was actually said (as in Bohr's contribution to the 1927 Solvay conference), that in itself can be interesting. When I was younger it was much more common for proceedings to include the questions and answers after the talk. That is a tradition which should be revived, as perhaps even more so than the contributions themselves they indicate what people were thinking at

*"Does anyone seek them out and search them for new work anymore...." It is not clear to me whether it is the new work which is being sought out in the proceedings, or whether proceedings are being sought out in order to be cited in some other new work.

the time. Another conference proceeding I have often cited[8] has, at the moment of writing, 89 citations according to ADS, more than most refereed-journal papers.

The Moriond conferences have the best of all worlds: a proper printed book of (relatively long) conference proceedings (distributed to the participants but also available to others), a freely available PDF of the same[9], and the slides of the individual contributions on the web. (Alas, some other conference websites have disappeared after a few years.) The facts that there are only plenary sessions, that everyone sleeps and eats in the same hotel at the conference venue, and that there are more hours of talks in the week (six full days and a closing session on the seventh) despite a break of four hours or so each afternoon (with the opportunity for skiing) make them my favourite serial conference, and they are better organized than most high-profile one-off conferences.

Yours faithfully,
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REVIEWS

Her Space, Her Time: How Trailblazing Women Scientists Decoded the Hidden Universe, by Shohini Ghose (MIT Press), 2023. Pp. 248, 22·5 × 15 cm. Price $29·95 (about £24) (hardbound; ISBN 978 0 262 04831 6).

Author Shohini Ghose is herself Professor of Physics and Computer Science at Wilfred Laurier University in Canada, and has been active in women-in-science issues for some time. Here she addresses seven topics in the recent history of physics, astronomy, cosmology, and such, focussing on contributions by women to our present understanding. You will find here many of the astronomers you might expect — Annie J. Cannon, Cecilia Payne-Gaposchkin, Henrietta Leavitt, Margaret Burbidge, Maria Mitchell, and Vera Rubin, with, I think, no major surprises in how the author describes their best-known contributions. At least the tip of the physics pillar might (should!) also be familiar — Lise Meitner (fission, who should have shared Otto Hahn's 1944 Chemistry Nobel), Maria Salomea Sklodowska (who received two Nobels, Chemistry and Physics, as Marie Curie), and C. S. Wu (Wu Chien-Shiung, the experimenter who found parity non-conservation as predicted by C. N. Yang and T. D. Lee, who got the prizes).

Surprises and potential disagreements arise when one looks more closely at who's in, who's out, and how the work and the person get classified. There is Margaret Burbidge (with her birth surname misspelled as Peachy rather than Peachey), sharing a chapter called 'About time: discoverers of the Big Bang' with Henrietta Leavitt. But Margaret was not a strong supporter of a hot, dense early Universe even in 1957 when the monumental B^2FH, 'Synthesis of the Elements in Stars', was published, and later in life definitely favoured some sort of quasi-steady-state or cyclic universe without a Big Bang starting time for everybody.

The chapter 'Escape Velocity: Pathfinders in Space Exploration' indeed includes women who worked for NASA and other space agencies (Valentina Tereshkova makes the cut; Sally Ride does not). Recently hailed Katherine Johnson is there, though not featured among "the Women who Powered NASA's Space Program". Most strangely, that chapter includes a Turkish woman whose name appears in IAU directories as Dilhan Ezer-Eryurt. Ghose calls her Eryurt in the text; lists her publications as Ezer, and apparently thinks that having worked at Goddard Institute of Space Studies makes her a contributor to space science. Actually her major contribution to astrophysics was calculations of the structure and evolution of stars with $Z = 0$, carried out with A. G. W. Cameron. She is sadly no longer with us, but was my 'go to' person in Turkey earlier in the century when American physicists were worried about conditions for scientists there.

The story in Chapter 6, 'Forces of Nature: the subatomic photographers', is a bit more complicated than the version here. Yes, Marietta Blau was unquestionably a/the pioneer of using nuclear emulsions as detectors for high-energy particles, and the Nobel went to Cecil Powell for using such emulsions to find mesons (as predicted by Yukawa who had won the previous year). What I missed were the contributions of Occhialini (who also worked with Patrick Blackett on his Nobel-graced work) and also in Powell's cosmic-ray group at Bristol, Cesare Lattes, who carried the technique back to his native Brazil. The Brazilian physicist in that chapter is Elisa Frota-Pessoa, who also worked with nuclear emulsions, and it is impossible not to suspect that she had learned of them from Lattes. I also felt in reading that chapter that author Ghose had not been hard enough on Herrtha Wambacher, Blau's student and apparently a loyal Nazi, who arguably tried to take more of the credit for nuclear-emulsion work away from Blau (who was in Vienna in 1938) than she, Wambacher, deserved.

Lots of surprises — Otto Hahn won a medal for his WW I service at the Battle of Ypres. The death toll in the WW II Bengali famine was apparently more like four million people than the three million I had remembered. The author is apparently not aware of programmes at many universities (including UCI) that try to arrange "spousal hires" to facilitate recruiting new faculty members (one of our best astronomers arrived as the husband of a woman selected by another department!). She apparently also is not aware that Albert Abraham Michelson did his prize-winning work in the US, and she describes Millikan as our first physics Nobelist.

The author describes a D.Sc. degree as the equivalent of a PhD (but don't they generally get to wear nicer-coloured academic robes?). On the other hand, she does an unusually good job of tracing out the path of stellar nuclear reactions from hydrogen to iron and beyond. A few other items left me wanting to verify names, dates, and all, for instance the statement that Ray Davis detected solar neutrinos in 1965, and that Otto Frisch thought of using "pure uranium" for a fission bomb, Frisch and Rudolf Peierls concluding that a few kilograms would be enough. —Virginia Trimble.

Quantum Drama: From the Bohr–Einstein Debate to the Riddle of Entanglement, by Jim Baggott & John L. Heilbron (Oxford University Press), 2024. Pp. 335, 24·5 × 16·5 cm. Price £26·99/$32·99 (hardbound; ISBN 978 0 19 284610 5).

Jim Baggott* is known mainly as a writer of popular-science books; the late John L. Heilbron as a historian of science. Heilbron lived in Copenhagen 1962–1963, he interviewed many of the founders of quantum mechanics, and archived and microfilmed their correspondence; he has also written a biography of Bohr[3]. They have teamed up for something in-between, a popular history-of-science book, more detailed than most popular-science books and a breezier read than most technical history-of-science monographs. It covers the time from the origins of quantum theory up to the present. Obviously, it can't be even close to a complete account in only a few hundred pages. Rather, as the subtitle states, it concentrates on the idea of entanglement, covering various interpretations of quantum mechanics, philosophical issues, experiments, and practical applications.

Except for the last with six, each of the four parts (which follow a nine-page prologue) has four chapters. The first part covers the early days (roughly from Planck's first work, conveniently in the year 1900, until the end of the 1920s) of quantum mechanics and provides a basic introduction to the topic. The latter can be found in many other books; the former, with more emphasis on the people involved, is not as common in books at this level. The second concentrates more on the main theme of the book, covering events from the fifth Solvay conference in 1927 until about the end of the 1930s, with the famous Einstein–Podolsky–Rosen paper and Schrödinger's cat playing prominent roles. Quantum mechanics is no longer just a system of rules for calculating experimental quantities, but has become a philosophical subject, with topics such as the measurement problem, the reality (or not) of macroscopic superpositions, the uncertainty relation, and so on, occupying the best minds in the field, not always agreeing. The most famous such disagreements are the famous Bohr–Einstein debates. (I recently read that the traditional view is, in the physics community, that Bohr is seen as having been right and Einstein wrong, whereas in the philosophy community it is the other way around. However, that simple dichotomy is as much an oversimplification as each premise on its own.) The title comes from a quotation from Bohr: "At the next meeting with Einstein ... our discussions took quite a dramatic turn." The third part, picking up after the distraction of World War II (in which many of the key players were involved in more practical pursuits) and continuing until about the end of the 1950s, introduces the alternative approaches of Bohm and Everett. Interesting is the degree to which some of the 'non-Copenhagen' pioneers followed those new

*I reviewed[1] a previous book[2] by Baggott in these pages.

approaches while at the same time a new generation (Weisskopf, Wheeler, von Neumann, Wigner, *etc.*) took over*: Bohr died in 1962, Einstein in 1955, Fermi in 1954, Schrödinger in 1961, Pauli in 1958. (Interestingly, some of the earlier generation died much later, *e.g.*, de Broglie in 1987, Dirac in 1984, Born in 1970, Jordan in 1980, von Weizsäcker in 2007, but in their last decades they were no longer leading the discussion in the field.) There is also a good discussion of attitudes in the field as expressed at conferences (where opinions are often more clearly on display than in journal articles). The last part introduces John Bell and the current importance of his work, *e.g.*, the experiments by the winners of the 2022 Nobel Prize in Physics (Clauser, Aspect, and Zeilinger), quantum cryptography, and quantum effects observable in (almost) macroscopic objects. In between is an interesting discussion of popular-level mysticism in connection with quantum mechanics (Capra[4], Sarfatti, Zukav[5], *etc.*). While that is often (correctly, in my view) looked down upon, it is important to remember that Schrödinger was very interested in eastern mysticism, Pauli in the psychological theories of Jung, Bohr put yin and yang on his coat of arms, and so on. (At least Schrödinger's 'mystical side' might be more akin to the religion of Lemaître, who was a Catholic priest yet seemed to be able to separate that from his work in cosmology, which has also been the case among some more modern openly religious cosmologists such as John Barrow and George Ellis.)

While there are few equations in the book, the fourth part goes into more detail than one might expect in explaining the ideas of Bell and the experiments of Clauser, Aspect, and Zeilinger. While the book can't cover everything — and doesn't attempt to — all the same, many readers will probably come across concepts and people usually not mentioned in overviews of (the history of) quantum mechanics, such as Grete Hermann. As such, it is complementary to many other books broadly covering similar ground. It is also better written than most books I've reviewed in these pages. There are black-and-white figures scattered throughout the book. Twenty-five pages of endnotes are mostly references to the sources listed on twenty-seven pages. The thirteen-page small-print index is especially thorough, especially for a 'popular' book, and demonstrates again that this book is a cut above most broadly similar books, both in terms of content and in terms of presentation. It should appeal to a relatively wide readership, especially due to its combination of detail and readability, including, despite the lack of astronomy, readers of this *Magazine*. — Phillip Helbig.

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Splinters of Infinity, by Mark Wolverton (MIT Press), 2024. Pp. 271, 23·5 × 16 cm. Price \$29·95 (about £24) (hardbound; ISBN 978 0 262 04882 8).

While the title *Splinters of Infinity* might suggest otherwise, this book is a history of the debate between Robert Millikan and Arthur Compton about

*I use 'generation' here less in relation to the year of birth and more in relation to the period in which the person in question was an active participant in the field.

the nature of cosmic rays and the fate of the Universe. The book tells a chronological story roughly from 1930 to 1937, with some backstory of each of the main characters and of the study of cosmic rays.

Known for their Nobel prizes in quantum physics, Millikan and Compton both shifted their careers to studying cosmic rays, then the cutting-edge physics of their day. Millikan, despite his prior work on electrons, believed cosmic rays were gamma rays. Compton, despite his prior work on X-rays and gamma rays, argued that they were charged particles. What's more is that Millikan, an openly religious man, claimed that cosmic rays were the "birth cries" of atoms being continuously formed and were proof that God's act of creation was still on-going. Following the Scopes trial of 1925, newspapers across the country, including the *New York Times* and the *Los Angeles Times*, revelled in reporting the most prominent American physicist pronouncing the harmony of religion and science and evidence that "the Creator is still on the job", in stark contrast to the prevailing theory even then that the Universe would end in heat death as it slowly disintegrates. Arthur Compton, rising in prominence, confidence, and funding, took up the challenge to align with the growing consensus, especially in Europe, that cosmic rays were charged particles. Articles chronicling the on-going dispute appeared in dozens of newspaper articles — sometimes on the front page — for years.

It may be hard to believe, even for experts in the field, that "cosmic ray" was once a household buzzword, front-page material, and the precursor to modern particle physics. Thought to be a possible source of free energy, cosmic rays attracted charlatans, crackpots, and 'healers' trying to sell their products with the buzzword of the day, much like one might find 'nano' and 'quantum' attached to modern-day equivalents. Cosmic-ray research was the biggest and most cutting-edge science around, and this book recounts the record-setting global expeditions by land, air, and sea to settle the debate.

Mark Wolverton, a science journalist and author of several books blending science and history, adopts a narrative approach to focus on this lesser-known story of scientific history. He is meticulous, evidenced by 22 pages of endnotes that are almost entirely references to books, newspaper articles, and personal correspondence among the main and supporting characters. The book is filled with biographical and historical details. For example, amid the "cosmic ray health centers" and comic-book stories about infinite free energy from the nucleus and from cosmic rays, Albert Einstein told reporters in 1934 that atomic energy was unlikely, giving a sense of the *zeitgeist* of the 1930s.

This book is not technical and would appeal to any reader interested in the historical details that led to our current understanding of cosmic rays and physics more broadly. *TIME* magazine described the Millikan–Compton debate as "one of the most reverberating scientific controversies of the century", more famous in its day than the Great Debate between Shapley and Curtis, but it is nonetheless a MacGuffin, a device to draw the reader in to a case study of science and of scientists, who, as always, are human. In their hunt for the secrets of cosmic radiation, they set hot-air-balloon altitude records, argue over primacy, invent the AND digital circuit, jump to faulty conclusions, drop their equipment to the bottom of a lake, and fall to their deaths in a crevasse — but save the data book. The story shows how science is a messy enterprise, full of ego and dead ends — literally! One also reads about how scientists of that time dealt with the press and public perception, in contrast to scientists of today.

For anyone working on cosmic rays, this book is a must-read. While *Splinters of Infinity* doesn't focus on physics that revolutionized modern technology, like atomic power or lasers, it will, however, interest readers who enjoy the personal and historical sides of science. The reader may also find this lesser-known area of physics interesting in its own right. As Mark Wolverton writes, "Cosmic rays remain one of the most intractable scientific puzzles of all time." — PAUL SIMEON.

At the Crossroads of Astrophysics and Cosmology: Period–Luminosity Relations in the 2020s, edited by Richard de Grijs, Patricia A. Whitelock & Márcio Catelan (Cambridge University Press), 2024. Pp. 333, 25·5 × 18 cm. Price £120/$155 (hardbound; ISBN 978 1 009 35304 5).

The best-known period–luminosity (P–L) relation in astronomy is undoubtedly that for Cepheid variables, discovered (as several of the chapters in this volume tell us) by Henrietta Swan Leavitt, though the powers-that-be have not (yet?) persuaded most practitioners to call it the Leavitt Law. Actually there are many such laws for many kinds of Cepheid variable stars and many other categories. The volume and the symposium it reports address only stellar sources (including binaries), though reverberation mapping of active galaxies (AGN) has a bit of the same flavour.

Did the SOC manage to corral a presentation touching on every known variable category? Not quite. Only the editors' preface mentions ZZ Ceti, V777 Herculis, and GW Virginis, pulsating white dwarfs of spectral types DA, DB, and DOther, which have their own instability strips, but were presumably declared not relevant to cosmology. I am not quite sure this is true, given potential implications for the ages of various stellar populations. But beta Cep, roAp, delta Sct, and gamma Dor do appear among the less-famous classes, not to mention BL Her and SX Phe. And yes, binaries, because the Roche geometry forces a period-separation–stellar-size limit that leads to a correlation of period and absolute brightness.

The front matter lists names of 126 participants, with no affiliations or countries of residence given (those appear only for first authors of the 27 articles). The conference photo, in glorious black and white like all the rest of the volume, is compressed onto a standard single page in portrait format and probably includes a comparable number of people, about whom it can be said that most paid the registration fee (name badges displayed) and at least those in the front row appear to have two legs each and shoes.

Wendy Freedman and Barry Madore are given the first word, on past, present, and future of the Cepheid extragalactic distance scale, and several other papers look specifically at Cepheids (including Type II's and anomalous Cepheids). Stars at the tip of the red-giant branch also get a fair amount of attention. In comparison to earlier studies of variable stars, the dominant impression here is MORE. Data on very many variables have recently come — or are coming — from the *Kepler* mission, OGLE, and *Gaia*. *JWST* is proving its worth both by extending P–Ls into the infrared and also by angular resolution much improved from *HST*. Cepheids in double-lined eclipsing binaries and in open clusters have become routine sources of extra information, though they were, once upon a time, thought not to exist.

Several things left me puzzled. There is a map of Japan (p. 164) showing the location of four 20-metre antennae spread somehow across the country, but the outline is an oval, and no islands are shown. The array is being used to measure parallaxes and circumstellar masers of massive AGB stars. The first author is A. Nakagawa of Kagoshima University, who undoubtedly knows where the antennae are.

Second, one paper discusses the variability (at the level of millimagnitudes) of red supergiants. I had thought of such stars as displaying just a few really big rising and falling convective blobs, which I would not have described as "granulations". Seeking enlightenment from our friend Google, I lit first on a reference to this book chapter and second to the journal article reporting roughly the same information from the same authors.

My third puzzlement concerned a paper dealing with the Period–Wesenheit relations for anomalous Cepheids (though with brightnesses between the two normal types of Pop I and Pop II). Who, I wondered, was Wesenheit? No references with that author's name cited in the paper carrying that title (or any of the others). Could it possibly be a word, not a name? Sounds German. Dust off German–English dictionary from grad school. Well, 'heit' is a particle that turns an adjective into a feminine noun. But Wesen is already a noun (spirit, essence, or some such). Back to the target paper. Lots of light-curves and an expression defining W, but no explanation of the name. Google to a paper by Barry Madore in 1982, which blames or credits our good friend Sidney van den Bergh 1975. Oops. His chapter in Vol. 9 (the last of the eight published) in the Kuiper Compendium, Stars and Stellar Systems. Not on ADS. Query a native speaker of German about the word, which he said is something like essence, but not obvious why it is part of a period–luminosity relation. Back to Madore; well, it is a combination of colours that will remove the effects of reddening if you have the good luck already to know that ratio of total to selective absorption in the colour system you are using, for instance, $A_v = 3{\cdot}1 \times E(B-V)$. And a visiting colleague has just suggested that perhaps Wesenheit is more informative in Dutch. — VIRGINIA TRIMBLE.

Early Disk-Galaxy Formation from JWST to the Milky Way, edited by Fatemeh Tabatabaei, Beatriz Barbuy & Yuan-Sen Ting (Cambridge University Press), 2024. Pp. 133, 25 × 18 cm. Price £110/$145 (hardbound; ISBN 978 1 009 39875 6).

This slim volume is the proceedings of IAU Symposium 377, held in Kuala Lumpur, Malaysia, in 2023. According to the preface the meeting was the first in South-east Asia since 1990 and was intended as a vehicle for raising the profile of astronomical research in Malaysia. There are 20 papers in two sections, 'Galaxies and Cosmic Dawn' and 'Milky Way and M31' plus a single paper on 'Astronomy in Malaysia' (which concerns the possibility that the creation of an ancient inscription was inspired by the AD 760 apparition of Comet Halley). The first section covers a range of topics, most of which have been, or could be, addressed by *JWST* observations, particularly at very high redshifts. The second section is more focussed, with several papers on chemical abundances in early Milky Way stars. Many of the papers are individually very interesting, but the volume as a whole is no more, arguably rather less, than the sum of its parts. Most contributions have already been published elsewhere, where the reader will actually be able to see the magenta crosses, orange dotted lines, *etc.*, alluded to in one figure caption, unlike in the entirely monochrome figure reproduction here. It is also noticeable that since the IAU Symposium volume which I reviewed last year (No. 374), the price has risen by 12%, despite No. 377 being only 40% of the length. It is hard to imagine there being any individual buyers at more than £5 per article, though libraries with long-term CUP/IAU contracts will presumably receive it, even if it never subsequently leaves their shelves. — STEVE PHILLIPPS.

Strong Gravitational Lensing in the Era of Big Data, IAU Symposium 381, edited by Hannah Stacey, Alessandro Sonnenfeld & Claudio Grillo (Cambridge University Press), 2024. Pp. 183, 25·5 × 18 cm. Price £120/$155 (hardbound; ISBN 978 1 009 39899 2).

Many of my own papers are on strong gravitational lensing and I considered attending the conference, so it seems appropriate for me to review the proceedings, in part to update myself on the field, which has already benefitted, and will continue to benefit, from recent and planned improvements in observations, hence the 'big data' in the title. The first strong-lensing system (defined as a gravitational-lens system which produces multiple images of the source, as opposed to weak lensing which is limited to magnification and, for resolved sources, distortion) was discovered about 45 years ago[1]. I was involved in a radio survey for strong lensing[2], which, discovering 22 lens systems (including one previously known), approximately doubled the number of known strongly lensed quasars.* As noted in the first contribution in these proceedings, it is expected that instruments such as *Euclid* and the *Roman Space Telescope* will discover about 100 000 such systems. Not only is that a quantitative change, but a qualitative one as well: no one person can have even a passing familiarity with all systems, and 'manual' modelling will have to give way to automated procedures.†

The book consists of five 'chapters' (really parts, if an article is a chapter). Those have no names but roughly correspond to the main topics mentioned in the preface: cosmology, dark matter, galaxies, clusters of galaxies, and high-redshift sources. More-specific topics are machine learning, measuring the Hubble constant, and substructure in galaxies. The book is far too short to give even an overview of the field‡, but does provide a useful short introduction to several currently hot topics. In some areas, applications of gravitational lensing, such as measuring the Hubble constant or small-scale structure in galaxies, are comparable to or better than other methods. For a while now, the theoretical side of lensing has been clear; the next several years will concentrate on the massive amounts of observational data; in that sense, the field now reminds me of that of the cosmic microwave background between *COBE* and *WMAP*, with interesting hints about what is to come, but a while before practical observational limits are reached. It appears that the community is ready.

My goal of getting a feel for current research was fulfilled, though I wonder what I am missing, since, comparing the book with the on-line programme, fewer than half of the contributions are included in the proceedings. (Most of

*At the end of 1998, Wambsganss[3] mentioned that by then "about two dozen multiply-imaged quasar systems [had] been found, plus another ten good candidates". Somewhat more than twenty years later, Hamed & Weisner[4], in an attempt to catalogue all known strong-lens systems, listed 1832.

†Another change is that most people now working in the field are younger than I am (I also know only about half a dozen of the hundred or so participants and recognize perhaps that many names in addition). That is not a problem in itself, but I wonder why there is so little knowledge of the history of the field. Several times at conferences, when meeting someone new who works on gravitational lensing, I've mentioned that I had been a student of Sjur Refsdal, only to be astounded by the fact that the other person had never even heard of him. That's almost as bad as working on the Hubble constant and not having heard of Hubble, especially since Refsdal essentially single-handedly founded the modern study of gravitational lensing, in a series of papers about sixty years ago (while also finding time to co-author what I consider to be the most interesting paper in relativistic cosmology[5].)

‡The proceedings of the 1993(!) gravitational-lens conference ran to 747 pages[6].

October Page 2024.indd 262 19/09/2024 14:33

those in the proceedings refer to refereed-journal papers, so assuming that that is also true of those not included as well, the information is out there, but not all in one place.) Unfortunately, instead of 'edited', 'collated' might be more appropriate, as apparently little actual editing was involved. Apart from my usual peeves about language and style, the number here probably setting a new record, there are several other annoying aspects: the list of participants is not in alphabetical (nor, as far as I can tell, any other) order; the author index (there is no subject index) lists some people twice, according to the number of initials; the reference format is not uniform; while it is sometimes good to list the titles of papers and even all authors, that is not the case for such a proceedings volume — some of the reference lists which do (the formats differ) are thus longer than the corresponding contributions; many figure captions refer to colour, though in the book itself all of the many figures are in black and white — unless one is already familiar with the topic, it is hard to guess which colour should correspond to which of the fifty shades of grey*; hyperlinks (not showing the actual URL nor any corresponding information) are useless on paper.

One can question the value of publishing books of conference proceedings in this day and age, especially if most contributions are essentially condensed versions of refereed-journal papers which will have already appeared before publication of the book (see also my correspondence piece in this issue[7]). (Although, with many journals now on-line-only, books of proceedings might be an alternative to printing a large number of pages for those who prefer reading on paper.) However, for contemporary readers, they can offer up-to-date reviews of rapidly developing fields (many traditional review articles are somewhat out of date by the time they appear), and questions and answers could prove useful for future historians of science, but neither of those is realized here.

Despite my qualms, for me it was an interesting read, and the relatively short length might even be an advantage if the goal is to get a taste of current research in the field. — Phillip Helbig.

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(7) P. Helbig, *The Observatory*, **144**, 254, 2024.

Astrophysics is Easy, 3rd Edition, by Mike Inglis (Springer), 2024. Pp. 434, 23·5 × 15·5 cm. Price £24·99 (paperback; ISBN 978 3 031 16804 8).

The third edition of Mike Inglis's book has been expanded to add extra chapters on exoplanets, relativity, and more on cosmology. Various thought questions have been added in the text along with some more mathematical ones at the end of chapters. In a book of this type obviously only a limited coverage can be given to any one topic but I was disappointed to see that in the discussion of planetary nebulae no mention was given to the fact that some of

*Each contribution is available *via* its own DOI. According to the notes on the first page of each contribution, some, but not all, are open-access (confirmed by spot checks). Colour figures are thus available on-line.

the shapes are caused by binary nuclei.

The general idea behind the book is to give the reader some idea of the background physics behind the kind of objects they may be observing. As such most chapters include examples of the kind of objects being discussed so that you have something to follow up on. Unfortunately, the coverage of topics has to be shallow as in most cases a whole book would be needed to cover them in much detail. I thought the chapter on amateur spectroscopy was good as this is an area more amateurs are getting into. I am not sure about the chapters on black holes and relativity. These are undoubtedly things that amateurs like to talk about but the detail here is shallow and the subject is complex.

I found a number of minor issues in the book. In the galaxy-cluster section, it is Stephan's Quintet not Stephen's Quintet. Wolf-Rayet stars are very massive stars that will explode as supernovae not planetary nebulae. In the galaxy section lenticular galaxies are mentioned but no indication is given as to how they form. My biggest quibble, however, was Inglis's use of Caldwell numbers in the sections where he gives objects to look at. There is enough of a problem in the literature with the tower of Babel of names for objects without adding another name to objects that already have perfectly good ones. No serious amateur would ever use a Caldwell number as it only adds to the confusion. Inglis also uncritically refers to some of the more extreme observations that are claimed in the (in particular US) amateur community. I would also question the reference section as it is mostly Springer books of variable quality and accuracy.

Given the above I would suggest that if someone wanted an overview of many of the topics the book would work but they would need to find another book to cover the interesting parts of many of the topics. I must admit I liked the earlier editions of the book, this one not so much. — Owen Brazell.

Essays on Astronomical History and Heritage: A Tribute to Wayne Orchiston on his 80th Birthday, edited by Steven Gullberg & Peter Robertson (Springer), 2023. Pp. 700, 24 × 16 cm. Price £109·99 (hardbound; ISBN 978 3 031 29492 1).

Wayne Orchiston, who turned 80 in 2023, has a great many friends, and 37 of us have contributed to the chapters of this volume. Though planned several years ago, it was not quite ready for presentation on his birthday celebration, and many months after official publication, many of us are just receiving the complimentary copies that are our second most important reward for contributing. The most important, of course, was the opportunity to say good things about Wayne! Orchiston was the founder of the *Journal of Astronomical History and Heritage* and still keeps a few fingers in that pie. He also founded two IAU Working Groups, and has been a leading presence in history of astronomy for many decades. Editor Robertson, after a career in science publishing, went "back to school" and earned a PhD in history of science with Orchiston. Gullberg (also an Orchiston student) recently (2024 May) announced triumphantly that the IAU Working Group he had been chairing was being abolished. Why? Because it is going to become a Commission (C5) on Cultural Astronomy.

What is on these 700 pages? It has been claimed that a complete model of the Universe would have to be as large (and perhaps as old) as the Universe itself. That is, a proper description of this tribute volume would also be 700 pages long, exceeding the capacity of the brown paper envelopes in which *The Observatory* travels to us. But my late Aunt Esther from Missouri said every meal needed seven sweets and seven sours. So here are seven frivolous items and seven serious ones (though the distinction is probably debatable for most, depending on whether you hear Mozart's last piano concerto as triumphant or mournful): (*i*) a five-metre-tall snowman on the campus of Williams College, posing with (sadly now deceased) author Jay Pasachoff and his wife Naomi, connoisseurs of solar eclipses; (*ii*) a Chuppah illustrating a transit of Venus, quilted by author Sarah Schechner for her 2013 marriage to the mechanic who had helped her dismantle a historic telescope, so that it could be reassembled and used for viewing the 2004 Venus transit; (*iii*) a calendar on which February has 30 days, while Sweden was switching from Julian to Gregorian calendar as described by author Lars Gislen; (*iv*) William Herschel claiming "the great probability, not to say almost absolute certainty of the Moon being inhabited" in the chapter by W. T. (Woody) Sullivan (more often associated with the history of radio astronomy); (*v*) a shepherd herding Inca constellations of the Serpent, the Toad, the Tinamou, the Mother Llama, the Baby Llama and the Fox, followed immediately by the Roasted Guinea Pig for dinner during author Steve Gullberg's trip to Peru; (*vi*) Joseph Weber with his childhood Jew-fro hairstyle only partly tamed by the US Naval Academy, shown to authors Trimble and Robertson; (*vii*) Joe Shklovsky wearing a 10-gallon Texas hat at the Fourth Texas Symposium in Dallas (1968 December) as immortalized by the camera of author Ken Kellerman.

And the Seven sours: (*i*) "the sad reality that this traditional [Australian Aboriginal] knowledge has been severely damned from the effects of invasion, colonialism, and community displacement" as discussed by authors Trevor Seaman and Duane Hamach; (*ii*) "the vexed and tendentious history of lunar nomenclature" that seems to have deprived some astronauts of "their" lunar craters, as pointed out by author William Sheehan (but, back at "frivolous" you should see Mount Marilyn!); (*iii*) the crew abandoning the incandescent USS Lexington in the Battle of the Coral Sea, shortly before John Bolton joined the British aircraft carrier HMS *Unicorn* which just barely fit under Sydney Harbour Bridge according to Trimble & Robertson; (*iv*) the rise and fall of time determination and dissemination as a justifying purpose for astronomical observatories, appearing in the chapters by Steven J. Dick and Roger Kinns; (*v*) what is apparently a genuine 1917 photograph of Sydney Observatory followed by dismissals from the government astronomer William Cooke in both 1925 and 1926 noted by author Nick Lomb; (*vi*) the sad-looking images of the sites of what were once the pioneering field stations of Australian radio astronomy, many photographed by author Harry Wendt; (*vii*) the narrow bounds of what astronomy should mean, as set by Bessel writing to Humboldt to encompass "precise measurement of the positions and orbits of celestial bodies…their appearance and the constitutions of their surfaces is not unworthy of attention, but is not the proper concern of astronomy," as quoted by [the late*] Alan. H. Batten. Luckily he was outvoted by astronomers adopting photography and spectroscopy. And every one of the chapters from which no quote is given above has something in it to cheer, puzzle, or inspire astronomers who are interested in our own history! — Virginia Trimble.

Atlas of the Messier Objects. Highlights of the Deep Sky, 2nd Edition, by Ronald Stoyan (Cambridge University Press), 2024. Pp. 372, 31·5 × 27 cm. Price £59·99 /$79·99 (hardbound; ISBN 978 1 00 936406 5).

The first edition of Ronald Stoyan's *Atlas of the Messier Objects* was an

* See obituary on p. 268

instant success and although now out of print commands a significant price on the second-hand market. Thus, the appearance of a second edition is to be welcomed. First of all it must be said this is not a guide that you would take into the field but a reference book for the home. The second edition has been considerably updated with new images for many of the objects and the astrophysical data updated to include distances from *Gaia* DR3 along with other information that has come to light since the publication of the first edition. Although the book has more pages than the first it is also thinner indicating a different type of paper. It is, however, still very heavy.

The book contains much useful information on Messier himself and the telescopes he used, as well as an English translation of his catalogue. The book also contains some information on the forerunners to his catalogue and the work that contemporaries were doing in cataloguing nebulae. There is also a brief section on the astrophysics of the types of objects found in the Messier catalogue. The main part of the book is ordered by the Messier catalogue number and the section on each object contains information on its history, what is known about it, and observations of it. Note that there are no charts to show where they are, hence it not being a field guide. The book could be combined with Stephen O'Meara's Messier book from the CUP *Deep Sky Field Guides* series to get more information, although much of the information in that book is now out of date. The reproduction of the drawings and images in the *Atlas* is first class which adds to the lustre of the book.

I found very few issues with the book and only a couple of nit-picking errors where the discoverer of M 1 was called Charles Bevis rather than John Bevis in one part, although correctly attributed later, and Admiral Smyth was referred to as Admiral Smith. I also found the text in the reference section was so small that one would need a magnifying glass to read it. These, however, in no way detract from an excellent publication that should be on the bookshelves of any deep-sky observer. I would suggest that this is now the definitive guide to the Messier objects. — Owen Brazell.

From The Library

Three Views of the Cosmos

The Great Ideas Today: Ptolemy, Copernicus, and Kepler, by Owen Gingerich, in *Encyclopedia Britannica*, 1993. Pp. 137–180.

Cosmology, by E. Finlay-Freudlich, in *International Encyclopedia of Unified Science* (University of Chicago Press), 1951. Vol. 1, No 8, 1951. Pp. 1–59.

The Recent Renaissance of Observational Cosmology, by D.W. Sciama, in *Atti della Reunion di Studio su Problemi di astrofisica* (Torino), 1969. Pp. 21-47.

These three came to me as part of the RAS Library deaccession project, with some of their pages still uncut. A nail file completed that task, revealing three very different opinions on what has been known about the Universe at various times and who is likely, or should be likely, to care about it all anyway

Each of the three has something you may never have thought of and could potentially enjoy. Gingerich uses the methods and data given in Ptolemy's *Almagest* to calculate the longitude of Mars on a particular date some 361 years after the death of Alexander the Great. And yes, he gets Ptolemy's answer, given in *Almagest* X, 8, but then has to ask the question "Did Ptolemy cheat?" The catch is that the observations Ptolemy used to select values of the five necessary quantities in the method (things like the ratio of the epicycle to the deferent) disagree with what the actual positions were on the advertised dates by as much as 1·4 degrees. Gingerich ends that section by telling us that astronomers have been aware of such problems with Ptolemy's data for a couple of centuries, and that, what is more, it is not the task of the historian of science to cast moral judgements on pioneers of the past.

For Finlay-Freundlich (who added the birth surname of his mother after moving out of Germany), the most important question is whether the Universe is closed and finite. He was of the opinion that "the relativistic treatment of the cosmological problem promises to give in the future a definite answer to the one question which appears to be the highest prize of all efforts, namely the question: Is the universe closed and finite?" He was worried that with H_0 somewhere around 500 km/sec/Mpc, "closed" would be rather small. And he carries lambda as a lower-case Greek letter with him for the rest of the chapter to expand the range of possibilities. Can we say that another 53 years of observations have justified his optimism? Maybe.

But as has been the case with others of my RAS Library acquisitions, perhaps the most interesting item in this brief volume is a yellowing invoice made out by B. H. Blackwell, Ltd., University Booksellers of Oxford to G. J. Whitrow, Esq. of Clapham, London SW4. That is to say that Whitrow's interests extended beyond philosophy of time to the observed Universe at least to the extent of 9 shillings, 9 pence (including 3 pence postage). This in turn gives your reviewer an opportunity to thank reader Steven Phillipps, who has found Rev. Richard Lacey Webb, a mystery guest in an earlier 'From the Library' review. He was the son of a bank clerk from Brecon, Wales, born in Bristol on 1909 May 29. He died as recently as 2004 November 30 in Norwich, having been rector of Wacton in Norfolk and later Rural Dean of Rockford and Norfolk. He was sufficiently interested in the cosmos to supplement one of his purchases with information from a newspaper article.

This brings us to Dennis Sciama, who by 1969 had given up confidence in Steady State cosmology in favour of the very isotropic microwave background radiation (implying a singularity in the past). He even presents Cavendish data on counts of radio sources ($\log N - \log S$), showing a slope steeper than $n = -1·5$ at the bright end, implying evolution of the source populations. He accepts that He/H would be only about 0·01 by number, not 0·1, if stars were the only source, writes of the αβγ proposal, and cites Wagoner, Fowler, and Hoyle for their 1967 calculation of the production of H, He, D, He-3, and Li in a hot Big Bang. The observation Sciama was looking forward to was the motion of our Earth relative to that microwave background, as a "linkup with Mach's Principle, which asserts that local inertial frames are unaccelerated relative to the Universe as a whole. We are on the verge of great clarification." Well, Mach's Principle, fondness for a finite closed Universe, and repeating Ptolemy's calculations do seem to have gone more or less out of fashion. But we still live in both wonderful space and 'Interesting Times', with the possibility of continuing to learn from our predecessors. — VIRGINIA TRIMBLE.

OBITUARY

Alan Henry Batten (1933–2024)

Alan Batten was born in Whitstable, Kent, on 1933 January 21. He was educated at Wolverhampton Grammar School and the Universities of St. Andrews (BSc 1955, DSc 1974) and Manchester (PhD 1958) and went to Canada in 1959 as a post-doctoral fellow at the Dominion Astrophysical Observatory in Victoria, B.C., joining the permanent staff there in 1961. He remained on the staff until retirement in 1991 and continued as a guest worker until 2011, and was still publishing papers in 2024. It was at the DAO that he became established as an authority on binary stars, writing *Binary and Multiple Systems of Stars* (Pergamon, 1973) and one of the team compiling the vital *Catalogues of the Orbital Elements of Spectroscopic Binary Systems*. He served as President of the Canadian Astronomical Society in 1972–74 and of the Royal Astronomical Society of Canada from 1976–78. From 1980–1988 he was the Editor of the latter Society's journal. He also served as a Vice-President of the Astronomical Society of the Pacific (1964–66) and of the International Astronomical Union (1985–91). In 1977 he was elected to Fellowship in the Royal Society of Canada and served on the Council of that Society, and was also a long-time Fellow of the RAS. From 1992 to 2002 he represented the International Astronomical Union by visiting astronomers in developing countries. He also held visiting appointments at the Vatican Observatory in Castelgandolfo, Italy (1970), the Instituto de Astronomia y Fisica del Espacio in Buenos Aires (1972), and was an Erskine Visiting Fellow at the University of Canterbury, Christchurch, New Zealand (1995). Locally, he has been a sessional lecturer in both astronomy and history in the University of Victoria. A warm-hearted and generous colleague who will be greatly missed, this 'English gentleman' passed away after a short illness on 2024 July 30.

Here and There

FOR OBSERVATIONS OF PISCES, PRESUMABLY

The private observatory at Dun Echt, 12 miles east of Aberdeen. — *The Observatory*, **144**, 55, 2024.

A WOBBLY NUMBER

Follow-up observations of HD 114762 with the Lick telescope determined its mass to be around 0.8 solar masses and the amplitude of its wobble to be just over 600 km/s. — *The Antiquarian Astronomer*, 2023 June (17), p.58.

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Advice to Contributors

The Observatory magazine is an independent 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. Authors of papers, *Notes*, correspondence, and meeting summaries may purchase reprints at cost price.

LAYOUT: The general format evident in this issue should be followed. ALL MATERIAL MUST BE DOUBLE SPACED. Unnecessary vertical spreading of mathematical material should be avoided (*e.g.*, by use of the solidus or negative exponents). Tables should be numbered with roman numerals, and be provided with brief titles. Diagrams should be numbered with arabic numerals, and have captions which should, if possible, be intelligible without reference to the main body of the text. Lettering should be large enough to remain clear after reduction to the page width of the *Magazine*; figures in 'landscape' format are preferable to 'portrait' where possible.

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

and for books:

(No.) Authors, [in Editors (eds.),] Title (Publisher, Place), year[, page].

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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CONTENTS

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