# THE OBSERVATORY

## A REVIEW OF ASTRONOMY

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# THE OBSERVATORY

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## MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 April 12 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 Q and A facility. The questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden. The AGM will be held on May 10 and will be for Fellows only. Our auditors this year are Professor Yvonne Elsworth and Professor Lorraine Hanlon.

The first talk today is 'Continental break-up along the East African Rift' and it's going to be given by Dr. Rita Kounoudis. She is a Postdoctoral Research Associate at the University of Oxford. Her research centres on understanding the evolution of plate tectonics using a diverse range of seismic techniques to map the structure and dynamics of the Earth's crust and mantle. She completed her PhD at Imperial College London in 2023 which focussed on understanding the process involved in continental break-up by imaging the subsurface along part of the volcanically and seismically active East African Rift. I look forward to the talk.

*Dr. Rita Kounoudis.* Plate-tectonic theory describes the evolution of Earth's rigid outer shell over geological time. However, precisely how continental plates break apart, or 'rift', to form new oceans is debated because there are few places on Earth where this process is currently active. Rifted continental margins, such as those along the coasts of Africa and South America, hold valuable information on the processes that once acted to rift them apart. However, these processes ceased long ago, and their remnants have been buried under thick ocean sediments and lava flows. In this talk, I will take you on a journey to an active continental rift that has captured the attention of numerous researchers — the East African Rift. Here, seismically and volcanically active narrow rift valleys cut through the elevated Ethiopian and Kenyan Plateaus, the highest topographical points on the African continent. Rifting has been on-going in East Africa for the last 20 million years, showcasing various stages of the rifting process, from incipient rifting in the south near Tanzania, to full-blown seafloor spreading towards the Red Sea in the north, where a new ocean floor is currently being born.

While much of the East African Rift has been well-studied through the years, an intriguing segment of the rift — the Turkana Depression — has remained largely unexplored. Located between East Africa's two uplifted plateaus, the Turkana Depression stands out for its subdued topography and unusual breadth, contrasting the narrower rift segments elsewhere. It also has a unique history, having hosted a previous failed rifting episode 50–80 million years before the formation of the East African Rift.

We first set out to investigate the cause for the Turkana Depression's low elevation compared to the adjacent plateaus. Early studies have speculated that the plateaus are each underpinned by buoyant, hot, mantle 'plumes' rising from deep within the mantle. Plume material might be absent below the Depression resulting in its lower topography. Alternatively, some studies have asserted the presence of a single unified African 'superplume' residing beneath the whole of East Africa. In this case, the Turkana Depression's lower elevations would instead be the result of a thinned plate, developed during its previous failed rifting episode. To distinguish between competing hypotheses, we require detailed images of the subsurface, where hot mantle plumes can be detected as slow-wavespeed material.

Mantle plumes below Ethiopia not only uplifted the plate, but they also gave rise to widespread magmatism, creating the world's youngest flood-basalt province on the surface. This significant magmatism altered plate structure to such an extent that it is no longer distinguishable above the seismically slow asthenosphere on which it sits. Whether this is the case below the Turkana Depression is uncertain and is another key to unravelling the region's tectonic evolution.

To address these questions, we require detailed imaging of the plate and deeper mantle facilitated by seismograph networks. These networks detect distant earthquakes, allowing us to analyse seismic waves that traverse the deep Earth geology *en-route* to the station. Despite nearly four decades of seismological deployments along the East African Rift, the Turkana Depression remained a critical gap, hindering a comprehensive understanding of the region. However, this changed in 2019 with a new US–UK–Ethiopian–Kenyan collaboration that installed the first temporary seismograph network in the Turkana Depression. We placed 34 seismometers in 1-m-deep holes, spread across a vast 200 × 300-km area of arid Ethiopian and Kenyan soil, for a two-year period.

Using a technique called seismic tomography, we first evaluate the cause of Turkana's low-lying nature. Our models reveal slow wavespeeds below the Turkana Depression and surrounding parts of East Africa, suggesting that the hot, buoyant material that is currently propping up the Ethiopian Plateau also exists below the Turkana Depression. The entire region is therefore underlain by a single unified 'African Superplume'. At the shallowest depths we find that the Turkana Depression does indeed have a significantly thinned crust (one that is at least 10 – 15 km thinner than its surroundings) the likely culprit for its subdued topography.

Next, we investigated whether voluminous plume-related magmatism has altered plate structure in the Turkana Depression. Surprisingly, the Depression retains a clearly discernible fast-wavespeed plate atop a slow-wavespeed asthenosphere, unlike the Ethiopian Plateau, where magmatism obscured this distinction. Despite their proximity and similar geodynamic 'superplume' setting, these two regions appear to have experienced markedly distinct magmatic histories, leading to profoundly contrasting plate structures.

To understand why these two regions are so different requires peering into greater depths in the mantle and appreciating the African plate's northward motion through geological time.

At depths of 410 km and 660 km below the Earth's surface lie two key mineral phase transitions: olivine-to-ringwoodite and ringwoodite-to-waldslyite, respectively. Together, these transitional depths define the boundaries of the mantle-transition zone. However, hot mantle temperatures, such as those from a mantle plume, alter these depths, suppressing the 410 km and elevating the 660 km, thereby reducing mantle-transition-zone thickness. Seismically mapping this thickness across East Africa reveals that the mantle transition zone is thinnest below the Turkana Depression, suggesting this may be where the African Superplume first reached the upper mantle. However, the African Plate has been moving northwards over time, and the Turkana Depression has only recently assumed its position above the thinnest transition zone. When Ethiopia's flood-basalt province formed 30 million years ago, the African Plate was located 500 km further south, lingering over the hottest part of the mantle. In contrast, the Turkana Depression spent much of its history above cooler regions, preventing the development of extensive magmatic systems.

*The President.* Can I invite questions? Did I gather that a new continent is going to split off from this? How long will it take?

*Dr. Kounoudis.* Tens, if not hundreds, of millions of years, but that is assuming there are no changes to the plate system.

*The President.* It's not definite that it will happen, but most likely?

*Dr. Kounoudis.* Yes. At the very north of Ethiopia, the Afar Depression is actually experiencing the very first signs of ocean development. The very southern bit of East Africa is just starting to rift in the last five to ten million years. Afar is where people go to understand the very last stages of breakup.

*The President.* This is quite a difficult area politically to work in, isn't it?

*Dr. Kounoudis.* In some cases, yes. We have not had to be accompanied by people with rifles but there have been conflicts in this part of the country. Where we were on the border between Ethiopia and Kenya, at a town called Moyale, the buildings showed lots of bullet holes only six months before we got there.

*The President.* Astronomy is much less dangerous!

*Professor Mark Lester.* Is it possible that those two boundaries get so close together such that the material in the bottom region gets pushed all the way through?

*Dr. Kounoudis.* The Turkana Depression is not completely melt-poor. There has definitely been volcanism on the surface and there are volcanoes on the top today, but it is nowhere near as significant as further north. I don't think that the boundary is necessarily extremely sharp but it does reach a point where it starts to erupt less on the surface. Maybe other parts of the rift may retain more melt in their deeper structure as opposed to it finally making its way to the surface. That is on-going research and people are trying to look at that transition.

*Professor Lester.* At the University of Leicester we have to fill in a risk-assessment form for international travel. I wondered how you managed to get it through your institution?

*Dr. Kounoudis.* Luckily for me, I had only just started my PhD when the proposal went through. My supervisor had to deal with that. At the time it was fine, there was not much unrest.

*Mr. Horace Regnart.* Are you able to do something to bring individuals and communities into your research for their benefit and bring them into the scientific community? Secondly, your research is very worthwhile in itself but is it telling us anything useful about the availability of specific elements which may be useful and necessary for generating and using renewable energy?

*Dr. Kounoudis*. In answer to your first question, there is a lot of work trying to collaborate with communities out there. We have done lots of outreach and we have tried to help the community in different ways. As you can imagine, the very remotest parts of Ethiopia don't have access to many educational resources such as books and pens so we contibuted as much as we could to that. There is a lot of collaboration with the community and we also bring researchers over here and help them work towards a PhD, for example. That is part of the proposal to work in East Africa.

*Mr. Regnart*. The use of geothermal energy and hot water might be relevant to that.

*Dr. Kounoudis*. Geothermal energy in particular, is very big in East Africa. It is a very hot part of the Earth and a lot of heat makes its way to the surface, especially where the plates are rifting. In Kenya and Ethiopia there are lots of projects on at the moment, trying to understand geothermal energy, in particular, in specific volcanoes along the Rift, and we are collaborating with them to see if we can tap into that energy. In places like this where you get magmatism, you also find critical metals, such as copper, which eventually precipitate.

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

The next talk is on-line. It will be given by Dr. Christopher Berry the awardee of the Fowler 'A' Award. His research focusses on the origins and properties of black holes and neutron stars; he also has a keen interest in public engagement and informal education. He studied at the University of Cambridge, obtaining his PhD from the Institute of Astronomy. He was a Postdoctoral Research Fellow at the University of Birmingham, where he worked on analyzing the first observations of gravitational waves. He moved to the Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) at Northwestern University where he was the CIERA Board of Visitors Research Professor in 2018, and then moved back to the UK to join the University of Glasgow in 2020, where he is currently a Senior Lecturer in the Institute for Gravitational Research. He has won the International Union of Pure and Applied Physics Young Scientist Prize in General Relativity & Gravitation and the Royal Astronomical Society's Fowler Award for Early Achievement in Astronomy.

*Dr. Christopher Berry*. Each time we observe the Universe in a new way we make discoveries — new aspects of familiar objects are revealed, and new systems are observed for the first time. Throughout the 20th Century, astronomy expanded by using more of the electromagnetic spectrum. Discoveries included radio pulsars, X-ray binaries, and gamma-ray bursts, each of which gave a new insight into the end-points of stellar evolution. On 2015 September 14, astronomy expanded to include the gravitational-wave spectrum, with the measurement of GW150914 by the twin *LIGO* observatories.

GW150914 came from a binary-black-hole coalescence. The physics of its source is encoded within the measured signal. Matching waveform templates to the data we may infer source parameters such as the black-hole masses. GW150914's source consisted of two black holes, each around 30 $M_{\odot}$, the first time such a system had been observed.

Gravitational-wave astronomy has progressed rapidly since 2015. The increasing sensitivity of the *LIGO–Virgo–KAGRA* (*LVK*) detector network has enabled a rapid growth in observations. By the end of their third observing run, the *LVK* Collaboration had 90 probable gravitational-wave candidates in their third *Gravitational-Wave Transient Catalog* (*GWTC-3*). The sources include binary black holes, binary neutron stars, and neutron-star–black-hole binaries. We have seen a diversity of sources, with black holes ranging in mass from below 5 $M_\odot$ to around 100 $M_\odot$, with the 30 $M_\odot$ of GW150914 being common.

These masses are different from the masses of black holes previously discovered in X-ray binaries. Part of the reason is observational selection effects. Higher-mass sources produce larger-amplitude gravitational waves, and so can be seen to greater distance. We can calculate the sensitivity of our gravitational-wave detectors, and correct for their selection effects. Doing so reveals a distribution that peaks at lower masses (around 10 $M_\odot$, similar to X-ray-binary black holes), a secondary bump around 35 $M_\odot$, and a tail to higher masses. This mass distribution extends to higher masses than other observations.

The key to understanding the difference between X-ray and gravitational-wave masses is considering evolutionary selection effects in addition to observational selection effects. Only a small fraction of X-ray binaries would go on to become merging binary black holes (preferentially those at higher masses). Furthermore, gravitational-wave sources are observed at higher redshift (typically around 0·1); allowing for the delay time between formation and merger, the progenitor stars were born at even higher redshift. This means that gravitational-wave observations probe stellar evolution at much lower metallicity than X-ray observations. As stellar winds increase with metallicity, it is expected that black holes from lower-metallicity stars are bigger. Therefore, the difference between the two observed populations does agree with our current understanding of binary evolution, and highlights how, by combining multiple observations, we can gain a more in-depth understanding of astrophysical sources.

Does this mean that we understand everything about black-hole masses? Not yet, as demonstrated by the most recently announced gravitational-wave observation GW230529_181500 (GW230529 for short). GW230529 is the first announced discovery from the currently on-going fourth *LVK* observing run. Its source is probably a neutron-star–black-hole binary. The black hole sits within the 3–5 $M_\odot$ range where there is a dearth of X-ray observations. To explain these observations, it had been proposed that the way supernovae explode produced a mass gap. The detection of GW230529 adds to the growing evidence that the proposed mass gap is not empty, and black holes can form in this range. This leaves the question as to why no X-ray binaries have been observed to have masses in this range (the absence cannot be fully explained by selection effects).

We do not measure just masses, but also spins and merger redshifts. The properties of these systems encode the fingerprints of their formation — details of binary evolution that are currently uncertain. Given a set of input physical assumptions, we can make population-synthesis predictions for these properties. By considering a range of input physics, we can see how each fits the observations, and map out the most probable values for these properties. This requires considering multiple formation channels, as omitting a relevant channel will lead to biassed inferences of the input physics. As the catalogue of gravitational-wave observations continues to grow, we will be able to reconstruct more precisely the underlying astrophysical population, and more precisely measure the uncertain input physics of coalescing compact-object binary formation.

The uncertainty on population inferences typically scales inversely with the square root of the number of observations. With the currently planned series of observing runs, we will soon go from of order $10^2$ to $10^3$ gravitational-wave observations. Hence, binary evolution will soon become a high-precision science.

Key parameters such as stellar-mass-loss rates could be constrained to a few percent. Adding in complementary information from other observations, such as the population of X-ray binaries, will further tighten constraints on possible binary-evolution physics. The coming decade will reveal many mysteries of black-hole formation.

*The President*. I'll invite questions from the audience.

*Dr. Berry*. I have been asked a question on-line. The *LISA* mission has recently been adopted. How awesome is *LISA* going to be? *LISA* was the subject of my PhD so I am very attached to it. *LISA* will look at lower-frequency gravitational waves, around millihertz frequencies. It will primarily see massive black holes in the range $10^5$ to $10^7$ solar masses, but also those stellar-mass black holes in wide binary systems. It will be fantastic — we'll get a complete census of the Galaxy for stellar-mass binaries, and see massive black-hole binaries back to the early Universe!

*The President*. It's a shame that we have to wait so long.

*Mr. Christopher Taylor*. If the 50–60 solar-mass black holes are single-star stellar remnants, what sort of original main-sequence masses are we talking about, and are there stars that massive in the present day Universe, or are these things remnants of the earlier stages of star formation?

*Dr. Berry*. Stars should not leave behind black holes with masses between 40–60 and 120–140 solar masses because of pair-instability supernovae. Therefore, from single-star evolution they do not make much sense. However, we are seeing systems in this mass range! We can potentially have stellar mergers or mass transfer in binaries. Then you can get a larger hydrogen envelope for a core below the pair-instability limit.

Another possibility is that black holes seen in this mass range could be second-generation black holes. We know that black holes merge and form bigger black holes, so in a globular cluster or nuclear star cluster they may go on to merge again. This is something I have investigated with my student Chase Kimball. We have performed a population inference and found that there are some promising candidates for hierarchical mergers among our observations.

I have also been asked: can you comment on the no-hair theorem? This is something that we are looking to test with our observations. We perform a variety of consistency tests that check if we do have black holes described by relativity. One we would really like to do is measure the spectrum of ring-down frequencies. This is often called black-hole spectroscopy. If we can measure the various frequencies, we can measure the mass and spin of the final black hole and check if these are consistent. There have been some claims that this is possible with GW150914, but there are many subtleties in the analysis, particularly around the time of the signal. We want a loud signal, where we can measure the ring-down, so a binary that is relatively high mass. As our detectors continue to improve, the prospects of getting this improve.

*Professor Phil Charles*. It's fantastic to see the final link between the observed emerging black holes with your work down towards the high-mass X-ray binaries and the low-mass X-ray binaries that we know about. In terms of high-mass black holes, the only one I can think of that can fit on these as a current system is Cyg X-1, but it's a very short-lived system with another very high-mass star. From your calculations and simulations here do you have any idea of how many high-mass black holes like in GW150914 that we can expect to find in our own Galaxy? That has been a source of great debate with the only black-hole systems that we know about in detail being the low-mass ones — we only have about 20 accurately constrained. How many are there?

*Dr. Berry*. On Cyg X-1 there have been some recent studies done by the COMPAS team. They found a very small probability that Cyg X-1 would go on to form a merging binary black-hole system. In terms of our own Milky Way, Camille Liotine and I have not looked yet at that question specifically. The good news is that we would definitely expect to see any with *LISA*.

[Editors' Note: Dr. Berry informs us that shortly following this talk, detection of *Gaia* BH3 was announced, showing that there are 30-solar-mass black holes in our Galaxy.]

*The President*. I hope you get to see it, Phil! Thank you very much indeed [applause].

Moving on, the next talk is by Dr. Ziri Younsi. Ziri's research focusses on testing gravity and fundamental physics, with his work helping to enable interpretation of the first images of supermassive black holes from the *Event Horizon Telescope* (*EHT*). He is also an active science communicator. He has studied at Cambridge and UCL, later working as a Humboldt Fellow at the University of Frankfurt, before moving back to the UK to join Mullard Space Science Laboratory as a Leverhulme Fellow and subsequently as a Stephen Hawking Fellow. He is a member of the *EHT*'s Science Council and co-leads the consortium's Gravitational Physics Working Group. Since 2014, he has worked within the *EHT*, developing and performing supercomputer simulations of black holes and horizon-scale black-hole imaging. He is a co-recipient of the National Science Foundation's Diamond Achievement Award, the 2020 Breakthrough Prize for Fundamental Physics, and the Royal Astronomical Society's 2021 Group Achievement Award.

*Dr. Ziri Younsi*. The *Event Horizon Telescope* (*EHT*) has produced images of supermassive black holes in both the galaxy Messier 87 (M87), and in our Milky Way, Sagittarius A* (Sgr A*). These images, which resolve material in the vicinity of the event horizon, showed the total intensity of the radio emission. Just a fortnight ago, in late March of this year, the *EHT* published the first-ever polarized images of Sgr A*, providing new insights into the magnetic-field properties of black-hole systems.

The first polarized images of the M87 black hole were published in 2021, revealing the magnetic structure of the accretion disc and its connection to the galaxy's prodigious relativistic jets. These new 230-GHz measurements of the polarized synchrotron radiation from the Galactic Centre black hole were more challenging to acquire, in part due to Sgr A* being more than one thousand times smaller in mass than M87, meaning structural variability occurs on time-scales of minutes rather than days or weeks. Through careful calibration of the data, together with consideration of interstellar refractive and diffractive scattering effects, these data were finally ready to be published, almost seven years after they were first recorded.

These polarized images of M87 and Sgr A* present the first polarimetric observations of material circulating around the event horizons of black holes. The 'swirly' pattern we observe indicates the orientation of the electric-vector position angle (EVPA) of the light. Since magnetic fields are responsible for producing the polarization we see in these data, the magnetic field is everywhere perpendicular to the streamlines seen in these images, indicating that the magnetic field is orientated towards and threads the event horizon (the dark central region in the image).

It is remarkable that, in spite of these two black holes differing in size by a factor of about 1400, they present morphologically similar polarization patterns.

One of the most exciting aspects of these new measurements is their ability to serve as a tool for discriminating between physical models of black-hole accretion. Prior measurements, which provide total intensity alone, are not able to discriminate clearly between models with different physical models, *e.g.*, for the plasma electron distribution function or magnetic-field topology. With these new data we are already able to exclude many physical models of Sgr A*, providing much more stringent constraints on the strength and orientation of the magnetic field around the event horizon, as well as the temperature of the radiating electrons in the accretion plasma. These measurements reveal a spiral polarization structure which is robust to all image-reconstruction methodologies, and strongly favour an accretion disc which is magnetically arrested. We also find that internal Faraday rotation alone cannot replicate the observed rotation measure: models and data favour the presence of an external Faraday screen which de-rotates the EVPA.

These are the first measurements of polarization on event-horizon scales, and we are already working on measurements at different epochs, at higher frequencies (where opacity is higher and scattering effects are weaker), and are working towards dynamical images (*i.e.*, movies) of the accretion onto the black hole. Upcoming observations of the polarization properties of radiation produced near black-hole event horizons will reveal how these mysterious objects interact with their surroundings, how they power and sustain some of the most energetic outflows in the Universe, and will help to clarify the foundational role magnetic fields play in extracting energy from their enormous gravitational potentials.

*The President*. Thank you very much. Questions?

*Professor Charles*. Those are absolutely fantastic images and the structure that you are getting out of them is glorious. When I first saw that image a couple of weeks ago, I was starting to get worried. I'm not a radio astronomer but in undergraduate lectures one of the things that we state is necessary for VLBI to work is that the object should not vary when the Earth is rotating. In my naïve fashion, you have already admitted that isn't true and I know that from the X-ray variability you have seen from Sgr A* and lots of other wavelengths. How do you get around that? You've admitted that some of the structure requires a large pinch of salt and when I saw that fabulous fine structure there, is that solid or just a best-fitting model with all kinds of assumptions about variability or lack of it?

*Dr. Younsi*. With Earth-rotation aperture synthesis the primary assumption is that the source is not changing on the time-scales on which we are making the measurements. There is some fudging but essentially you have calibrator sources and you know each of these separate telescopes in the array based on their gains, and so on, what the time variability is and you know from independent measurements what the time variability is of a given source at each different telescope. You have a noise-injection model in which you inject the temporal variability of each telescope for that given day, for the various atmospheric effects in such a way that it makes the source quasi-stationary. It turns out that this has been calibrated against other sources such as quasars and it seems to work quite well. This is also something that is tested with five or six different image-reconstruction algorithms and the one that we have seen today seems to be pretty robust as well. The only way we are going to get around this is to have a better understanding of how that material along the line of sight is diffracting and scattering the light, because you have all this material moving across the line of sight and changing. There is a periodic structure to this but there is also a stochastic element as well. Periodic structures are something that are well-modelled and that we can mitigate for. The stochastic component is more difficult and it is that component that we are not able to remove that accounts for the first blobs being effectively artefacts of the reconstruction. It is no coincidence that those blobs are also aligned with the major axis of the beam. It is not an easy thing to do and requires a lot of calibration and self-consistency checks.

*The President.* Are you satisfied with that?

*Professor Charles.* I'm going to be using lots of salt!

*Mr. Taylor.* Could this be the origin of the global galactic magnetic field?

*Dr. Younsi.* I have no way to comment on that using the data we have right now. If we think about it all as a dynamo and this thing is rotating, you can have a battery-type mechanism where you can induce the rotation that generates and sustains a magnetic field — that's possible. I think that one would first have to look at wider-field studies. *MeerKat*, for instance, a couple of years back showed some very beautiful images of magnetic fields in the plane of the Milky Way moving out into the nuclear region and the disc, and you can see lovely vertical magnetic fields as well as turbulent eddy structures; understanding the connection of that with the central region is one of the million-dollar questions. Theory would tell us that they are connected; large-scale simulations that we perform up to the Bondi radius or larger seem to show that they are connected. The question is always what is happening in the region in the transition between the smaller scales and the larger scales. That is really tricky to model, so I would say that theory tells that they are connected, but being able to understand the detail of what is happening on different scales as you move from plasma kinetic scales to MHD scales to much larger scales is something that is very poorly understood right now.

*Mr. Regnart.* Is there any known explanation for the huge mass discrepancy between the Milky Way's black hole and that in M87? Is this to do with differential methods of growth, accretion that is circular rather than infalling, or repulsion and regrowth from seed?

*Dr. Younsi.* M87 is a giant elliptical which is very far away — 16 or 17 Mpc. We think it's older and the question I suppose is "are black holes primordial and born with 1 billion solar masses or is there some mechanism or channel through which, let's say, a stellar-mass black hole can reach the size of Sgr A* and potentially grow even larger?" There is no single channel which can account for everything that we see. This is why it is so important to look at proto-galaxies with the *JWST* at very high $z$ and see whether the cores of those proto-galaxies in the early Universe really are supermassive black holes at millions or billions of solar masses. This would indicate that they have a primordial origin either from the Big Bang or from some enormous collapse of gas and dust when the galaxies were first forming, although even that is tricky to explain. It could be galactic mergers — it is very hard to say. This is why galactic archaeology and understanding the origin of our Milky Way with *Gaia* is allowing us to reverse integrate and understand what is happening in the past, and that is also why I showed these Fermi bubbles to say that there was some violent activity in the past; the truth is that we don't know for sure. I would love to know but I think the whole community is very aware of this and is striving to understand it.

*The President.* I think that it's true to say that there is a correlation between galaxy mass and black-hole mass. That implies something, but what?

*Dr. Younsi.* Yes, indeed.

*The President.* Can we thank you again for a very interesting talk. [Applause.] It's fascinating to get close to the black holes in a safe way. There is a drinks reception in Burlington House to which you are all invited. Next month is the AGM for Fellows only, followed by the Presidential Lecture which will be open to all on-line and that will be on Friday, May 10th.

# REDISCUSSION OF ECLIPSING BINARIES. PAPER 21. THE TOTALLY-ECLIPSING B-TYPE SYSTEM IQ PERSEI

*By John Southworth*

*Astrophysics Group, Keele University*

IQ Per is a totally-eclipsing binary system containing a B8 V star and an A6 V star in an orbit of period 1·744 d with eccentricity and apsidal motion. We use new light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*) and published spectroscopy from Lacy & Frueh[1] to measure the physical properties of the component stars, finding masses of $3{\cdot}516 \pm 0{\cdot}050$ $M_\odot$ and $1{\cdot}738 \pm 0{\cdot}023$ $M_\odot$, and radii of $2{\cdot}476 \pm 0{\cdot}015$ $R_\odot$ and $1{\cdot}503 \pm 0{\cdot}016$ $R_\odot$. Our fit to the light-curve is imperfect, with a small sinusoidal trend in the residuals *versus* orbital phase and a slight mismatch in the depth of secondary eclipse, but the total eclipses mean the system is still well-characterized. The distance to the system from its masses, temperatures, apparent magnitudes, and bolometric corrections is in agreement with the parallax distance from *Gaia* DR3. Theoretical models cannot adequately match the measured properties of the system, and new spectroscopy to confirm the temperatures and determine the chemical compositions of the stars would be useful. A Fourier analysis of the residuals of the best fit to the light-curve shows many peaks at multiples of the orbital frequency, and one significant peak at 1·33 $d^{-1}$ which is not. This pulsation and the properties of the primary component are consistent with it being a slowly-pulsating B star.

## *Introduction*

This work continues our series of papers[2] presenting analyses of detached eclipsing binaries (dEBs) with a significant observational history and available radial-velocity (RV) measurements, based on new high-quality light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*[3]). Our aim is to increase the number of stars, and the precision of their measured properties, in the *Detached Eclipsing Binary Catalogue*[4] (*DEBCat*★), which lists all known dEBs with mass and radius measurements to 2% precision and accuracy. These results represent

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

TABLE I

*Basic information on IQ Persei. The BV magnitudes are each the mean of 93 individual measurements*[20].

| *Property* | *Value* | *Reference* |
|---|---|---|
| Right ascension (J2000) | $03^h59^m44^s{\cdot}68$ | 21 |
| Declination (J2000) | $+48°09'04''{\cdot}4$ | 21 |
| Henry Draper designation | HD 24909 | 22 |
| *Gaia* DR3 designation | 246797724301643904 | 23 |
| *Gaia* DR3 parallax | $3{\cdot}4478 \pm 0{\cdot}0313$ mas | 23 |
| *TESS* Input Catalog designation | TIC 265767012 | 24 |
| *B* magnitude | $7{\cdot}778 \pm 0{\cdot}013$ | 20 |
| *V* magnitude | $7{\cdot}733 \pm 0{\cdot}012$ | 20 |
| *J* magnitude | $7{\cdot}561 \pm 0{\cdot}030$ | 25 |
| *H* magnitude | $7{\cdot}591 \pm 0{\cdot}031$ | 25 |
| $K_s$ magnitude | $7{\cdot}544 \pm 0{\cdot}018$ | 25 |
| Spectral type | B8 V + A6 V | 1 |

an important resource of empirical measurements of stellar properties against which theoretical models of stellar evolution can be benchmarked[5,6], and the availability of large archives of light-curves from space missions enables such work for a large number of objects[7].

Here we study the system IQ Persei (Table I), which contains a late-B star (hereafter star A) and an early-A star (star B) in an orbit of period 1·744 d. It is one of many whose variability was discovered by Hoffmeister[8] using photographic plates obtained at Sonneberg. It is a visual double with a companion at 39·3 arcsec which is fainter by 1·58 mag in the *Gaia G* band. Meisel[9] assigned spectral types of B8 Vp: to IQ Per and A0 Vnp: to the visual companion. Burke[10] narrowed down the orbital period to be either 6·974 d or its submultiples 3·487 d or 1·743 d. Hall, Gertken & Burke[11] presented *UBV* light-curves which confirmed the shortest of the possible orbital periods, the eccentricity, and that the system exhibits total eclipses. They also derived its photometric properties using the Russell–Merrill[12] method. Bischof[13] presented new times of minimum and Young[14] a first spectroscopic orbit for both stars.

Lacy & Frueh[1] (hereafter LF85) published a detailed analysis of IQ Per, and their measurements of the physical properties have been used in many subsequent papers. They obtained a set of 20 spectra using a Reticon detector at the 2·7-m telescope at McDonald Observatory, measuring from these RVs of both stars plus projected rotational velocities of $V_A \sin i = 68 \pm 2$ km s$^{-1}$ and $V_B \sin i = 44 \pm 2$ km s$^{-1}$, where 'A' denotes the more massive primary (star A) and 'B' the less massive secondary (star B). LF85 also obtained light-curves in the *V* and *R* bands; these data cover all of the secondary and almost all of the primary eclipse. They deduced photometric spectral types of B8 for star A and A6 for star B.

IQ Per also shows apsidal motion dominated by tidal effects, and this has been measured by a multitude of researchers using essentially the same gradually-growing compilation of times of mid-eclipse. Apsidal motion was predicted by Hall *et al.*[11], and confirmed by LF85 who found an apsidal period of $U = 140 \pm 30$ yr. Drozdz *et al.*[15] improved this measurement to $119 \pm 9$ yr. Değirmenci[16] obtained complete *BV* light-curves and used them to determine the photometric properties of the system and $U = 122 \pm 7$ yr. Lee *et al.*[17] obtained four new timings and $U = 122{\cdot}2 \pm 0{\cdot}3$ yr, where the error bar is anomalously small. Wolf *et al.*[18] presented nine new times of minimum and used these and published times to determine $U = 124{\cdot}2 \pm 6{\cdot}5$ yr. The most recent assessment of the apsidal motion period of IQ Per is by Claret *et al.*[19] who included the *TESS* data to obtain $U = 116{\cdot}2 \pm 3{\cdot}9$ yr.

### *Photometric observations*

IQ Per has been observed in two sectors by *TESS*: sector 19 at cadences of 120 s and 1800 s; and sector 59 at cadences of 120 s and 200 s. Further observations are scheduled in sector 86 (2024 December). We downloaded both sets of 120-s-cadence data from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[26]. We adopted the simple aperture photometry (SAP) data from the SPOC data reduction[27] with a quality flag of "hard", normalized them using LIGHTKURVE, and converted them to differential magnitude.

The two light-curves are shown in Fig. 1. That from sector 59 has a greater coverage and lower scatter, but the basic shape of the light variation is consistent between sectors. When the two light-curves are overlaid on the same plot the eclipses do not quite line up. This is due to apsidal motion changing the relative times of eclipses in the 1069 d between the sectors. For the record, the numbers of data points are 17 058 for sector 19 and 18 367 for sector 59.

A query of the *Gaia* DR3 database† returns a total of 142 sources within 2 arcmin of IQ Per, as expected due to the faint limiting magnitude of *Gaia* and the proximity of our target to the Galactic plane. Aside from the nearby companion mentioned above, all of the stars are fainter by at least 5·5 mag in the *G* band.

### *Preliminary light-curve analysis*

We performed a first analysis of the data using version 43 of the JKTEBOP‡ code[28,29]. We concentrated on the data from sector 59, as these are of higher quality than those from sector 19 and we do not want to combine the sectors due to change in the argument of periastron between the sectors. This work confirmed that the fractional radius of star A ($r_{\rm A} = R_{\rm A}/a$ where $R_{\rm A}$ is its radius and $a$ the semi-major axis of the relative orbit) is close to the limits of applicability of JKTEBOP and thus it was advisable to use a more sophisticated code for the final analysis.

We therefore fitted the sector-59 light-curve using JKTEBOP only to determine the orbital ephemeris and the coefficients of a polynomial to normalize the brightness of the system to zero differential magnitude. We then subtracted the polynomial, converted the times of observation to orbital phase, and combined them into 1000 phase bins. The resulting phase-binned data were then suitable for the next step in the analysis.

### *Analysis with the Wilson–Devinney code*

The main analysis of the light-curve was undertaken using the Wilson-Devinney (WD) code[30,31], which uses Roche geometry to represent the shapes of the stars. We used the 2004 version of the code (WD2004), driven by the JKTWD wrapper[32], to fit the 1000-point phase-binned light-curve. Following

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

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

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

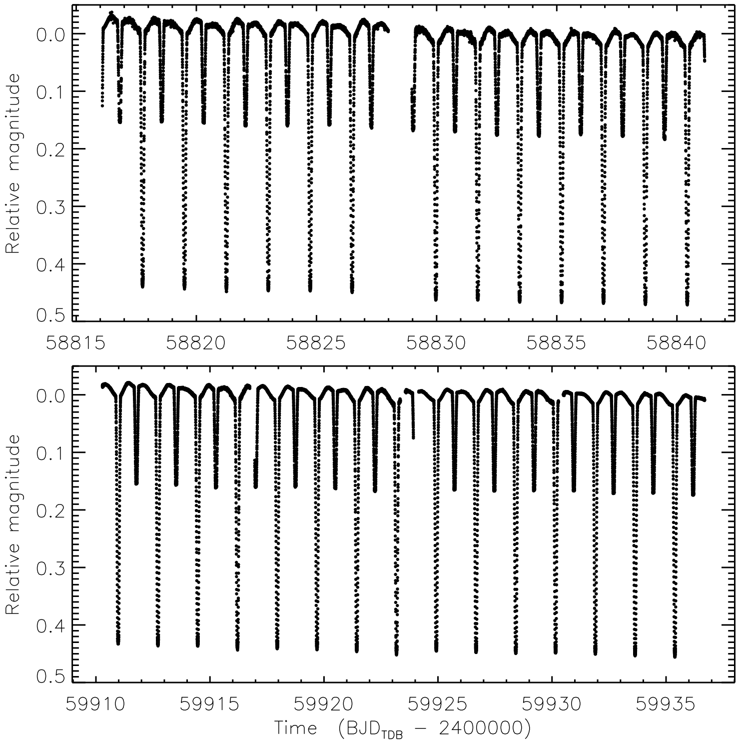


Fig. 1

*TESS* short-cadence SAP photometry of IQ Per from sectors 19 (upper panel) and 59 (lower panel). The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median.

our usual practice, we first describe the adopted solution of the light-curve and then discuss the alternative approaches which comprise our error analysis. The parameters used in WD2004 are described in the WD-code user manual[33].

The fitted parameters in the adopted solution were: the potentials of the two stars; the orbital inclination; the orbital eccentricity; the argument of periastron; a phase offset; one limb-darkening (LD) coefficient per star; the light contribution of star A; the effective temperature ($T_{\rm eff}$) of star B; and the amount of third light. For LD we used the logarithmic law[34] with the nonlinear coefficient fixed[35] to theoretical values from Van Hamme[36]. Albedo values and gravity-darkening exponents were fixed to 1·0 (suitable for radiative atmospheres), synchronous rotation was assumed, the simple model of reflection was used, and the mass ratio was fixed to the spectroscopic value from LF85.

Our adopted solution differs from our usual approach in that we have chosen as default to operate the WD code in MODE=2, where the $T_{\rm eff}$ values and light contributions of the stars are linked. Our initial experiments using MODE=0 gave similar fits but for albedo values significantly greater than unity, a situation we have noticed several times in the past[2,32,37,38]. This problem does not occur in WD MODE=2. Table II contains the parameters of our adopted fit.

TABLE II

*Summary of the parameters for the* WD2004 *solution of the TESS light-curve of IQ Per. 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 | 2 | |
| 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 | 0·493 | |
| Rotation rates | 1·0 | 1·0 |
| Bolometric albedos | 1·0 | 1·0 |
| Gravity darkening | 1·0 | 1·0 |
| $T_{\rm eff}$ value of star A (K) | 12300 | |
| Bolometric linear LD coefficient | 0·7321 | 0·6565 |
| Bolometric logarithmic LD coefficient | 0·0714 | 0·2421 |
| Passband logarithmic LD coefficient | 0·2354 | 0·2849 |
| *Fitted parameters:* | | |
| Potential | 4·838 ± 0·019 | 4·814 ± 0·050 |
| Orbital inclination (°) | 88·63 ± 0·52 | |
| Orbital eccentricity | 0·0677 ± 0·0022 | |
| Argument of periastron (°) | 200·0 ± 5·2 | |
| $T_{\rm eff}$ value of star B (K) | | 8180 ± 360 |
| Light contribution | 10·30 ± 0·18 | |
| Passband linear LD coefficient | 0·486 ± 0·067 | 0·38 ± 0·17 |
| Third light | 0·054 ± 0·014 | |
| *Derived parameters:* | | |
| Fractional radii | 0·2336 ± 0·0009 | 0·1418 ± 0·0014 |

Fig. 2 shows the fit of the model to the data, which is imperfect. We tried all possible options available in the WD code to improve the fit (see our work on V1388 Ori; ref. 39) but were unable to do so. There is an increased scatter through the primary eclipse, which is due to the numerical resolution of the WD2004 code. There is a sinusoidal trend in the residuals at twice the orbital frequency; its shape is not consistent with any of the ellipsoidal, reflection, or Doppler-beaming effects[40,41]. A similar but not identical trend has previously been seen for the dEBs ζ Phe[2] and KIC 9851944[42]. Possible causes include the assumption of point masses in the Roche model, and thus neglect of the mass of the envelopes of the stars, and the brightness changes due to pulsations (see below). The relatively poor fit during secondary eclipse is an artefact of the sinusoidal trend, which causes incorrect normalization of the light-curve in the region of the secondary eclipse and a slight deformation of the eclipse to obtain the overall best least-squares fit. In our analysis below we make the assertion that our best fit — whilst not a good fit — nevertheless yields reliable parameters which can be used to determine the physical properties of the component stars; the reader is free to disagree if they wish.

We determined the error bars of the fitted parameters in the WD2004 analysis by considering a range of possible choices in delineating the adopted solution. The scatter of the data is small, and the residuals *versus* the best fit are significantly larger, so the contribution of Poisson noise is negligible. Instead we

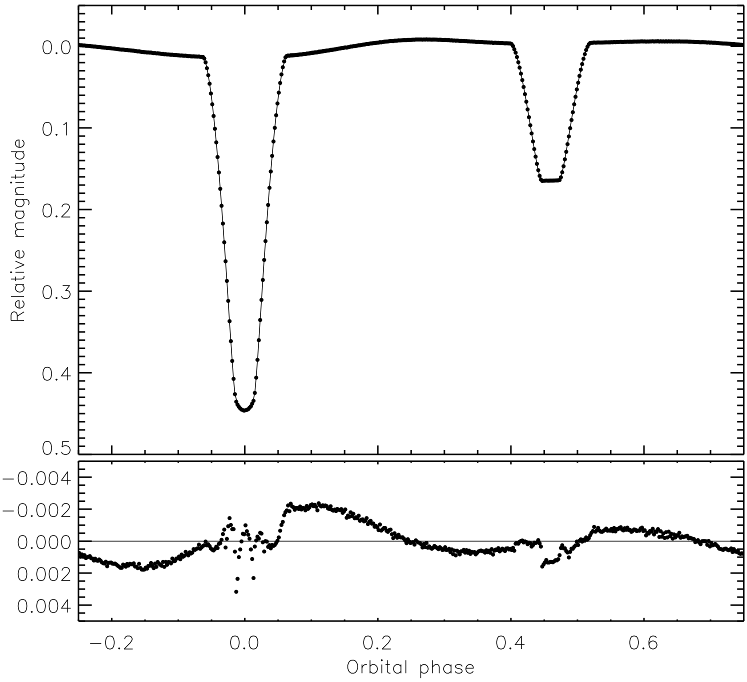


FIG. 2

Best fit to the binned light-curve of IQ Per 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.

ran a set of alternative solutions varying one or more control parameters or input physics from the adopted solution. These alternative solutions included: use of a light-curve binned into 500 phase points instead of 1000; numerical precisions of 40 and 55–59 instead of the maximum 60; a different approach to polynomial normalization of the data before phase-binning; changing the spectroscopic mass ratio by its uncertainty; changing the rotation rates by ±0·1; changing the gravity-darkening exponents by ±0·1; changing the albedos by ±0·1; using the square-root LD law; fixing all LD coefficients at the theoretically-predicted values; and using the Cousins *I* band instead of the *R* band as a surrogate for the *TESS* passband.

The result of this process was a large set of alternative parameter values. The differences for each parameter *versus* the adopted solution were calculated then added in quadrature to obtain the final uncertainty for that parameter. These are the error bars reported in Table II. We also give a breakdown in Table III of the error bars for the fractional radii, as these are the most important results from the WD analysis. The final uncertainties in the fractional radii are 0·4% for star A and 1·0% for star B. The $T_{\rm eff}$ of star B from this analysis is not reliable because the *TESS* passband is not an available option for the WD2004 code. We also obtained a fit to the *TESS* sector-19 data, finding it to be consistent with that for the sector-59 data but with a different small trend in the residuals. We postpone further analysis of these trends to a future work.

TABLE III

*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* (%) | |
|---|---|---|
| | $r_A$ | $r_B$ |
| Binning into 500 phase bins instead of 1000 | −0·06 | 0·15 |
| Setting the numerical precision to N1=N2=40 | 0·07 | −0·32 |
| Different polynomial normalization | 0·16 | 0·19 |
| Changing mass ratio | 0·00 | −0·07 |
| Changing rotation rates by ±0·1 | −0·09 | 0·05 |
| Changing gravity darkening by ±0·1 | −0·15 | 0·22 |
| Changing the albedos by ±0·1 | 0·02 | 0·03 |
| Using the square-root limb-darkening law | −0·02 | −0·05 |
| Fixing limb-darkening coefficients | 0·00 | 0·41 |
| Using the Cousins *I*-band | 0·30 | −0·72 |

### *Radial-velocity analysis*

LF85 presented 20 medium-resolution spectra, and measured 20 RVs for star A and 16 for star B using cross-correlation. We digitized the data and modelled the RVs with the JKTEBOP code to determine the velocity amplitudes of the two stars. A time of minimum close to the mean time of the spectra was chosen* and a shift in orbital phase was included as a fitted parameter. We also fitted for the velocity amplitudes ($K_A$ and $K_B$) and systemic velocities ($V_{\gamma,A}$ and $V_{\gamma,B}$) of the stars. Due to the apsidal motion in the system, we fitted for the argument of periastron ($\omega$) but fixed the eccentricity at the photometric value (Table II). Alternative solutions with eccentricity fitted or with $V_{\gamma,A} = V_{\gamma,B}$ gave results which differed by much less than the uncertainties, indicating that the orbital solutions are robust. We followed LF85 by allocating half weight to two spectra with a lower count rate, and iteratively adjusted the error bars of the RVs of each star to obtain a reduced $\chi^2$ of 1·0.

The fitted orbits are shown in Fig. 3. The parameters of the fit are $K_A = 101{\cdot}95 \pm 0{\cdot}65$ km s$^{-1}$, $K_B = 206{\cdot}2 \pm 1{\cdot}2$ km s$^{-1}$, $V_{\gamma,A} = 0{\cdot}55 \pm 0{\cdot}47$ km s$^{-1}$, $V_{\gamma,B} = 0{\cdot}65 \pm 0{\cdot}88$ km s$^{-1}$, and $\omega = 73{\cdot}0 \pm 5{\cdot}0$. These are all in good agreement with the values found by LF85, but have smaller error bars because we fixed the eccentricity to a known value instead of fitting it separately for the two stars.

### *Physical properties and distance to IQ Per*

We determined the physical properties of IQ Per from the results of the WD2004 code and RV analyses given above. For this we used the JKTABSDIM code[44]. The results are given in Table IV. The masses of the stars are measured to 1·5% precision, and the radii to 0·5% (star A) and 1·1% (star B) assuming the WD2004 fit is good enough to give reliable parameters. Our results are in excellent agreement with those from LF85, highlighting the robustness of such information for totally-eclipsing binaries (and our use of the same RV data). We also retain the $T_{\rm eff}$ values given by LF85, which were based on photometric colour indices for the individual stars. The pseudo-synchronous rotational velocities are consistent with the values measured by LF85.

*HJD 2444926·749 from table 5 of LF85

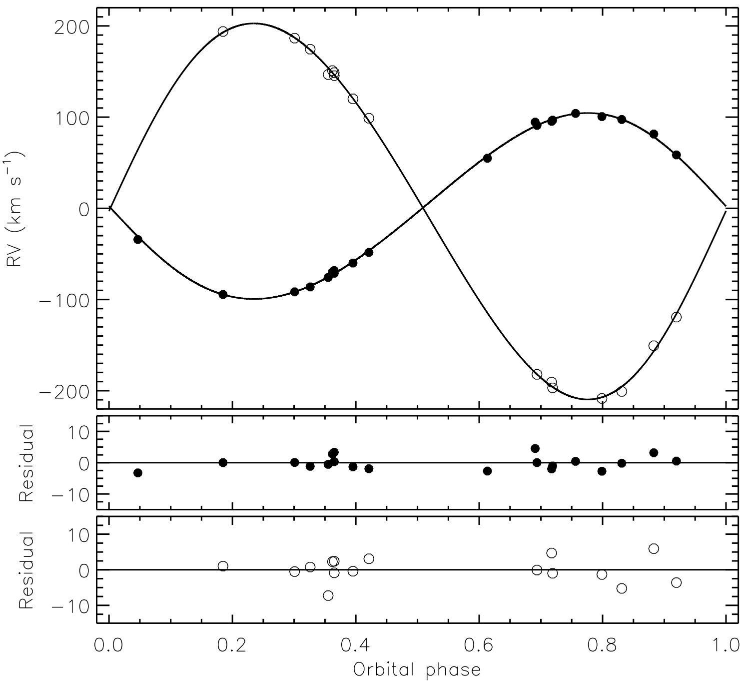


FIG. 3

Radial velocities of IQ Per from LF85 (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 IV

*Physical properties of IQ Per defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 43). The $T_{\rm eff}$ values are from LF85.*

| *Parameter* | *Star A* | *Star B* |
|---|---|---|
| Mass ratio $M_{\rm B}/M_{\rm A}$ | 0·4944 ± 0·0043 | |
| Semi-major axis of relative orbit ($R^{\rm N}_{\odot}$) | 10·598 ± 0·047 | |
| Mass ($M^{\rm N}_{\odot}$) | 3·516 ± 0·050 | 1·738 ± 0·023 |
| Radius ($R^{\rm N}_{\odot}$) | 2·476 ± 0·015 | 1·503 ± 0·016 |
| Surface gravity (log[cgs]) | 4·1967 ± 0·0042 | 4·3244 ± 0·0090 |
| Density ($\rho_{\odot}$) | 0·2317 ± 0·0028 | 0·512 ± 0·015 |
| Synchronous rotational velocity (km s$^{-1}$) | 71·84 ± 0·42 | 43·61 ± 0·47 |
| Effective temperature (K) | 12300 ± 170 | 7675 ± 100 |
| Luminosity $\log(L/L^{\rm N}_{\odot})$ | 2·102 ± 0·025 | 0·849 ± 0·022 |
| $M_{\rm bol}$ (mag) | −0·514 ± 0·061 | 2·618 ± 0·056 |
| Interstellar reddening $E(B-V)$ (mag) | 0·12 ± 0·03 | |
| Distance (pc) | 278·1 ± 3·8 | |

We estimated the distance to the system using our measured radii, the apparent magnitudes in Table I, and bolometric corrections from Girardi *et al.*[45]. Imposing an interstellar reddening of $E(B-V) = 0{\cdot}12 \pm 0{\cdot}03$ mag to bring the $BV$ and $JHK_s$-band distances into agreement, we obtained a distance of $278{\cdot}1 \pm 3{\cdot}8$ pc. This is a reasonable match to the distance of $287{\cdot}5 \pm 2{\cdot}6$ pc from the *Gaia* DR3 parallax of IQ Per, supporting the reliability of the $T_{\rm eff}$ values from LF85.

We compared the measured properties of the components of IQ Per to the predictions of the PARSEC theoretical stellar-evolutionary models[46]. The large difference between the two stars means they are a high-quality test of theoretical predictions, and in this case the test is failed. We can obtain a good match to the masses and radii of the stars for a metal abundance of $Z = 0{\cdot}017$ and an age of 80 Myr, but the predicted $T_{\rm eff}$ values are too large (~16000 and ~8200K, respectively). A higher or lower metal abundance gives a poorer fit to the radii. A metal abundance of $Z = 0{\cdot}030$ and an age of 45 Myr can match the radius of star A and the $T_{\rm eff}$ of star B, but not the radius of star B and the $T_{\rm eff}$ of star A. A spectroscopic analysis to confirm the $T_{\rm eff}$ values and obtain a metallicity measurement for the stars would be very helpful in exploring this discrepancy further.

*Pulsation analysis*

An increasing number of dEBs are known to harbour pulsating stars[47,48]. We performed a search for pulsations in IQ Per using the residuals of the JKTEBOP fit to the *TESS* sector-59 light-curve. An amplitude spectrum was calculated using version 1.2.0 of the PERIOD04 code[49] and is shown in Fig. 4. We find a large number of small signals at multiples of the orbital frequency, which is expected due to the trend with orbital phase seen in the residuals from the JKTEBOP and WD2004 fits (*e.g.,* Fig. 2). No significant frequencies were found from 22 $d^{-1}$ up to the Nyquist frequency of 360 $d^{-1}$.

There are three frequencies which are not at multiples of the orbital frequency, at 0·75, 1·33, and 2·11 $d^{-1}$. These are probably related as the highest frequency is approximately the sum of the two lower frequencies. Of these, only the 1·33 $d^{-1}$ frequency is significant[50], with a signal-to-noise ratio of 6·2 and an amplitude of 1·3 mmag (calculated using PERIOD04). Based on this detected frequency and the masses of the stars, we conclude that star A is a slowly-pulsating B star[51,52]. It thus joins the small but increasing sample of such stars in dEBs[53]. The prospects for asteroseismology of this star are poor as only one significant pulsation has been detected with a frequency not corresponding to a multiple of the orbital frequency.

*Conclusion*

IQ Per is a dEB containing a $3{\cdot}5$-$M_\odot$ B-star and a $1{\cdot}7$-$M_\odot$ A-star in an orbit of short period (1·744 d) which is eccentric and shows apsidal motion. We have used new light-curves from *TESS* and published RVs from LF85 to determine the masses and radii of the component stars to high precision (0·5–1·5%). The significant differences between the two stars makes IQ Per a good test of stellar theory. The masses, radii, and $T_{\rm eff}$ values of the stars cannot be fitted for a single age and metallicity using the PARSEC models. A more extensive analysis could be performed by obtaining spectroscopic $T_{\rm eff}$ and metallicity measurements and by including in the analysis internal-structure constants measured from the apsidal motion.

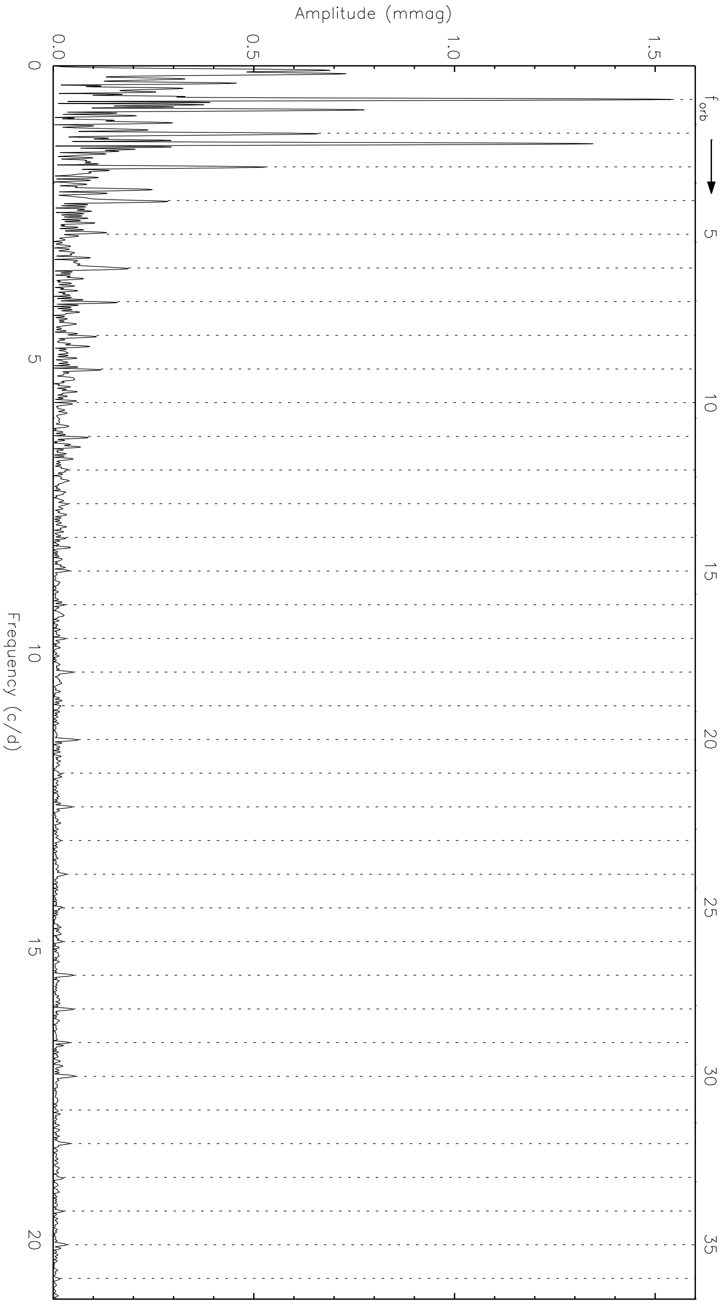


Fig. 4

Frequency spectrum of the *TESS* light-curve of IQ Per. Multiples of the orbital frequency are shown along the top.

Our fit to the *TESS* light-curve is imperfect, with a roughly sinusoidal residual *versus* orbital phase and a slight mismatch of the depth of the secondary eclipse. However, the total eclipses mean the radii of the stars can still be measured reliably from the times of the contact points. A frequency spectrum of the residuals of the fit has many peaks at multiples of the orbital frequency, as expected due to the residuals *versus* the best fit. It also shows one significant peak at 1·33 $d^{-1}$, away from multiples of the orbital frequency, and less-significant peaks at 0·75 $d^{-1}$ and 2·11 $d^{-1}$. These results are consistent with star A being a slowly-pulsating B-star.

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## CORRESPONDENCE

*To the Editors of 'The Observatory'*

### *Book Reviews*

I look forward to Phillip Helbig's book reviews. In the 2024 June issue review of Bill Press' memoir *More Than Curious*, he writes[1] of Press "I've never met Bill Press". As a final year undergraduate at Caltech, I got to know him as well as any undergraduate might know a professor. During the 1973–4 academic year, Press was an assistant professor teaching PH 236, a year-long postgraduate-level course in General Relativity. That year was the first in many the course had not been taught by Kip Thorne: he was on sabbatical, recovering from having spent 90% of the preceding three years on completion of *Gravitation* by Misner, Thorne & Wheeler, more often called '*MTW*'. Publisher W. H. Freeman shipped the first paperback copies struck off the press to Caltech. I still have mine on my bookshelf, and consult it on occasion, still.

So far as I know Bill had no prior experience teaching. I did not regret missing out on taking PH 236 from Thorne, however. Press taught a splendid course, unlike any other I had at university. One aspect stands out in memory. Those of us taking the course were used as beta testers of what ultimately became *Problem Book in Relativity and Gravitation* by Lightman, Press, Price & Teukolsky (Princeton University Press). Each week, we were given fifteen to twenty problems with solutions attached. We were to work through as many as we desired, consulting solutions as needed, and flagging any errors we found, or supplying solutions of our own. (As I recall, none of mine made it into the published version.) We would set aside one problem to work without consulting the solution, and mark it as such for the graders (Saul Teukolsky and Alan Lightman, before his career move to literary fiction). The honour system at Caltech ensured we abided by these conditions. For the final exam, we were supplied with all the (corrected) problems *sans* solutions, and enjoined to work as many as we could in three hours. Naturally, everyone took care to review all the problem sets before the day. I can't say how badly this arrangement traduced the norms of postgraduate final examinations, but as a pedagogical matter, I think it worked brilliantly: we got acres of practice applying what we learned from Press and *MTW*, and the exams were the least stressful of any I had as an undergraduate.

The third quarter of the course was devoted to physical cosmology, mostly taught using Weinberg's *Gravitation and Cosmology*, the account of cosmology in *MTW* being its weakest part.

In the same issue, Helbig also reviewed[2] Carlo Rovelli's *White Holes*. At one point he refers to Dante's *Paradise Lost*. May we look forward to seeing Milton's *Inferno*?

Yours faithfully,
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*References*

(1) P. Helbig, *The Observatory*, **144**, 150, 2024.
(2) P. Helbig, *The Observatory*, **144**, 157, 2024.

## REVIEWS

**Space: The Human Story**, by Tim Peake (Century), 2023. Pp. 328, 23·5 × 15 cm. Price £22 (hardbound; ISBN 978 1 529 91350 7).

More than six decades ago, a 27-year-old lieutenant in the Soviet Air Force, named Yuri Gagarin, made history by becoming the first human to leave our planet and experience the alien environment of outer space. After completing one orbit around the Earth, the courageous young man with the infectious smile ejected from his spacecraft and parachuted back to the steppes of Kazakhstan, to be greeted by a cow and two bemused peasant farmers. Since Gagarin's pioneering feat, well over 600 people from many nations have risked their lives to venture beyond Earth's atmosphere and explore the 'final frontier'. Their stories are the focus of this historical summary written by UK astronaut Tim Peake, who spent six months on the *International Space Station* in 2016. The book includes many of the most memorable events of the Space Age, covering the exploits of the early pioneers who ventured forth in the Vostok, Mercury, and Gemini missions, the Apollo lunar expeditions, and the orbital workshops that culminated in the giant *International Space Station*.

The account follows a logical format, starting with a chapter about how astronauts are selected, then moving on to preliminary training and assignment to a mission. The remaining chapters are devoted to the launch process, operations in orbit, walking in space, and returning back to Earth. Although Peake does include some anecdotes from his astronaut career, and refers in places to the forthcoming Artemis lunar missions, most of the book is focussed on the historic achievements, problems, and failures of the US and Soviet/Russian space programmes since Gagarin's breakthrough in 1961 April. There is no discussion of the Chinese human space programme or the recent advent of commercial space tourism, and the book's only illustrations are provided by two inserts of colour photos.

Although most of the material has been covered in other volumes, the book is an entertaining read and I would recommend it to anyone not familiar with the exploits of the spacefarers who have volunteered to leave our planet behind in order to explore and exploit the near-vacuum of space. — Peter Bond.

**Japan in Space: Past, Present and Future**, by Brian Harvey (Springer Praxis), 2023. Pp. 421, 23·5 × 15·5 cm. Price £27·99 (paperback; ISBN 978 3 031 45571 1).

Brian Harvey has been writing about global space activities since the late 1980s, covering the Russian, Chinese, European, Indian, and American space programmes. This volume is a follow-on to two previous books which largely focussed on developments in Japan, bringing the story up to date. This time, the author concentrates solely on the evolution of the Japanese space programme, from its early rocket experiments and the launch of its first satellite in 1970, to the development of sophisticated launch vehicles and spacecraft, and the country's participation in the *International Space Station* (*ISS*) programme.

Today, few outside the scientific community are aware of Japan's significance as a key partner to other leading space powers, most notably the United States and Europe. However, the country has made its mark over the past 50 years by developing its own military surveillance, engineering, and navigation satellites; contributing the *Kibo* science laboratory to the *ISS*; creating a family of indigenous launch vehicles; and making history by returning the first surface samples from two asteroids.

Harvey's thorough, detailed account examines the early history of Japan's space programme, the country's current state of development, and its future plans. He also describes the infrastructure that includes Japan's ocean-side launch sites, training centres, testing facilities, and tracking stations. Another area of focus covers the political and financial difficulties that the country's space industry has faced, not least an ambivalent relationship with the United States.

Once the premier spacefaring nation in Asia, Japan is now left in China's shadow. However, the future still holds much promise, including missions to Mercury and the moons of Mars, and the long-term prospect of Japanese astronauts setting foot on the Moon and driving roving vehicles across its surface. — PETER BOND.

**How to Write and Publish a Scientific Paper, 9th Edition**, by Barbara Gastel & Robert A. Day (Cambridge University Press), 2024. Pp. 348, 23 × 15 cm. Price £27·99/$34·99 (paperback; ISBN 978 1 009 47753 6).

If you are an established professional scientist, you probably think you already know how to write a scientific paper, and of course that's essentially true. But a quick glance at this book might be enough to tell you that you still have things to learn. For first-time paper writers, it will be very useful indeed. This is the ninth edition, which argues that people do find it helps them.

When I looked at the list of contents, I was not surprised. Every conceivable topic is covered, together with quite a few that I would not have thought of. There are eight main sections: 'Preliminaries' (including such basic topics as What is Scientific Writing? and What is a Scientific Paper?); 'Preparing the Text', with subsections on all the necessary parts from Title to References; 'Preparing the Tables and Figures'; 'Publishing the Paper', starting with an explanation of Copyright; 'Doing Other Writing for Publication'; 'Conference Communications'; 'Scientific Style' (including Use and Misuse of English); and 'Other Topics in Scientific Communication', including How to Write a Thesis and How to Work with the Media. There are four useful Appendices (including Words and Expressions to Avoid, with two columns: Jargon and Preferred Usage; we would all benefit from looking at that one).

The text is clearly and logically written, so the book is a pleasure to read. It is lightened from time to time by relevant cartoons, including two from Peanuts. There is a pertinent quotation at the head of each of the 42 sections (*e.g.*, "Manuscripts containing innumerable references are more likely a sign of insecurity than a mark of scholarship", attributed to William C. Roberts). There is a glossary, a list of References, and an Index. A very useful reference book for all scientists who want to have their work read — and that's all of us, isn't it? — ROBERT CONNON SMITH.

**Pisgah Astronomical Research Institute: an untold history of spacemen & spies**, by Craig Gralley (History Press), 2023. Pp. 158, 22 × 14 cm. Price $23·99 (about £19) (hardbound; ISBN 978 1 4671 5218 1).

PARI, the Pisgah Astronomical Research Institute, was founded in 1998 by Don Cline and his late wife, Jo. It now focusses on both live and remote astronomical education and also houses many collections of astronomical glass plates, deaccessioned by Harvard and many other observatories. But the site started life as a NASA tracking station (1963–1981) and next was owned and operated by the US National Security Agency (1981–1995). The author is a former senior executive of the US Central Intelligence Agency. The above is meant to be an 'other books received' summary.

A review would continue: It isn't often that a book, especially a history book, hits one's mailbox just in time to provide a slice of information needed for the next day's teaching. But this one did. In its tracking-station days, the two 85-foot-diameter radio dishes could pick up the signal from a 5-Watt source on a satellite 200 000 miles away. How much is that in janskys? Well, for some plausible source of frequency and bandwidth, it's about one. That was indeed the faint end of the radio-source counts in the early days of Big Bang *versus* steady state, Ryle *versus* Hoyle, and so forth, and the very brightest radio sources ranging up to maybe a kilo-Jy. How much is a jansky? It is $10^{-26}$ watts per square metre per hertz. (Remember that the limiting sensitivity of human hearing is somewhere around $10^{-12}$ watts per square metre over some frequency range, maybe 300–6000 Hz.)

Why did the book arrive on my desk? It was a present from PARI founder, Don Cline (a friend of long standing) and the author Craig Gralley, each of whom autographed an early page. It has 125 informative footnotes, a short index, some historical black-and-white photos, and some perfectly lovely colour ones, including the PARI campus at night, illustrating how to illuminate grounds and buildings, while sending very little light upward to undarken the dark night skies of rural North Carolina. The *AAATS-3* satellite that took the first colour photograph of the whole earth in 1967 and the first *Earth Resources Technology Satellite* (*ERTS*) were both commanded from the PARI site, when it was called NASA's Rosman Station. The *ERTS* image provided shows New Jersey and was taken on 1972 November 10.

Cline himself is a meteoriticist, and one of the colour photos shows him holding up a piece of chondrite close to three young female students. Two of them look frightened. Perhaps they are remembering the DoD days? Had it ever occurred to you that radomes not only keep the rain off, they keep cameras that pass overhead (on the Other Guy's satellites) from seeing where your spying dishes are pointed. There are lots more photographs and many more unexpected pieces of information. Many thanks Don and Craig! — Virginia Trimble.

**General Relativity: The Theoretical Minimum**, by Leonard Susskind & André Cabannes (Penguin), 2023. Pp. 387, 20 × 13 cm. Price £10·99 (paperback; ISBN 978 0 141 99986 9).

Leonard Susskind has been a professor of theoretical physics at Stanford for almost five decades. He is best known for his technical work on string theory and various applications of quantum theory. This book is one of many*, with various co-authors, based on his lecture series *The Theoretical Minimum*; the lectures themselves are available as videos on the internet. This is the first book in the series which I have read. Books on General Relativity can be divided into physics-first or maths-first and of course also differ with regard to breadth, depth, and level of (mathematical) detail. This book is rather different in that it is neither strictly maths-first nor physics-first, although it does follow the common pattern of an introductory physics chapter, then a few chapters on maths, before moving on to discuss applications. However, rather than deliver essentially all of the maths first, Susskind presents the basics of tensors, curvature, geodesics, and metrics before three chapters on black holes, but in those chapters brings in more maths (*e.g.*, various types of coordinates) as needed. The Einstein field equations don't appear until the ninth chapter, before the final one on gravitational waves.

It also differs from most other books in that the basic concepts are presented in enough detail actually to learn them relatively easily. However, the details are conceptual, not necessarily mathematical. The emphasis is on understanding,

*So far, there are also books on classical mechanics, quantum mechanics, and classical field theory and Special Relativity. The next volume will be on cosmology, followed by one on statistical mechanics.

not on mechanical calculation. Common topics such as the difference between contravariant and covariant tensors and Christoffel symbols are *explained* rather than just presented. Although one learns only 'the theoretical minimum', this book is probably the best I have read so far for those who actually want to learn General Relativity. The book reads like a series of good lectures, on which of course it is based. (It "is adapted from a course...at Stanford in the Continuing Studies program to an audience of adults"; I'm not sure what Susskind wants to imply about normal students at Stanford.)

By now even Susskind should know that Wheeler didn't coin the term 'black hole', though he did popularize it. Other than that, I noticed no mistakes in the book. Somewhat unorthodox is the fact that equations are not punctuated, and equations, theorems, *etc.*, named after people are usually with neither the definite article nor the possessive form (*e.g.*, "given by Pythagoras theorem", "solving Einstein field equations"). I found it somewhat strange to discuss comparing the observations of someone falling into a black hole with those of someone watching that from afar without mentioning redshift, though the description is, of course, correct. Susskind is also somewhat dismissive of videos (by professional relativists) which purport to show what one would actually see if falling into a black hole and so on, though he doesn't say why. Those minor points don't distract from the main narrative, but might be interesting to follow up for those interested in Susskind's perspective.

There are several black-and-white diagrams scattered throughout the book, and of course, equations, though not a huge number of the latter. There are a few footnotes but neither endnotes nor references; apart from the chapters ('lectures') there is only a short preface by both authors and a six-page small-print index. The book is well written and I will probably read the others in the series, and hopefully review the upcoming one on cosmology in these pages. — Phillip Helbig.

**Cultural Astronomy in Latin America**, edited by Steven R. Gullberg & César Augusto zen Vasconcellos (World Scientific), 2024. Pp. 398, 23·5 × 16 cm. Price £135 (hardbound; ISBN 978 981 12 8192 1).

*Cultural Astronomy in Latin America* is a book by and for experts. Its 14 chapters address (mostly) archaeological sites and artifacts associated with the Inca culture and Mayan written records. At the edges, as it were, are (*i*) Mark Raney looking at the star lore of the Hopi and Zuni Indians of the American Southwest and comparing it with the views of the Aztecs of what is now Mexico; (*ii*) Armando Madrid on how astronomy brought by European immigrants to southern Argentina has blended with and survived alongside the myths of the local indigenes, and (*iii*) Walmir Thomazi Cardosa with a "long 20th century" look at a grab-bag of entities from the Brazilian northwest Amazon, including light beams, asterisms, and snake myths. The chapters are not ordered North to South (or South to North) nor early to late, nor even alphabetically by author. Perhaps the chapters are in the order the texts reached the editors. Many of the authors have affiliations in the countries that host(ed) the cultures they have written about. You won't be surprised to hear that these (mostly) pre-Columbian groups of people were interested strongly in what the Sun does (rising, setting, and in between), a bit less strongly in what the Moon does (and trying to fit the two sorts of cycles together), and often also in patterns of stars in the sky and perhaps the motions of Venus among them. These were also the interest of early (and contemporary!) peoples of the Old World. The specific myths are different, though water makes a frequent appearance, as from time to time do pyramids and various circles. And the hope of forecasting rain from the phases of the

Moon (Kepler had similar hopes for his astrology). More realistic were uses of solar phenomena to keep track of times for planting and harvesting crops and thanking the Gods in festivals for successful agricultural years,

How do I know the book was meant for experts? Nearly every chapter uses indigenous words for concepts or phenomena without translation in a glossary. Only rarely does a map locate the site. And the asterisms (that is patterns of stars assigned names and significance different from those of our own Babylonian-to-Greek-to-Lacaille-to-IAU constellations) are mostly described rather than shown as dots on a skymap with coordinates, although the Pleiades are mentioned in several chapters.

Unquestionably there is something to be learned from every chapter, but I was particularly glad to encounter the one by editor Steven R. Gullberg on the Chankillo astronomical complex in north-central Peru. A watercolour of the site, by the editor's wife Jessica Gullberg, graces the cover of the volume. There are 13 towers (about as high as an Editor) along the crest of a ridge, separated by home-pool lengths. An observer situated at either an east or a west observation point will see the Sun rise or set in the gaps between the towers on days like the solstices and equinoxes. The Moon on this somewhat elevated horizon also peeks through from time to time. Dendrochronology and C-14 dating place use of the site around 250–200 BCE, and it is therefore clearly pre-Incan. The same site is identified as one of the most persuasive preliterate astronomical locations in a forthcoming book with very different origins*. — Virginia Trimble.

**Einstein in Time and Space: A Life in 99 Particles**, by Samuel Graydon (John Murray), 2023. Pp. 317, 20 × 13 cm. Price €14 (about £12) (paperback; ISBN 978 1 529 37250 2).

The 'Particles' in the title are anecdotes. (They are preceded by a nine-page introduction which gives a more conventional but very good overview of Einstein's work, life, and times.) We've all heard anecdotes about Einstein: why he dropped out of high school, his childhood fascination with a compass, the fate of his daughter, his stolen brain, his time at the patent office, and so on. A few of those presented here were new to me: I knew about his newspaper advert offering tutoring, and his friendship with Maurice Solovine, but didn't know (or had forgotten) that they met through his ad. There is also some interesting background information: Einstein famously explained Brownian motion, Brown having found that it applied to all small particles, whether of biological origin or not (initially having observed pollen grains, Brown had at first thought that it was some sort of vital sign), by testing all sorts of materials, including, for some reason, filings from the Great Sphinx of Giza! (Perrin was awarded a Nobel Prize for confirming Einstein's predictions involving Brownian motion.) Also new to me were details of his romance with Marie Winteler, mostly unknown to the world until the corresponding letters were published in the fifteenth volume of Einstein's *Collected Papers* in 2018. (Einstein had boarded with the family of her parents, Jost and Rosa. Einstein's sister Maja married Marie's brother Paul, and Einstein's friend Michele Besso married Marie's sister Anna.)

Similarly to the autobiographical stories of Richard Feynman written up by his friend Ralph Leighton[1,2†], this book consists essentially of only such anecdotes, just briefly discussing Einstein's work or more banal details of his life. However,

*Noah Brosch, *Of Stars and Stones: Diffusion versus Convergence in Archaeoastronomy*, to be submitted shortly for publication, 2024.

†Depending on the edition, for both books Leighton is sometimes referred to as co-author or editor, and for the former Edward Hutchings is sometimes referred to as editor.

twenty-six pages of references to the sources of quotations point the reader to the origin of such anecdotes. The five-page 'Sources and Acknowledgements' section not only lists but also gives information about several biographies of Einstein and other works, by Einstein and others, used in researching the book. The author is the science editor of the *Times Literary Supplement* and the book is very well written, both in terms of content and in terms of style. Those wanting a breezy introduction to Einstein's life as well as those wanting to track down details of one of the many famous anecdotes will find this book very useful. And what a life it was: in 1905, Einstein "was still working six days a week at the Patent Office, he had a one-year-old son to help look after, and that year he wrote twenty-one reviews* for an academic journal. He also moved house in May. And yet he managed to produce five scientific papers in six months, three of which would eventually transform physics." Even that is an understatement: apart from those three, the two papers on Special Relativity and the one on the photoelectric effect, there was the paper on Brownian motion mentioned above and his doctoral thesis on the determination of the Avogadro constant, two of the main papers which made it clear that atoms are real. As Pais[4] points out, his thesis was extremely important at the time and is one of his most highly cited works. Such an output would be impressive even today, but is even more so after having visited the flat he lived in at the time, as I did in 2015. And that was all before he got his first academic job.

I noticed only one mistake: it was not "much later" after the definitive discovery of the acceleration of the Universe about a quarter of a century ago that it was realized that the cosmological constant, which Einstein had introduced for another reason in the first paper on relativistic cosmology[5], could provide the reason for such acceleration. On the contrary, that was clear long before the acceleration had been discovered, at least as far back as the 1920s. Interestingly, the only acknowledgement regarding the scientific content of the book, rather than matters of production and so on, is for someone who checked the physics content and "explained some of the more technical issues of cosmology". Some of the chapters start with a black-and-white photo, most of which are of people. I've already mentioned the 'Sources and Acknowledgements' and the references to quotations. In addition, 'Credits' gives details on both 'Text' and 'Pictures'. As such, this book might be the quickest way to track down the original sources for the topics covered in the book. An eight-page index in somewhat smaller print ends the book.

All in all, a very enjoyable read, even for those who have heard most of the stories before, and a useful jumping-off point for those wanting more details. — PHILLIP HELBIG.

## *References*

(1) R. P. Feynman, "*Surely You're Joking, Mr. Feynman!": Adventures of a Curious Character* (W. W. Norton), 1985.

(2) R. P. Feynman, "*What Do You Care What Other People Think?": Further Adventures of a Curious Character* (W. W. Norton), 1988.

(3) J. Renn, *Einstein's Annalen Papers* (Wiley), 2005.

(4) A. Pais, '*Subtle is the Lord...': The Science and the Life of Albert Einstein* (Oxford University Press), 1982.

(5) A. Einstein, *Sitzungsb. Kön. Pr. Akad. Wiss.*, **VI**, 142–152, 1917.

*Those reviews are neither book reviews nor referee reports, but rather summaries of papers published elsewhere, mostly about thermodynamics, sometimes in languages other than German such as English, Italian, and French. They also provided additional income[3]. See https://einstein-annalen.mpiwg-berlin.mpg.de/home for a summary of Einstein's relationship with *Annalen der Physik*.

## From The Library

**The Cause of an Ice Age**, by Sir Robert Ball (Kegan Paul, Trench, Trübner, & Co.), 1891. Pp. 180, 20 × 13 cm. Price about £9 for a used copy from an on-line bookseller (hardbound; no ISBN).

A popular theory for explaining the ice ages involves the periodic changes in the Earth's orbit and the precession of the equinoxes. This theory is known as 'Milanković cycles' after the Serbian scientist Milutin Milanković (1879–1958), who wrote about this in the 1920s. However, similar theories had been around for some decades before the 1920s.

An earlier version of this theory was proposed by the Irish astronomer Sir Robert Ball (1840–1913), a prolific author of popular books and Royal Astronomer of Ireland (1874–1892), in this book. It was the first volume in a series, *Popular Science*, edited by Sir John Lubbock (1834–1913, later the first Lord Avebury). Ball's writing skill is evident in this highly readable and easy-to-follow little book. He makes a very strong case for the validity of this theory. He demonstrates that if the year is divided into two seasons, summer from vernal to autumnal equinox, then winter from autumnal to vernal equinox in the northern hemisphere, 63% of the Sun's annual supply of heat to that hemisphere is received in summer and only 37% in winter, whatever the condition of the Earth's orbit and axis. (He points out that Sir John Herschel wrongly states that the share is 50% in each season.)

The maximum possible difference between the length of summer and winter is 33 days, so one season is 199 days and the other is 166 days (page 97). When summer is much longer than winter, the 63% is stretched out and the 37% is compressed into a shorter period. He argues that the resultant warm but not hot summers and mild winters must lead to a "beneficent climate" (page 99). Conversely, when winter is much longer than summer, the 37% is stretched out and the 63% is compressed into a shorter period. This means that there are short, hot summers and long, cold winters. "This is the condition required for the development of glaciation. During the rigours of the winter the ice and snow accumulate, while the succeeding brief summer is not able to thaw as much water as has been solidified during the winter" (pages 106–107).

Whatever the merits or demerits of the theory that this book presents, it is an excellent model of how to present a scientific theory to the general public. — Lisa Budd.

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## ASTRONOMICAL CENTENARIES FOR 2025

*Compiled by Kenelm England*

The following is a list of astronomical events, whose centenaries fall in 2025. Births and deaths of individual astronomers are taken from *Biographical Encyclopedia of Astronomers* (Springer, 2007) and the on-line Obituary Notes of Astronomers and Obituary List of RAS Fellows. For events before 1600 the main source has been Barry Hetherington's *A Chronicle of Pre-Telescopic Astronomy* (Wiley, 1996). For the 17th to 20th Centuries lists of astronomical events came from Wikipedia and other on-line sources, supplemented by astronomical texts made available through the NASA Astrophysics Data System. Discoveries of comets, asteroids, novae, and other objects for 1925 appeared in the February issue of *Monthly Notices of the Royal Astronomical Society* in the following year. There were also references from *Popular Astronomy*, *Journal of the British Astronomical Association*, and *Publications of the Astronomical Society of the Pacific*. Professional discoveries and observations were followed up in *Philosophical Transactions of the Royal Society of London*, *Astronomische Nachrichten*, *Astronomical Journal,* and *Monthly Notices of the Royal Astronomical Society*. Gary Kronk's *Cometography* Volumes 1–3 (CUP, 1999–2007) provided details on all the comets. Details on meteorites can be found in the Meteoritical Society's Bulletin Database. Finally, NASA's Five Millennium Canons of Eclipses and planetary tables were consulted for information on eclipses and planetary events.

*1925*

*January 1*: Greenwich Mean Time for astronomers changed so that days began at midnight, not at noon.

*January 1*: The International Astronomical Union changed the system of temporary designations for asteroids, dividing the year into 24 half-months. This allowed for designations of asteroids on archive photographs and is still used today.

*January 1*: Cecilia Helena Payne (Ratcliffe College and Cambridge) completed her PhD thesis 'Stellar Atmospheres: A Contribution to the Observational Study of High Temperature in the Reversing Layers of Stars,' providing evidence that stars are almost entirely made up of hydrogen and helium.

*January 12*: Death of Gideon Turner Davis. Born in 1843, he was a British amateur astronomer, founder member of the BAA, who observed the Sun, Moon, planets, comets, the colours of stars, and supernova SN 1885A in the Andromeda Galaxy; author of *Astronomical Sketches*.

*January 24*: A total solar eclipse was visible over the eastern United States. Several observatories were close to the central track and could provide permanent facilities for a large number of eclipse expeditions, both professional and amateur. Although some sites were clouded out, many photographs were obtained of the solar corona during totality. Maximum duration 2 min. 32 sec. [Saros 120].

*January 31*: Birth of John Marsh Wilcox, an American astronomer, Professor of Applied Physics and Director of the Stamford Solar Observatory, who wrote papers on interplanetary magnetic fields; FRAS 1966; died 1983.

*February 3*: Death of Oliver Heaviside. Born in 1850, he was a British mathematician and physicist, studying electromagnetism; proposed the existence of the Earth's ionosphere; FRS 1891.

*February 8*: A partial lunar eclipse was visible from the Americas, Europe, Africa, the Middle East, Asia, and Australia [Saros 132].

*February 18*: Birth of Alois Purgathofer, an Austrian professional astronomer at the Vienna Observatory (1954–84), working on the photometry of Galactic star clusters and a detailed study of asteroid (51) Nemausa; died 1984.

*February 21*: Death of the Reverend Joel Hastings Metcalf. Born in 1866, he was an American Protestant minister and amateur astronomer, who discovered

41 asteroids and seven new variable stars. He was most famous for his discovery of comets 97P/1906 V2 (Metcalf-Brewington), C/1910 P1 (Metcalf), C/1913 R1 (Metcalf), C/1919 Q2 (Metcalf), and the recovery of 23P/1919 Q1 (Brorsen-Metcalf), discovered in 1847.

*March 1*: Death of John Adelbert Parkhurst. Born in 1861, he was an American astronomer at the Yerkes Observatory, observing variable stars; observed the total solar eclipses of 1918, 1923, and 1925; FRAS 1905.

*March 2:* Birth of Sergey Ivanovich Syrovatskii, a Soviet astrophysicist at the Lebedev Physical Institute, Moscow, whose main field of study was magnetohydrodynamics of the solar corona; died 1979.

*March 2:* Birth of Bertrand John Harris, a British astronomer at the Royal Observatory, Greenwich (1946–57), and the Perth Observatory, Western Australia (1957–74); involved in several international co-operations; observed proper motions of stars and cometary positions; FRAS 1951; died 1974.

*March 7*: Death of Sir William Peck. Born in 1862, he was an amateur astronomer, lecturer, and writer; Director of the Edinburgh City Observatory (1889–1925); FRSE 1889; knighted 1917.

*March 22*: Grigory Abramovich Shajn (Simeis Observatory, Crimea) began his first night of observations for asteroids and found a diffuse object of magnitude 11. The following night Josep Comas Sola (Fabry Observatory, Barcelona) also found the comet. It was a very distant object, closest to the Earth on March 25 (3·4159 AU) and moved very slowly away. It was last seen on June 17, when it was magnitude 14. The comet reached perihelion on September 6 ($q$ = 4·1808 AU) and was recovered after solar conjunction on October 16. The comet was followed by large telescopes until 1926 March 9 and again from 1926 October 15 until 1927 March 4 [Comet C/1925 F1 (Shajn-Comas Sola)].

*March 24*: William Reid (Rondebosch, South Africa) discovered an 8th-magnitude comet in Virgo, while searching for comets. It was confirmed by professional observatories and remained consistently magnitude 8, although a short tail began to appear. The comet was closest to the Earth on May 18 (1·0505 AU) and moved south, brightening slightly to magnitude 7. After perihelion on July 29 ($q$ = 1·6332 AU), it moved north and faded, until it was lost in the Sun's glare on 1926 January 12. The comet was observed again from 1926 July 17 to December 31, when it had faded to magnitude 17. The orbital period is about 6000 years [Comet C/1925 F2 (Reid)].

*March 27*: Death of Carl Gottfried Neumann. Born in 1832, he was a German mathematician and physicist, working on Newtonian mechanics.

*April 3*: Lucien Orkisz (Mount Lysina, near Cracow, Poland) discovered this 9th-magnitude comet two days after perihelion ($q$ = 1·1095), as it came out of the Sun's glare. It brightened slightly to magnitude 8 during most of April and was closest to the Earth on May 6 (1·4759 AU). A large number of observations were made from European observatories. The comet began to fade to magnitude 9 in mid-June and magnitude 11 in mid-July. It was followed during the rest of the year and was last observed on 1926 May 12. The orbit is distinctly hyperbolic, and the comet will never return [Comet C/1925 G1 (Orkisz)].

*April 15*: Death of Willem Henri Julius. Born in 1860, he was a Dutch professional astronomer at the University of Utrecht, studying solar spectra at the Heliophysical Observatory.

*April 22*: Birth of John Edward Geake, a British planetary scientist at UMIST (1957 – 92), studying the surfaces of the Moon and the satellites of Jupiter and Saturn; FRAS 1953; died 1998.

*April 30*: At about 8.15 pm a bright light was seen in the sky and detonations were heard, as three stones fell at Queen's Mercy, near Malatiele, South Africa (now Lesotho). Several masses totalling about 7 kg were recovered, although some had been broken up by a medicine man. It is an H6 chondrite [Queen's Mercy Meteorite].

*May 2*: Death of Johann Palisa. Born in 1848, he was an Austrian astronomer at the Austrian Naval Observatory in Pola, where he discovered 28 asteroids, and at the Vienna Observatory, discovering another 94 asteroids; searched for intra-Mercurian asteroids during the total solar eclipse of May 1883; prepared photographic plates for the *Palisa-Wolf Sternkarten* star atlas.

*May 3*: At midday a meteorite landed in the village of Vilarelho da Raia, 8 km north of Chaves, Portugal. Two very strong explosions were heard, followed by a sound resembling cannon fire. Three pieces, weighing 2·95 kg, were recovered, showing a brown-black crust around grey rock. The meteorite is a howardite, a type found on a body such as (4) Vesta [Chaves Meteorite].

*May 14*: Periodic Comet Schorr, discovered in 1918, returned to perihelion ($q$ = 1·8307 AU) but was not recovered despite several photographic searches. The comet remains lost [Comet D/1918 W1 (Schorr)].

*May 16*: Birth of Nancy Grace Roman, an American astronomer, working on stellar spectroscopy at the Yerkes Observatory, and radio astronomy at the Naval Research Laboratory (1954–9); Chief of Astronomy at NASA (1959–79), on orbital astronomical satellites leading to the *Hubble Space Telescope*; died 2018.

*May 16*: Death of the Reverend Aloysius Laurence Cortie SJ. Born in 1859, he was a Jesuit priest and mathematics teacher at Stonyhurst College; FRAS 1891; observed the total solar eclipses of 1905, 1911, and 1914; delegate at the International Union for Co-operation in Solar Research; Director of the Stonyhurst Observatory (1919–25).

*May 25*: Robert Watson (Beaufort West, Cape Province, South Africa), an amateur astronomer, was walking to work shortly before sunrise (5.50 am), when he noticed a star in line with α Crucis and β Carinae. On checking *Norton's Star Atlas*, he recognized it was a nova (mag. 2·3). As he was a telegraphist, he immediately sent a message to the Royal Observatory, Cape Town, which confirmed the discovery.

The nova continued to brighten to magnitude 1·2 on June 9. Observatories in the Southern Hemisphere began taking spectra, showing a hot (Class F) continuum but hydrogen emission lines soon appeared. The nova faded to magnitude 4 on July 4 but brightened again to magnitude 1·9 on August 9. Fading resumed, but the star remained a naked-eye object until the end of the year. It faded very slowly to mag. 6·5 in 1927, 7·5 in 1928, and 9·5 in 1934. In February 1928 Bernhard Hildebrandt Dawson (La Plata Observatory, Argentina) discovered a nebula around the star. It is now at minimum (mag. 11·9) [RR Pictoris].

*May 29*: Death of Vitold Karlovich Tserasky. Born in 1849, he was a Russian astronomer, Director of the Moscow University Observatory (1890–1916); worked on the photometry of variable stars with his wife Lydia Petrovna Tseraskaya (1855–1931) and created a reference library of photographic plates.

*June 3*: Death of Nicolas Camille Flammarion. Born in 1842, he was a French amateur astronomer who became famous for his books on astronomy, particularly Mars; founder and first president of the Société Astronomique de France and its journal *l'Astronomie* in 1887.

*June 11*: Predictions were made for this very favourable return of Periodic Comet Tempel 2, which allowed Joachim Otto Stobbe (Hamburg Observatory) to recover the comet at magnitude 12. The comet steadily brightened and was closest to the Earth on July 26 (0·3202 AU). It was about magnitude 6·5 and had a short, fan-shaped tail. Then the comet faded fairly quickly to magnitude 12 on November 18 and magnitude 16 when last seen on December 13. Several spectra were obtained showing absorption bands due to $C_2$ and cyanogen [Comet 10P/Tempel 2].

*June 25*: A meteorite landed at Renca, San Luis in Argentina. About 300 g of this L5 chondrite was recovered [Renca Meteorite].

*July 4*: Death of Colonel Ernest Elliott Markwick. Born in 1853, he was a British army officer and amateur astronomer, FRAS 1879; founder member of the BAA and President (1912–14); variable-star observer, discovering the variables T Centauri and RY Sagittarii; Director of the BAA VSS (1899–1909).

*July 7*: Death of Karl Hermann Gustav Müller. Born in 1851, he was a German astronomer at the Astrophysical Observatory, Potsdam (1877–1921), studying the solar spectrum and the photometry of planets and asteroids; compiled the *Potsdam Durchmusterung* star catalogue; observed the transit of Venus in 1882 and the total solar eclipses of 1887 and 1900; Secretary of the Astronomische Gesellschaft (1896–1924).

*July 8*: Birth of Marat Usmanovich Sagitov, a Soviet physicist, studying gravity fields of the Earth, Moon, and Mars' moon Phobos; died 1988.

*July 13*: Micha Kamienski predicted the return of Periodic Comet Wolf, which was recovered by Wilhelm Heinrich Walter Baade (Hamburg Observatory) when only magnitude 15. The comet barely brightened during August and was closest to the Earth on September 21 (1·5137 AU). After perihelion on November 8 ($q$ = 2·4347 AU), it slowly faded and was last seen on December 19 [Comet 14P/Wolf].

*July 14–22*: A meeting of the International Astronomical Union was held at Cambridge, England, where there was controversy over still excluding delegates from the defeated Central Powers. It was decided to continue starting the Julian Day at noon.

*July 20*: An annular solar eclipse was only visible from the South Pacific [Saros 125].

*July 23*: King George V and Queen Mary visited the Royal Observatory, Greenwich, as part of the 250th anniversary celebrations.

*July*: A nova was recorded in the Triangulum Galaxy (Messier 33).

*July*: Nine pieces of iron were found by brick workers at the Lundwall Brickworks in Opava, Czechoslovakia. They formed a 20-m circle in a settlement of Palaeolithic hunters dating from 16 000 BC. The 5-percent nickel and Widmanstätten patterns reveal their meteoritic nature [Opava Meteorite].

*August 14*: Alexandre Schaumasse (Nice, France) recovered Periodic Comet Borrelly close to the predicted position at magnitude 15. The comet gradually brightened to magnitude 11 at the end of September but had no tail. It reached perihelion on October 7 ($q$ = 1·3882 AU) but moved towards the Earth, as it moved away from the Sun. It remained at magnitude 11 until perigee on December 14 (0·9739 AU). Then it faded at the beginning of 1926 and was last seen on May 11 [Comet 19P/Borrelly].

*August 16*: Birth of Umberto Dall'Olmo, an Italian history scholar at the University of Bologna, who wrote articles on medieval records of eclipses, aurorae, meteors, and comets; amateur astronomer, observing the solar eclipse of 1961; died 1980.

*August 21*: Grigory Abramovich Shajn (Simeis Observatory, Crimea) discovered asteroid 1925 QD on a photographic plate, which was also imaged on August 24. No orbit could be calculated. In 1988 Syuichi Nakano announced that these were pre-discovery observations of Periodic Comet Whipple, discovered in 1933. The comet was closest to the Earth on September 6 (1·6695 AU) and reached perihelion on 1926 February 4 ($q$ = 2·4837 AU) [Comet 36P/1925 QD (Whipple)].

*August 28*: Ms. M. Wolfert (Terneuzen, Zeeland, the Netherlands) observed a bright fireball across the sky at about 11.30 am, describing it as "a golden egg with a golden arrow." The meteor broke into three pieces and landed 45 km north, near the village of Ellemeet, "with a loud noise, so loud that horses and cows took fright." The main mass of 970 g broke into four pieces. Most were sent to the Sonnenborgh Observatory, Utrecht, for analysis. A second piece turned up in 1927 but had been exposed during the winter and was heavily weathered. The meteorite is a diogenite, probably from the asteroid (4) Vesta [Ellemeet Meteorite].

*August 28*: In the early evening a fireball nearly as bright as the Full Moon was seen above the town of Lanzenkirchen, Austria. After loud detonations, two stones fell. One weighing 5 kg was recovered the next day. A second 2-kg mass was found five weeks later. The meteorite is an L4 chondrite [Lanzenkirchen Meteorite].

*September 4*: At about 4 pm two stones were seen to fall near the town of Numakai, Hokkaido, Japan. M. Tanaka found one piece. It is an H4 chondrite [Numakai Meteorite].

*September 9*: Periodic Comet Brooks 2 had been missed in 1910 and 1918, so there was some uncertainty in its position. Grigory Abramovich Shajn (Simeis Observatory, Crimea) found images of the comet on a pair of photographic plates on September 21, when it was closest to the Earth (0·8985 AU) and magnitude 12·5. Then he found it on a pair taken on September 9. The comet was magnitude 13 during October and reached perihelion on November 1 ($q$ = 1·8617 AU). Then it faded and was last seen on 1926 January 8 [Comet 16P/Brooks 2].

*September 14*: Max Wolf (Heidelberg Observatory) discovered a nova (mag. 8·6) in Aquila on photographic plates, which he confirmed on September 19. A check on previous photographs showed no star at the position. Annie Jump Cannon (Harvard College Observatory) examined 130 plates from 1899 to 1925 and found no object until September 8, when it was mag. 9·8, and 9·2 on September 23. The star was still about magnitude 9 in October and November.

Several spectra were obtained, as the nova continued to fade very slowly to magnitude 10·6 in 1927, 11·7 in 1928, and 14·8 in 1934. It is now at minimum (mag. 16·5) [DO Aquilae].

*September 15*: Death of Henry Curwen Lord. Born in 1866, he was an American astronomer at the Ohio State University, observing radial velocities and the spectrum of the solar eclipse in May 1900; FRAS 1897.

*September 16*: Death of Aleksander Aleksandrovich Friedmann. Born in 1888, he was a Russian mathematician and physicist, who wrote papers on the expansion of the Universe and the curvature of space from 1922 to 1924; Director of the Geophysical Observatory, Leningrad, 1925, and reaching 7400 m in a balloon flight.

*September 20*: Frank Elmore Ross (Yerkes Observatory) discovered what appeared to be a nova (mag. 9·1) in Aquarius, recorded on an archive plate taken on 1907 August 12. Ida Elizabeth Woods (Harvard College Observatory) checked 677 plates taken from 1890 to 1925 and found that the star was fainter than magnitude 12 on 1907 July 16 but 8·4 on August 8. It faded from 9·7 on August 14 to 12·6 on August 27. The star was at minimum (mag. 17·5) until 1962, when it underwent another outburst. At first designated a recurrent nova, it is now an SU UMa dwarf nova [VY Aquarii].

*October 20*: Periodic Comet Faye reached perihelion on August 7 ($q = 1{\cdot}6180$ AU). Wilhelm Heinrich Walter Baade (Hamburg Observatory) recovered the comet close to the predicted position. Later Joachim Otto Stobbe (Hamburg Observatory) found further images taken on August 29 and September 11. The comet remained about magnitude 14 during the rest of the year with a well defined coma and a faint tail. After being closest to the Earth on 1926 January 2 (1·2812 AU), it steadily faded and was last seen on March 14 [Comet 4P/Faye].

*November 13*: Leslie Copus Peltier (Delphos, Ohio) discovered a comet in Bootes, while searching for comets. He described it as magnitude 8–9 and moving rapidly south. The Harvard and Yerkes Observatories were not able to confirm the discovery. On November 19 Antoni Wilk (Cracow, Poland) discovered an 8th-magnitude comet well to the southwest of Peltier's discovery, so it took some time to confirm the comets were identical, its motion exaggerated by a close perigee on November 17 (0·5743 AU). The comet was well observed at the end of November, as it reached perihelion on December 7 ($q = 0{\cdot}7636$ AU). Then the comet began to fade to magnitude 10 by the last observation on December 31, as it slipped over the horizon [Comet C/1925 V1 (Wilk-Peltier)].

*November 17*: While making observations of the several comets recently discovered, George van Biesbroeck (Yerkes Observatory) found another much brighter comet in Ursa Major. Having reached perihelion on October 2 ($q = 1{\cdot}5662$ AU), it was magnitude 8 and had a distinct tail. The brightness remained, as the comet approached the Earth and was at perigee on 1926 January 29 (1·3512 AU). Then it began to fade and was last seen on June 10. The comet had been bright enough for spectra showing $C_2$ and cyanogen absorption bands [Comet C/1925 W1 (Van Biesbroeck)].

*November 28*: Death of Jean-Baptiste Alfred Pérot. Born in 1863, he was a French physicist, who developed with Charles Fabry the Fabry-Pérot interferometer, used in spectroscopy; awarded the Janssen Medal (1912) and the Rutherford Medal (1918).

*December 13*: George Edmund Ensor (Pretoria, South Africa) discovered the eleventh comet of the year in Reticulum, while observing variable stars. It was magnitude 8 with a tail 15 arcminutes long. The comet was observed from South Africa until 1926 January 22, when it entered the Sun's glare. Perihelion came on February 11 ($q = 0{\cdot}3226$ AU) and perigee on March 12 (0·8750 AU). The comet was spotted by observers from a balloon on February 23. Very faint images were recorded on March 10 and 16, with the final observation on April 13 [Comet C/1925 X1 (Ensor)].

*December 14*: Death of John Browning. Born in 1835, he joined his father's business in London, making nautical instruments, optics, and spectroscopes; wrote *How to Work with the Spectroscope* (1878); FRAS 1865.

*December*: A nova was recorded in the Triangulum Galaxy (Messier 33).

Willem Jacob Luyten (Harvard College Observatory) analysed photographs of Proxima Centauri from 1889 to 1902 and concluded that it was very slightly closer to the Earth than $\alpha$ Centauri.

Nineteen novae were recorded in the Andromeda Galaxy (Messier 31).

Charles Pollard Olivier published *Meteors*.

A small piece of iron meteorite (33 g) was found at Murchison Downs, Western Australia. Its mineral content is identical to the impactor at the Dalgaranga meteorite crater 200 km to the southwest. It is likely to have been carried there by Aboriginal Australians as a ritual trophy [Murchison Downs Meteorite].

Ford Howard Story (Glenormiston Station, Queensland) found an iron meteorite 40·8 kg in weight 8 km west of his house. He sold it to the University of Queensland in 1926 [Glenormiston Meteorite].

Hanns Walter Kornblum and Ernst Krieger released *Wunder der Schöpfung* (*Wonder of the Creation*), a documentary film on astronomy and space.

The Museum of the History of Science opened in Oxford, containing many early astronomical instruments.

*1825*

*March 1*: Birth of Henry Martyn Parkhurst, an American stenographer at the US Senate, an amateur astronomer, observing the Great Comet C/1843 D1 and a programme of Mira variable stars from 1883 to 1907; died 1908.

*March 10*: Death of Karl Brandan Mollweide. Born in 1774, he was a German mathematician and astronomer at the Pleissenburg Observatory and the University of Leipzig.

*March 23 & 24*: Captain Henry Kater (Regent's Park, London) made detailed observations of the asteroid (2) Pallas, which improved the asteroid's orbit.

*May 1*: Birth of Johann Jakob Balmer, a Swiss schoolteacher and mathematician, discovered a formula for calculating wavelengths of spectral lines, noted in the Balmer series; died 1898.

*May 9*: Birth of George Davidson, an American scientist at the US Coast Survey (1845–95), surveying the Pacific coastline, extended to Alaska; Professor of Geography at the University of California; made astronomical and magnetic observations, including the total solar eclipses of 1869 and 1880 and the transits of Venus in 1874 and 1882; died 1911.

*May 19*: Jean Félix Adolphe Gambart (Marseilles, France) discovered a tailless comet about 2 arcminutes across in Cassiopeia. It developed a distinct tail by the end of the month. The comet was at perihelion on May 31 ($q = 0{\cdot}8890$ AU). On June 10 it was about magnitude 6 when closest to the Earth (0·7808 AU) before fading, and was last observed on July 15 [Comet C/1825 K1 (Gambart)].

*May 20*: Birth of George Phillips Bond, an American astronomer, son of William Cranch Bond, succeeded his father as Director of the Harvard College Observatory (1859–65); discovered Saturn's moon Hyperion in 1848 and Comet C/1850 Q1 (Bond); died 1865.

*June 21*: Death of Johann Carl Burckhardt. Born in 1773, he was a German astronomer at the Gotha Observatory and the Observatoire de l'École Militaire in Paris; calculated orbits of asteroids and comets.

*June 27*: Death of Edward Pigott. Born in 1753, he was the son of the British astronomer Nathaniel Pigott; observed the transit of Venus in 1769 and the transit of Mercury in 1786; discovered a nebula (the Black Eye Galaxy, Messier 64) in Coma Berenices in 1779, short-period comet 226P/Pigott-LINEAR-Kowalski in 1783, the first Cepheid variable η Aquilae in 1784, and the variables R Scuti and R Coronae Borealis in 1795.

*July 13*: Johann Franz Encke calculated a new orbit for Encke's Comet in June 1825 and found that it was very unfavourably placed on the far side of the Sun. Jean Élix Benjamin Valz (Nîmes, France) suspected a comet near the predicted position, but his next observation was only on the 25th. Encke's Comet did brighten during August and was observed by a number of European astronomers. It was last seen on September 7 and reached perihelion on September 16 ($q = 0{\cdot}3448$ AU) [Comet 2P/Encke].

*July 15*: Jean Louis Pons (La Marlia, Italy) found a faint comet in Taurus, while searching for Encke's Comet. It was also discovered by Wilhelm von Biela (Josephstadt, Austria) on the 20th and James Dunlop (Paramatta, New South Wales) on the 21st. In August the comet brightened and developed a tail 1·5 degrees long. It became a naked-eye object in September and could be seen in bright moonlight. The comet was closest to the Earth on October 12 (0·6177 AU), when the curved tail was 14 degrees long. By now it was only visible from the Southern Hemisphere and put on a spectacular show. The comet reached perihelion on December 11 ($q = 1{\cdot}2408$ AU) and was lost in the Sun's glare. A single observation was made by Lieutenant George Peard on board HMS *Blossom* at Buenos Aires on 1826 February 7. The comet was recovered by European observers in April and last seen on July 8 [Comet C/1825 N1 (Pons)].

*August 9*: Jean Louis Pons (Florence, Italy) discovered a faint comet in Auriga, which was observed from Europe until August 27. It remained faint and reached perihelion on August 19 ($q = 0{\cdot}8835$ AU) [Comet C/1825 P1 (Pons)].

*September 27*: Russian captain Otto von Kotsebue, commanding the sloop *Predpiyatiye* (*Enterprise*), was in Honolulu harbour, when he recorded a meteorite landing. According to his ship's log "while the heavens were quite clear, a thick black cloud formed itself over the island . . . The wind was perfectly calm, until all of a sudden, a violent gust blew from the northeast, and at the same time a crashing noise proceeded from the cloud as if many ships were firing their guns." Two stones fell into a street and broke into several pieces. About 2·4 kg of this L5 chondrite was recovered [Honolulu Meteorite].

*October 26*: Birth of Johann Friedrich Julius Schmidt, a German professional astronomer at the Bonn and Olmütz Observatories, making numerous drawings and measurements of lunar features; Director of the Athens Observatory (1854–84), completing a 2-metre map of the lunar nearside in 1874; observed T Coronae Borealis four hours before its outburst in 1866; died 1884.

*November 7*: Jean Louis Pons (Florence, Italy) discovered yet another comet near γ Eridani, when it was round and lacked a tail. It was at perigee on December 3 (1·8343 AU) and remained a faint object, difficult to observe during December. Observations continued at the beginning of 1826, and the comet was last seen on April 10. It remained a distant object and was at perihelion on 1826 April 22 ($q = 2{\cdot}0077$ AU) [Comet C/1825 V1 (Pons)].

Aristides Franklin Mornay recognized that an iron mass being used as an anvil in the village of Yanhuitlan, Oaxaca, Mexico, was a meteorite. This IVA iron meteorite weighed 421 kg, rather weathered by exposure for 20 000 to 30 000 years and affected by heating during metalwork [Yanhuitlan Meteorite].

Joseph Johann von Littrow published *Populäre Astronomie* (*Popular Astronomy*).

Montgomery Robert Bartlett published *Young Ladies' Astronomy*.

*1725*

*April 13*: A partial solar eclipse was visible only from the South Pacific [Saros 105].

*April 27*: A total lunar eclipse was visible from East Asia, the Pacific, and the Americas [Saros 117].

*May 12*: A partial solar eclipse was visible from northern North America and the Arctic [Saros 143].

*June 19*: An eclipse of Jupiter's moon Io was observed from Rome.

*July 3*: A meteor was observed to fall near Mixbury, Oxfordshire. An object weighing 9 kg was retrieved, but it is doubtful that it was the meteorite [Mixbury Meteorite].

*July 7*: Ignatius Kögler (Peking, China) observed an eclipse of Jupiter's moon Io.

*July 21*: Samuel Molyneux (London) observed an eclipse of Jupiter's moon Io. It was also observed from Rome.

*July 28*: James Bradley (Wanstead, near London) began a series of observations on the eclipses of Jupiter's moon Io. Observations were also made from Rome and Lisbon in order to calculate the relative longitudes.

*August 16*: Giuseppe Campani (Rome) made a detailed observation of the lunar crater Plato.

*September 11*: Birth of Guillaume-Joseph-Hyacinthe Jean-Baptiste LeGentil de la Galaisière, a French astronomer, who questioned whether transits of Mercury and Venus could be measured accurately to calculate planetary distances but spent eleven years attempting to observe the transits of Venus in 1761 and 1769 without success; died 1792.

*September 24–26*: Arthur Dobbs (Trinity College, Dublin) observed bright auroral displays.

*October 21*: John Burroughs (Bristol, England) observed a lunar eclipse and recorded timings. The eclipse was total from Europe, Africa, the Middle East, and Asia [Saros 122].

*November 4*: A partial solar eclipse was visible only from the Southern Ocean and Antarctica [Saros 148].

*November 10*: William Derham (Windsor, Berkshire) observed an eclipse of Jupiter's moon Europa.

*December 8*: William Derham (Windsor, Berkshire) observed an eclipse of Jupiter's moon Io.

*December*: Samuel Molyneux (London) and James Bradley (Wanstead, near London) began a series of accurate observations of the star γ Draconis to look for parallax in the star. Instead they discovered the aberration of light.

George Lynn (Northampton) observed eclipses of Jupiter's moons.

John Flamsteed's widow Margaret Flamsteed and his assistants Joseph Crosthwait and Abraham Sharp published Flamsteed's star catalogue *Historia Coelestis Britannica*.

Eustachio Manfredi published ephemerides for the planets from 1726 to 1750.

*1625*

*January 26*: Wilhelm Schickard (Tübingen, Württemburg) discovered a comet in the evening sky, describing it as a "long hair extending west to east, slightly upwards." On February 11 the comet's tail extended 45 degrees from Eridanus to Lepus. On the 12th Schickard found the comet had moved westward and its tail stretched from Eridanus to Lepus and past Sirius, fully 60 degrees long. This was the last observation.

*March 8*: A total solar eclipse was visible across Mexico and the Caribbean [Saros 114]. Maximum totality lasted 3 min. 50 sec.

*June 8*: Birth of Giovanni Domenico Cassini, an Italian-French astronomer, observed the planets, establishing the rotation periods of Mars and Jupiter, discovered Saturn's moons Iapetus, Rhea, Tethys, and Dione and the main division in Saturn's rings; established the Cassini family of astronomers in Paris; died 1712.

*August 13*: Birth of Erasmus Bartholin, a Danish doctor and astronomer, professor at the University of Copenhagen, edited Tycho Brahe's works, and observed comet C/1665 F1; died 1698.

*December 16*: Birth of Erhard Weigel, a German mathematician, who attempted to rename all the constellations using European heraldry; died 1699.

Johannes Kepler published *Tychonis Brahei Dani hyperaspistes adversus Scipionis Ciaramontii* (*Defender of Tycho Brahe the Dane against Scipio Ciaramonti*) on Tycho's observations of the comet of 1577.

Death of Johann Bayer. Born in Bavaria in 1572, his star atlas *Uranometria* introduced Greek letters for stars and 12 new constellations for the southern sky.

*1525*

*January 6*: Birth of Caspar Peucer, a German astronomer, Professor at the University of Wittenberg, who wrote on astronomy and observed the supernova of 1572; defended the practice of astrology; died 1602.

*December 1*: Birth of Tadeas Hajek (Thaddaeus Hagecius), a Bohemian doctor, mathematician and leading astronomer, who wrote numerous astronomical books; observed the bright comets C/1556 D1, C/1577 V1, and C/1580 T1 and the supernova of 1572; died 1600.

Death of Mahmud ibn Qutb al-Din Muhammad Mirim Celebi. Born in about 1475 he was an Ottoman official and astronomer, who wrote on astronomy, astrology, optics, and history.

A meteorite was seen to fall near Milan, Italy; an uncertain object [Milan Meteorite].

*1425*

(about) Ibn al-Attar at Cairo was completing a treatise on building various kinds of quadrants.

*1325*

*May 22*: A very bright meteor was seen from Florence, Italy, recorded by Johannes Villanus in his *Historia Universalis*.

Roger of Stoke completed an elaborate astronomical clock at Norwich Cathedral.

(about) Birth of Henry of Langenstein, a German astronomer, who observed comet C/1368 E1 and wrote a number of books on astronomy; very critical of French court astrologers; died 1397.

(about) Ibn al-Sarraj in Aleppo, Syria, was constructing two kinds of astrolabe.

(about) Al-Bakhaniqi in Cairo compiled a table of co-ordinates for constructing astrolabes used at different latitudes.

*1225*

*March 29*: Japanese astronomers observed a comet, according to *Nihon Temmon Shiryo*. It was also seen on March 31 and April 2. In Russia the *Nikonian Chronicle* recorded that "a star appeared called 'the Lance', which extended from east to west in the form of a lance, and thus it remained for seventeen days." The report would be consistent with a comet having a long, straight tail and appearing in the morning sky before sunrise.

Qaisar ibn Abi-l-Qasim (al-Hanafi) constructed a celestial globe with horizon and meridian circles.

(about) Birth of Thomas Aquinas an Italian Catholic theologian, who united Aristotle's cosmology with Church doctrine; died 1274.

(about) Alexandre de Villedieu wrote *De Sphaera*.

*1125*

A very bright meteor was seen to fall from the sky, recorded by Honorius of Autun in his *Imago Mundi* (*Image of the World*).

*925*

*April 11*: An eclipse of the Moon was observed from Baghdad. The total lunar eclipse was visible from the Middle East and Asia [Saros 85].

*July 22 & 23*: The Chinese saw that "many stars flew west at midnight; small stars flew southwest," recorded in *Ssu-tien-k'ao*.

*October 30*: The Chinese observed a comet in the southwest with its tail pointing southeast, recorded in *Hou Han Shu*.

An aurora was seen from Egypt.

(about) Abu Ali al-Husayn ibn Muhammad al-Adami, an Arab astronomer and instrument maker in Baghdad, wrote a handbook on sundials *Techniques, Walls, and the Making of Sundials*.

*825*

*April 27*: The Chinese observed Mars cross through the star cluster Praesepe in Cancer.

(about) Al-Hasan, an Arab astronomer at Baghdad, built an astronomical observatory in his house and wrote his *Book on the Movement of the Sphere*.

*725*

*February 11*: The Japanese observed a comet in Cassiopeia, recorded in *Dainihonshi*.

*625*

The Chinese astronomer Wang Hs'iao-t'ung completed *Jigu Suanjing* (*Continuation of Ancient Mathematics*), including astronomical constructions and was working on the revision of the Chinese calendar.

*525*

Dionysius Exiguus published a table calculating the date of Easter, using the Christian Era for the first time.

*325*

*June 19–August 25*: The Roman emperor Constantine I held the Council of Nicaea on Christian theology and fixing the date of Easter as the first Sunday after the first Full Moon following the Vernal Equinox.

*225*

*December 9*: Chinese astronomers discovered a 'sparkling star' in Leo Minor with a tail stretching across the Head of Leo, recorded in *Sung Shu* and *Chin Shu*. The comet was in the morning sky before dawn.

*125*

*April 5*: An eclipse of the Moon was observed by Ptolemy at Alexandria, where one-sixth of the disc was eclipsed. The partial lunar eclipse was visible from Europe, Africa, the Middle East, and Asia [Saros 53].

*December–January* (*126*): The Chinese discovered a 'guest star' between α Herculis and α Ophiuchi, probably a bright nova, recorded in *Hou Han Shu*.

Zhang Heng designed and constructed a hydraulic-powered armillary sphere.

(about) Death of Plutarch. Born in about AD 45, he was a Roman historian writing in Greek on ancient lives; also wrote *De facie in orbe lunae apparet* (*On the Moon's Face*) on the features seen on the surface of the Moon and a description of a total solar eclipse.

*76 BC*

*May*: The Chinese discovered a 'guest star' in Pisces, recorded in *Han Shu* and *T'ung K'ao*. Although generally regarded as a nova, it is more likely to have been a tailless comet.

Pliny the Elder wrote in his *Natural History* that "a spark was seen to fall down from a star and increase in size as it approached the Earth, and after becoming as large as the Moon it diffused a sort of cloudy daylight, and then returning to the sky changed into a torch." This could describe a comet or an exceptionally bright fireball.

*176 BC*

*August*: Livy recorded that "at Tusculum a torch was seen in the sky." This may have been a comet or, more likely, a bright meteor.

*276 BC*

(about) Birth of Eratosthenes of Cyrene, a Greek mathematician, astronomer, poet, and scholar, Chief Librarian at the Library of Alexandria, founded early chronology, estimated the Earth's circumference as 252000 *stadia* (about 47 880 km); died about 195 BC.

*676 BC*

*April 15*: There was an eclipse of the Sun observed from China, recorded in *Chun Tsew*. The eclipse was total from Central India, Southeast Asia, and China [Saros 47].

*776 BC*

*July 19–23*: The 1st Olympic Games were held at Olympia, Greece, when Coroebus of Elis won the stadion running race. The Olympic *stadion* (190 m) became a standard unit of length for Greek mathematicians and astronomers.

*976 BC*

Pliny the Elder wrote in his *Natural History* that "a terrible comet was seen by the people of Ethiopia and Egypt, to which Typhon the king of that period gave his name, it had a fiery appearance and was twisted like a coil, and it was very grim to behold: it was not really a star so much as what might be called a ball of fire." The chronology of the time was very uncertain.

*7176 BC*

A very strong solar flare struck the Earth, recorded in carbon-14 levels in the tree rings of European Oaks and Eastern Alpine Conifers corroborated by enhanced beryllium-10 and chlorine-36 levels in Greenland ice cores. The event was comparable to the AD 774 record and much stronger than the Carrington Event of September 1859 [Miyake Event 7176 BC].

## OBITUARY

### *Reverend Robert Owen Evans (1937–2022)*

The late Robert (Bob) Evans OAM was an extraordinary visual astronomer. His work in supernova discovery is unparallelled, having discovered 42 supernovae visually, and another five from photographs, a record that is unlikely ever to be surpassed.

Bob Evans took up supernova hunting around 1955, but his first adequate instrument, a 10-inch Newtonian telescope, was assembled only in about 1968. He made his first official supernova (SN) discovery in 1981. By 1986, of the 13 SNe discovered visually, 11 were found by Bob. At that time Bob noted one advantage of visual observing was the possibility of immediate notification of discoveries — as is true today. Many of his detections were made before maximum light, where time is very much 'of the essence', to give professional observatories a chance to do their best research.

While living in Coonabarabran, New South Wales, he used his own 16-inch (40-cm) telescope. From early 1995 to mid-1997 he also had limited access to the 40-inch telescope at Siding Spring Observatory, resulting in about 10 000 galaxy observations, another three visual supernovae discoveries, and an additional four supernovae spotted on photographs made at the observatory. For an amateur astronomer, being granted access to professional telescopes is a rare honour, but Bob was a rare and gifted amateur. Some have said that he possessed preternatural observing skills; in reality he worked very hard studying and memorizing photographs of hundreds of galaxies and spent hours every night observing. He became extremely good at it.

By 2001, he had made 33 visual discoveries and by the end of 2005, despite the increasing competition from automated telescopes, the total number had already increased to 40 visual supernova discoveries plus one comet. In 2005, Evans relied almost exclusively on his 31-cm Dobsonian. He reported 6814 galaxy observations in a period of 107 hours and 30 minutes, spread out over 77 nights. During that time, he found four supernovae; three had already been discovered by others, the fourth was SN 2005df, which was Evan's third supernova discovery in NGC 1559 (after SN 1984J and SN 1986L) and his 40th visual discovery. Supernova 1983N, spotted by Evans in 1983 in the galaxy M 83 long before it reached its peak, turned out to be the first discovery of a new type of supernova, later named Type 1b.

Bob Evans also featured prominently in Bill Bryson's book *A Short History of Nearly Everything* which quotes him as saying "There's something satisfying, I think, about the idea of light travelling for millions of years through space and just at the right moment as it reaches Earth someone looks at the right bit of sky and sees it. It just seems right that an event of that magnitude should be witnessed."

In 1990 Bob became a trustee of the Linden Observatory after the observatory was left in Trust by the Australian telescope maker Ken Beames in 1989 for the purpose of education in astronomy. He was the longest-serving trustee, and his tenure brought much needed stability to the observatory and the work to conserve the site for future generations of amateur astronomers.

As anyone who shared the observing field with Bob will attest, his knowledge of the sky and ability to use a telescope to find and observe galaxies was extraordinary. Bob's abilities as a visual observer were unique, and in this age of computerized telescopes and cameras, there may never be another quite like him. The astronomical community was privileged to have him as a member, and he will be sorely missed.

Bob Evans passed away on 2022 November 8, aged 85, following a short illness. He is survived by his wife and four daughters. — Ian Bridges.

[Editorial note: The Editors are grateful for the assistance of Professor F. G. Watson.]

## *Here and There*

A DEGREE OF ERROR

Campi Flegri's biggest eruption, which happened 36,000 years ago, wasn't quite large enough to qualify as 'super', but it was still Europe's greatest volcanic blast in at least 200,000 years. It dumped ash across the Mediterranean region and spawned a bitter volcanic winter across Europe, with temperatures reduced by up to 9 C (48·2 F). — *BBC Science Focus*, 2024 July, p. 70.

## 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.

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

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

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

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Figures may be submitted, separately, as standard Adobe PostScript files, or as PDF files but authors must ensure that they fit properly onto A4 paper.

The Editors welcome contributions to the *Here and There* column. Only published material is considered, and should normally be submitted in the form of a single legible photocopy of the original and a full reference to the publication, to facilitate verification and citation.



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## NOTES TO CONTRIBUTORS

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