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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2023 October 13 at $16^h\ 00^m$
in the Meeting Room of the Linnean Society, Burlington House

Mike Edmunds, *President*
in the Chair

The President. Good afternoon and welcome to this A & G Highlights meeting for October. This is a hybrid meeting. Those on-line will be muted and should use the chat facility to ask questions. These will be read out at the end of each talk by Dr. Sue Bowler.

It is my great pleasure to introduce our first speaker, Dr. Tim Lichtenberg, winner of the Winton Award in Geophysics for Early Achievement. He got his PhD in 2018 in the Department of Earth Sciences at ETH in Zurich. From 2018–2022 he was SNSF and Simons PDRF in the Atmospheric, Oceanic and Planetary Physics Department at the University of Oxford. Since 2022 he has been Assistant Professor at Kapteyn Astronomical Institute at the University of Groningen. I invite him to give his talk on 'Molten exoplanets as a window into the earliest Earth'.

Dr. Tim Lichtenberg. One of the greatest unsolved questions with regard to our origins and the diversity of life in the Universe is what the environment of nascent Earth looked like after planetary formation. Prebiotic synthesis in lab environments has made enormous strides in the past years uncovering chemical conditions that seem suitable to birth life as we know it *via* chemical means. These emergence paths rely on relatively stable atmospheric settings with a surface ocean and an atmosphere rich in feedstock molecules such as hydrogen cyanide. At the same time, exoplanet science has undergone a tremendous expansion in the number of detected planets, reaching the realm of high-density worlds potentially similar to the Earth in some aspects.

However, given that most exoplanets detected *via* the transit method orbit very close to their star, they receive intense stellar irradiation — seemingly disconnected from the planetary environment that we envision for the early Earth. However, those planets, in fact, enable us to probe key physics and chemistry of the earliest episodes of atmospheric formation of rocky planets in general. In particular, a key constraint on the origin of life is the apparent detachment of nitrogen and carbon oxidation states in extant biomolecules — nitrogen feedstocks are preferred in highly reduced forms, but carbon oxidation states of biomolecule precursors are preferred in neutral to mildly oxidising redox states. This places chemical constraints on the transition from the primary to secondary atmosphere on the early Earth.

Rocky planets are born from magma — the high-energy environment of planetary accretion vaporizes and melts new-born planets, similar to the long-term molten states of rocky exoplanets that orbit close to their primary star. By observing and characterizing the chemical redox environment of these atmospheres we can thus gain an understanding of the diversity of atmospheric regimes, and the likelihood for prebiotic chemical environments suggested by laboratory experiments. A key factor in the distribution of atmospheric volatiles is the internal chemical differentiation of planets — these set the distribution of redox-active elements such as iron, and thus drive atmospheric chemistry to first order. On the Earth we have evidence that internal processes strongly altered the atmospheric composition by redistributing core-forming metal and hydrogen during the early Hadean, together with loss of the primary atmosphere by atmospheric escape. The amount of change of atmospheric composition alters the greenhouse forcing of the planetary atmosphere. By studying atmospheric composition of exoplanets we can thus gain a first-order insight into the primary redox state of the planet.

Importantly, however, the planetary phase state has a first-order control on the fractionation of atmosphere-forming volatiles, such as nitrogen and carbon. These elements are distributed between core, mantle, and atmosphere. If the atmosphere is in equilibrium with a highly molten mantle, such as the magma-ocean epoch on Earth, for example, different atmospheres than for solid planets are expected. In the next few years there will be two primary means of obtaining access to this phase: detailed atmospheric characterization of individual planets that orbit inside the orbital runaway-greenhouse threshold, and demographic studies of the bulk densities and thus global compositions of exoplanets. Insight into both of these will be crucial for obtaining a better understanding of whether the chemical composition and distribution of volatile elements on Earth is rare or frequent among high-density planets. In the upcoming years, we will gain a better sense of the distribution of solid and largely-molten planets, and the effects of mantle phase state on planetary differentiation and atmospheric distribution, paving the way towards a more detailed exploration of wider-orbit planets. Understanding the time evolution of rocky planets and their outgassing atmospheres will be central to obtaining knowledge on the earliest atmospheric states of rocky planets in general, and thus being able to conclude back on our own world, and the nascent environment of the origins of life as we know it.

The President. Thank you very much for a fascinating talk. Can I, first of all, invite questions in the room?

Dr. Quentin Stanley. In the development of the planet there seemed to be the oxidation of the magma at the same time as the atmospheric escape. They seemed to be in conflict but I take it that it is much more complex than that?

Dr. Lichtenberg. There are multiple effects in the interior of the atmosphere that are happening at the same time, and this is exactly the point I want to make. In this particular case actually the internal processes and the atmospheric processes tend to oxidize the planet over time and especially with regard to these two mechanisms that are here, they both work in the same direction. There is a process which is called iron disproportionation in the interior, and atmospheric escape, both typically tend to oxidize the planet but on different time-scales and to different magnitudes. I think it will be an important challenge of the upcoming ten years or so to start trying to tear apart these processes, and understand which ones are overwhelming which other processes.

Mr. Horace Regnart. Do you agree that some or all of the numerous hypotheses as to the formation of life, when the time comes, may all be accurate postdictions?

Dr. Lichtenberg. I think, ultimately, that I am the wrong person to answer that question [laughter] but I can speculate.

The President. Speculate!

Dr. Lichtenberg. I think that you are probably right in that everything that we think at the moment is based on the fact that we have this one instance and one example and we try to make it work, given the facts that we have. I'm half-astronomer, half-geoscientist, and from my perspective what would be very interesting to see is whether there are any global biospheres within 10–20 pc. If there is something like this, we can actually empirically test whether other chemical signatures of other planets behave similarly to our own and then, I think, we are in a very different game. Then we can start to distinguish different postdictions from each other; so I think that you may be right that the origin-of-life hypotheses are postdictions. But I think they have very different origins and different evolutionary aspects that they bring in, and I think at some point there is a chance that we will distinguish at least some of them from each other, so I am an optimist.

The President. Have we any more questions on-line or in the room? No? Then can we thank Tim again for a fascinating talk. [Applause.]

Now we move on to the Fowler Award for young, promising geophysicists. Dr. Oliver Allanson is Assistant Professor in Space Environment in the Space Environment and Engineering Group in the School of Engineering at the University of Birmingham. He is also an Honorary Senior Lecturer in Mathematics at the University of Exeter. He holds a UKRI NERC Industrial Research Fellowship to understand better and improve our modelling of space science and space weather (2021–2026). He is particularly interested in the importance of non-linear physics in radiation-belt modelling, and his current work considers the fundamental theory, modelling, and observation of high-energy charged-particle dynamics in the plasma of Earth's radiation belts which he will now greatly simplify for us. The title of his talk is 'Understanding the Earth's radiation belts — our local, super-scale, relativistic particle accelerator'.

Dr. Oliver Allanson. It's an honour and a privilege to be able to talk to you today about the radiation belts, and I'd like to thank the RAS for the opportunity to do so. I'm giving quite a broad talk, and I know that there is a diverse audience today, so I really want to hammer home the point that science is a collective endeavour. I am and have been a part of the UK Space Science (MIST and UKSP) communities, which probably totals around 250 people. My specialism in terms of this talk is in the final few slides. So I'm giving a shout out to some colleagues and mentors that I have been lucky enough to work with. We are greater than the sum of our parts, and have had a lot of success in recent years building strong networks. Long may that continue.

Our story begins in the late 1950s which represents the beginning of the space age, with the successful launch of a series of *Sputnik* satellites by the Soviet Union and *Explorer* satellites by the United States. A team led by James Van Allen of the University of Iowa discovered one of the Earth's radiation belts. It was unexpected and not understood at the time, since the team were in fact looking to measure something called cosmic rays. However, the team measured an amount of radiation very much higher than expected at an altitude of approximately 1200 km, so much so that the instrument broke down. The discovery of the radiation belts has become synonymous with this now famous quote by Ernest Ray, a colleague of James Van Allen: "My God, space is radioactive". The discovery could have been heralded as one by the Soviet Union. But recorded history tells us that the former Soviet Union refused Australian colleagues the opportunity to analyse the data, and thus they missed this opportunity. So we now have our first piece of information. Space is not empty — it is full of radioactive material! This radioactivity is referring to energetic particles. And when we talk about radiation belts we are specifically talking about particles with velocities that are significant fractions of the speed of light, maybe even very close to the speed of light.

There is a fascinating history to tell regarding the early studies of the radiation belts, a sequence of at least two space-based nuclear tests by the USA, and three by the former Soviet Union, and no doubt a web of geopolitical concerns. However, that is not our story today. Instead I will tell you of the history of photons, electromagnetic forces, and charged particles that eventually become the radiation belts. In so doing I hope to give an appreciation of what a space scientist is considering, and contending with, and to convince you that the radiation belts are fascinating, complex, and rich with fundamental physics questions. We are lucky to be able to call it our laboratory.

The Sun is a very hot and very large body of gas, and overwhelmingly composed of hydrogen and helium. It is approximately 1·5 million km wide, meaning that over a million Earths would fit inside the Sun. Temperatures reach 15 million degrees in the core. For some context, the temperature of a gas stove on high might reach approximately 1000 degrees. Now, atoms and molecules very much prefer to remain neutral, which means that the sub-atomic charged particles that make them up love each other very much. It takes an enormous amount of energy to separate an electron from a hydrogen nucleus, which is a proton. However, the temperature of the Sun is sufficient to do this, above around 100 000 degrees. This means that electrons can escape the protons, and move more freely, which means that we have moving charged particles. A gas composed of freely moving charged particles behaves very differently to a neutral gas, and therefore deserves a special name — which we call a plasma. As some of my family will know, I very much like to tell people that overwhelmingly, the Universe is plasma — so it's probably important.

So we have this enormous object making this plasma. What does that mean for us on Earth? Specifically, everything within what we call the magnetosphere? Well, the most energetic particles in the Sun have enough energy to escape the gravitational field and stream out to fill the Solar System. They do this at around 400 km sec^{-1}. To put that into perspective, Concorde travelled at roughly 600 m sec^{-1}. So, once you do the maths you're talking about something moving at over 600 times the speed of Concorde. So we certainly have light, and we have established that we have plasma. Which gets there first? Well, plasma is fast but nothing is faster than light. It takes approximately eight minutes for light to travel the 150-million km to reach the Earth, and about three to four days for typical solar wind speeds. So let's start with light.

As I mentioned, it takes light from the Sun approximately eight minutes to reach the Earth. Light carries energy (and you can think of that as being bundled up in a wave or a photon), which can be transferred to material particles in Earth's atmosphere. As discussed earlier, this can lead to the charged particles that make up atoms to break free from their bonds. This happens on the day-side of the Earth, and leads to the production of plasma to make an ionized layer called the ionosphere, reaching several-hundred km altitude. Some of the more energetic particles from the ionosphere leak further out and up along magnetic-field lines. This creates a much larger body of plasma called the plasmasphere, extending out to approximately 20–30 000 km, but this is highly variable. Let's talk about temperatures. Are we reaching the radiation-belt energies? No!

The next important source of energetic plasma has a direct origin in the solar wind. There is a universal process called magnetic reconnection that enables this plasma to enter the magnetosphere (the Dungey Cycle). Magnetic-field lines carried by the solar wind impinge on the geomagnetic dipole field, and become stressed at the node of the magnetosphere. Under stress, the field lines reconfigure at the day-side of the Earth in a process analogous to that of bar magnets reordering themselves, and drag solar-wind plasma towards the night-side of the Earth. A similar process then occurs again on the night-side, which pushes plasma (originally solar wind in origin) towards the Earth.

So we've learned about the cold plasmasphere and we've learned about a way in which solar-wind plasma can eventually find its way into the magnetosphere. And we call this population the ring current. However, we are still a factor of 10 or 100 below the radiation-belt energies. The main ingredient missing is the one that I myself study, namely electromagnetic-wave–particle interactions. That is what we need to give the missing energy boost to the particles.

System-scale 'ultra-low' frequency waves generated by the interaction of the solar wind with the magnetosphere, and small-scale 'very/extremely-low' frequency waves generated by the injected plasma from the night-side of the Earth can resonantly interact with the charged particles that are otherwise trapped. These interactions can raise energetic electrons in the radiation belts to relativistic energies. This happens *via* processes analogous to a surfer riding a wave in the sea. Therefore it is a selective mechanism, as not all surfers manage to ride a wave!

To conclude, radiation-belt science is relativistic particle acceleration, transport, and loss. It is measurable in our Solar System lab 'before' (solar atmosphere and solar wind), 'during' (*in situ*), 'remotely' (ground-based), and 'after' (precipitation). The energy in the radiation belts is a manifestation of the energy emitted by the Sun, but enhanced. It is very important for space-weather risk — satellites, astronauts. It was the first scientific discovery of the space age, but as full of open questions as ever.

The President. Thank you very much. What is the main risk to humanity?

Dr. Allanson. I think the main threat is power outages. Energetic particles in space end up impacting on power networks, the result of which is very expensive. What I would add is that we are in the golden age of data collection on the one hand but the last solar cycle has been relatively benign so we have built up this understanding of what is going on with space weather. The possibility that we may have become a little complacent is an interesting question.

The President. The next one could be much worse?

Dr. Allanson. I hope not, but it's possible.

Mr. Steve Cookson. I have a similar question with a name on it — the Carrington event. There have been similar events recently where whole sections of hardware on the eastern seaboard of the USA went down because of space-weather events, and I wondered if you could speak more generally about space-weather events? Does this occur at the peak of the solar cycle, for instance?

Dr. Allanson. The most intense activity occurs on the declining phase of the solar cycle because we have a high solar wind.

The President. The Carrington event happened in 1859 — how likely is it that there will be another one? Are the statistics roughly known or not?

Dr. Allanson. I'm not the best person to ask that.

Dr. Annelies Mortier. The strength of the solar cycle is not predictable so it's difficult to know.

Dr. Paul Wheat. A lot of this is magnetic shielding we are getting from the Earth but with lots of micropollutants high in the atmosphere, such as plastics, jet fuel, *etc.*, and the ozone problem. Is that changing the protection we are getting at all? Are more particles coming in now and causing space-weather effects because of chemical changes in the upper atmosphere due to man-made effects?

Dr. Allanson. Most of what I have spoken about today is happening at far higher altitudes than the micropollutants that you mention. However, the effects that you mention are certainly important. Atmospheric and ionospheric density and composition affect signal propagation and satellite drag at lower altitudes. Some of my colleagues at Birmingham do work on that.

The President. Any questions on-line? None at the moment.

Dr. Jaqueline Mitton. You haven't mentioned the aurora. I have two questions. Firstly, is the study of the aurora from the ground contributing anything useful to research, and secondly could you comment on what causes aurorae because most people do not seem to get that quite right?

Dr. Allanson. There are definite links between the radiation belts and the aurora. The chorus waves, the whistler-mode waves — they are one cause of the aurora. The chorus waves scatter particles and make them more field-aligned, then precipitate into the atmosphere. Chemistry happens and we get an aurora. The aurora also occurs because of the process happening on the night-side of the Earth bringing particles back towards the Earth. That sends a whole bunch of plasma along the field lines; they will then be sufficiently energetic to propagate into the atmosphere and we get an aurora. There is a definite link between the things I have mentioned today and aurorae.

Dr. Mitton. From the point of view of serious research does the study of aurorae from the ground contribute anything?

Dr. Allanson. It is absolutely real science.

The President. It is a distance thing. The auroral phenomenon happens much closer to Earth than the bulk of the radiation belts but is one feeding into the other?

Dr. Allanson. It is true that the radiation belts do not generate much current but they do precipitate and this does cause changes in the atmosphere.

Mr. Leonard Mann. Do cosmic rays have any effect on the radiation belts or are they swamped by the Sun's radiation?

Dr. Allanson. They will go straight through and collide with the atmosphere. The number density in the radiation-belt environment, what we call the plasma trough, is of the order one electron per cubic centimetre.

Professor Mike Cruise. I notice you have the Cabinet Office Risk Register there and at the top of the list is the pandemic. It had been there for eight years before 2019. The point of this register is that you identify the risks and do something to mitigate them, which is something the Government never did with respect to the pandemic. Is the Government doing anything to mitigate these radiation effects?

Dr. Allanson. We have been quite fortunate in the radiation-belt community to secure quite chunky amounts of funding.

Professor Cruise. That's not what I asked [laughter].

Dr. Allanson. What we have done with that is to take our results to the Met Office to aid in forecasting — that is one aspect. The Met Office also engages with industry. It doesn't just engage with scientists and the public.

Mr. Regnart. Thank you for your fascinating irradiation of my ignorance on this subject. In your drawing-it-together slide you mention the ring-current temperature going up from 100 million to one billion K. Just to check, is that a milliard (a thousand million) or a mathematical billion (a million million).

Dr. Allanson. The first one.

The President. No further questions? Then thank you very much [applause].

The next speaker is Dr. Annelies Mortier. This is the continuation of a Specialist Discussion Meeting held earlier today. She is going to talk about 'Weighing exoplanets through a telescope network'. Annelies is Assistant Professor at the University of Birmingham and an observational astronomer. Her undergraduate studies were done at the Universities of Ghent and Leiden. She obtained her PhD from Porto. Before moving to Birmingham in 2022 she was a postdoc at the University of St. Andrews and a Senior Kavli Fellow at the University of Cambridge. We look forward to your talk.

Dr. Annelies Mortier. Ever since the discovery of the first exoplanet in the 1990s, we have witnessed an exponential rise in the number of known exoplanets with over 5000 exoplanets discovered so far. In the past five years, this exponential rise has noticeably slowed down. This is partly due to a shift towards in-depth characterization of known exoplanets, but partly due to detection genuinely getting harder.

Exoplanets are typically detected and characterized *via* two methods. The photometric transit method uses the dip in stellar flux when an orbiting planet passes between the star and the observer to measure precisely the orbital period and planet radius. This technique can successfully be done from space using satellite missions such as *Kepler* or *TESS*. The second method, and indeed the method that was used to find the first exoplanet orbiting a solar-type star, is the spectroscopic radial-velocity (RV) method. An orbiting planet exerts a gravitational pull on its host star, changing the radial velocity in a periodic manner. The semi-amplitude of that periodic signal is then related to the planet mass.

I am part of the *HARPS-N* Collaboration which aims to characterize terrestrial planets *via* radial-velocity measurements. *HARPS3* is a high-resolution optical spectrograph, installed at the *Telescopio Nazionale Galileo* on La Palma. What makes the instrument capable of finding exoplanets is its long-term stability below the metre-per-second level. Earth-like exoplanets have RV semi-amplitudes well below 10 m s^{-1} and a true Earth twin only induces a variation of 10 cm s^{-1} on its solar-type host star. One of the main science goals of the *HARPS-N* Collaboration is to measure planet masses of small transiting exoplanets that were discovered *via* photometric space missions. With both a planet radius and mass, we then get a bulk density of the small planets, allowing for studies of their possible compositions. With our collaboration, we have contributed greatly to the mass measurements of small exoplanets.

While thousands of small exoplanets are known, only about 100 exoplanets smaller than Neptune have both their mass and radius measured precisely. Furthermore, almost all these exoplanets orbit their star within the orbit of Mercury. This is due to the bias of the transit method towards shorter periods since planets orbiting further away from their host star will have less probability to transit from our point of view. This is easily shown through a geometric argument. The RV technique, however, has no such bias. While the semi-amplitude of the signals will decrease with increasing orbital distance, gravity will always be there and an RV signature is thus always detectable, unless the planetary system is exactly face-on.

Can RVs thus more easily be used to detect Earth twins? When looking into the semi-amplitudes of exoplanet signals, we find that the first detected exoplanets had semi-amplitudes of 50–100 m s^{-1}. This gradually lowered with instrumentation and computational methods improving. However, for the past decade, there is seemingly a barrier of 1 m s^{-1} below which we struggle to detect planetary signals. Current instrumentation is stable below that level, so there is something else holding us back.

The main barrier in finding the small signals is the star itself, generating signals intrinsic to their surface features that can drown out or even mimic the signals of genuine exoplanets. These stellar signals happen on different time-scales, from seconds to years, and easily have amplitudes well above 1 m s^{-1}. While some stellar effects, such as oscillations or spots, are well understood, others, such as supergranulation, are not well understood yet. For these purposes, we use Sun-as-a-star telescopes coupled with planet-hunting spectrographs to study the variations of solar activity in our data, where the *HARPS-N* Collaboration was the first to start this back in 2015.

But even with excellent instrumentation and better understanding of the physics and nature of these stellar signals, what we need most of all is more overall observing time. Due to the stellar signals happening on all time-scales, it is crucial that we have well-sampled data, preferably nightly, if we want to find the signal of a true Earth twin or indeed any small long-period exoplanet. Simulations have shown that thousands of measurements will be required over a decade to find confidently a true Earth twin. The *Terra Hunting Experiment* on the newly-built *HARPS3* spectrograph, seeing first light in 2025, will be the first of its kind where a handful of solar-like stars will be observed nightly for 10 years in a hunt for the smallest and longest-period exoplanets.

As this experiment will only be able to study 40 stars at most, we need more of its kind. Going to bigger telescopes does not take away the need for the thousands of data points that will always be required to find the planetary signals, regardless of the telescope size. As such, there is an opportunity to use 2–4-metre-class telescopes and outfit them all with stabilized spectrographs. We (Annelies Mortier and Heather Cegla) are currently gathering support to get such a network realized and have just held an RAS Specialist Discussion Meeting on the topic. A network of stabilized spectrographs will unlock the ability to get firm statistical samples on the small-exoplanet population and will finally allow us to answer the question: how unique is our Solar System?

The President. Thank you very much. Two to four-metre telescopes, six of them, and half the observing time for ten years — who is going to fund it?

Dr. Mortier. The *JWST* is more expensive still!

The President. Is this an international programme?

Dr. Mortier. We are not the only country which is interested in this, but the UK currently leads on stellar variability as well as the design and calibration of stability in spectrographs, but there is interest from other countries to do this. We would like a lot more than six telescopes in a worldwide international network.

Professor Miller. Where does *ARIEL* help with all this?

Dr. Mortier. *ARIEL* is very interested in this. This is an ESA mission to look at exoplanet atmospheres, particularly on small planets. The problem with doing exoplanet atmospheres, especially for small planets in order to interpret the data, is that they need to know the scale height of the atmosphere which is related to mass, so we need to have precise masses at the 20% level for all the planets. If they don't actually know the scale height, which they don't, they can't know the atmospheres, so they need the mass which we can give them.

Dr. Stanley. Further to the comments about extra value from this project, you can obviously measure stellar oscillation in stars such as Betelgeuse, so perhaps you could sell telescope time to other scientists and answer the President's questions at the same time as raising funds which could offer a broad advantage to a large section of the astronomical community.

Dr. Mortier. And not just to the astronomical community, but also to the solar community. You can easily invest in several solar telescopes because you already have your spectrograph. *PLATO* will do stellar observations as well but there is much more you can do from a stellar as well as solar perspective.

Dr. Stanley. So low cost, high benefit.

Dr. Mortier. The entire team is not really low cost! Super benefit!

The President. You mentioned *Gaia* and that you are waiting for them to release their astrometric data. How much difference will that make?

Dr. Mortier. What *Gaia* has released already has changed a lot. Thanks to the *Gaia* parallaxes we have really precise radii for all of our stars which obviously helps in getting a better stellar mass and hence planetary mass. In terms of their planets, while *Gaia* is preparing to release thousands of exoplanets, they will all be long-period Jupiters; they can't do small planets at all.

The President. When will those data be released?

Dr. Mortier. The last date I heard was 2025.

The President. Any further questions? I'd like to comment that this afternoon has been fascinating to me. I'm old enough to remember when we had no idea whether there were any other planets. To come along and hear that you are actually beginning to think of Earth twins and the technical ability required to do that. The temperature and pressure controls on the spectrograph were just not possible 20–30 years ago. It is a very interesting and exciting story and it worries me that it might be ten years of observing before you find out — can you hurry up please?

Reverend Garth Barber. Could you comment on Proxima b? It seems that next door we might have what might be termed a twin Earth?

Dr. Mortier. It's not just Proxima Centauri b. As you know Earth-sized planets in the temperate zone of a star abound. I wouldn't call Proxima Cen b Earth's twin because of the nature of its star, which is cooler and actually is why we found it in the first place. There have been studies on the nature of Earth twins and possible life. Everything we think we know about life is based on one data point but what we do know about life on Earth is that it needs UV energy to kick-start it. This is something you can test in a lab and from the experiments it has been shown that the star is simply too small and not powerful enough to give that UV energy, even if the planet is close in.

The President. It's the life but not as we know it that might be even more interesting!

Mr. J. Penston. Can I ask a follow-up question? If we are looking for Earth twins should we not find a solar twin first?

Dr. Mortier. We are thinking long and hard about the kind of stars we will be looking at with *HARPS3*, so there is interest in a solar twin. The definition of an Earth twin is an intriguing one — some say you can find an Earth twin around an M dwarf but I disagree. We are currently looking at stellar parameters and abundances in the solar neighbourhood, so that we can make an informed decision.

Professor Miller. I wonder if I can make a comment and a slight reminiscence? I can remember the RAS meeting when Michel Mayor came and first announced his discovery of an exoplanet. Ironically, the people who gave him the hardest time were the proponents of the space mission called *Eddington*. *Eddington* is now called *PLATO*.

Dr. Mortier. Back in the day this was a really hard sell. In Europe, we found that the Americans were technologically ahead of us and were searching for a long-period Jupiter with their spectrographs. In Europe they were looking for short periods and that is when they found it. It only took the Americans a couple of months to find another six more hot Jupiters that were in their data all along.

Dr. Wheat. I know that *Kepler* looked at stars which are quite distant. It seems to me that we should be looking in the zone within 25 to 50 light years of the Sun. Is there any prioritization of that particular zone?

Dr. Mortier. The biggest downside of *Kepler* is that these stars are all too faint for us. For thousands of Earth-size planets that they found we can't get masses at all. *PLATO* has been re-designed to focus on bright stars, *TESS* and *CHEOPS* also. However, there is such a thing as being too bright from space, so it's a matter of finding a balance. With *HARPS3* from the ground we are definitely going to look close by, but that is purely from a photon perspective. The *HARPS3* sample is limited to stars brighter than *V* magnitude 7·5 whilst the space missions have looked at magnitude 7 and fainter.

The President. Watch this space over the next ten years. Thank you very much again [applause]. May I remind you that there is a drinks reception about to begin in the RAS Council Room. The next A & G Highlights meeting will be on Friday, November 10th. I look forward to seeing all of you then.

LETTERS FROM DUN ECHT: A NETWORKED OBSERVATORY

By Peredur Williams
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The Archives of the Royal Observatory Edinburgh preserve the out-going letters of Lord Lindsay's private observatory at Dun Echt, providing a detailed picture of its development and operation during its twenty-year (1872–1892) existence. Nearly all were written by the two astronomers in charge, David Gill until mid-1876, followed by Ralph Copeland until the observatory's merger with the Royal Observatory. Here we look primarily at their communications with other astronomers to consider how the observatory maintained its connections with the astronomical world through correspondence and the exchange of telegrams using the Science Observer code devised in Boston, as well as the publication of the *Dun Echt Circulars* and *Copernicus*. Also quoted are some letters which fill the gaps in the published accounts of the observatory to round out our picture of its operation.

Introduction: the Dun Echt letter books

The private observatory at Dun Echt, 12 miles east of Aberdeen, established and maintained by Lord James Ludovic Lindsay (who became 26th Earl of Crawford on the death of his father in 1880)[1] was "a Grand Amateur's observatory insofar as it was the property of a single enthusiastic individual, yet it was a professional one in the respect that it had a properly salaried Director who undertook the business of research."[2]. Besides the formal reports included in the annual Reports of Council published by the Royal Astronomical Society in its *Monthly Notices*, we can gain a vivid insight into the day-to-day running of the observatory from the preserved copies of practically all of the letters written by (mostly) the two astronomers employed by Lindsay to direct his observatory. The first of those was David Gill, who was largely responsible for setting up the observatory and subsequently went on to a distinguished career as Her Majesty's Astronomer at the Cape of Good Hope[3,4]. In 1876, he was succeeded at Dun Echt by Ralph Copeland, who had led an adventurous early life[5,6] and who would go on to become Astronomer Royal for Scotland, effectively 'inheriting' the Dun Echt instruments and library which Lord Crawford presented to the Nation for the revitalization of the Royal Observatory Edinburgh[7]. Both men had participated in Lindsay's Transit of Venus expedition[8].

The out-going letters were written in ink and the copies were made by pressing moistened tracing paper against them. This produced mirror images usually visible through the tracing paper, but many are blurry where the ink has run over the years, sometimes from page to page, making reading difficult. The sheets of tracing paper were numbered and bound into volumes, typically a thousand in each. Unfortunately, the incoming letters were not archived to anything like the same extent; the relatively small number surviving are on a variety of sizes of paper including notelets and could not easily have been bound in sequence even if they had been retained. Fortunately, however, we have letters from Lord Lindsay to Copeland in the first few years of his tenure which are certainly informative — not only about the work of the observatory but also goings-on at the Council of the Royal Astronomical Society on which Lindsay served for many years, being President in 1878–80. In the case of Gill, the account of his early career by Haley[9] cites many incoming letters retrieved from the Royal Geographical Society archive, which complement the letters in the ROE archives.

The Dun Echt letters covered a wide range of topics, two categories of which are particularly interesting for the historian of the observatory: those to telescope and instrument manufacturers, and to astronomers in Britain and overseas. Those to the telescope and instrument makers, particularly Howard Grubb of Dublin, T. Cooke and Sons of York, Troughton & Simms, and Adam Hilger show Gill and Copeland to be excellent instrumentalists, providing detailed suggestions but exacting in their requirements. After his appointment to the Cape, Gill continued his dealings and friendship with Grubb, and pointed the way to many improvements in Grubb's designs[10]. The substantial body of letters to instrument makers, often with sketches, is worthy of a separate study; the present one is primarily concerned with the astronomical correspondence. In the early years of the observatory, much of this was connected with preparations for the 1874 Transit of Venus expedition and later even more with the subsequent reduction of the observations, which continued for some years.

Gill's letters, 1872–1876

Most of David Gill's letters were concerned with the setting up of the observatory and instruments. He also wrote frequently to Lord Lindsay, who was often away from Dun Echt, keeping him appraised of progress. Beside the specification and acquisition of the instruments, and building of the observatory, there was little time to consider its scientific programme beyond the forthcoming Transit of Venus. At the beginning of 1872, however, before most instruments were delivered, Lindsay intimated to George Airy, the Astronomer Royal, his willingness that the Dun Echt observatory could take up the systematic observations of Jupiter's satellites that Airy had advocated[11] at the RAS. As Lindsay was about to depart for the Continent, he asked Gill to follow this up with Airy. On January 23rd, Gill wrote to Airy[12] giving a detailed account of the proposed instrumentation and resources. In line with his own views on the division of labour amongst observatories, Airy replied[13] advising Gill to devote the work of the Dun Echt Observatory to observations with equatorial telescopes, as Gill had not "yet learnt what soul-wearing work is the reduction of meridional observations".

Gill's astronomical preparations for the Transit of Venus were centred on the determination of the longitude of their observing station at Belmont on Mauritius and observations of Juno around the time of its 1874 opposition, which would provide an alternative determination of the solar parallax, independent of observations at other stations. In a letter[14] to Professor Auwers of Berlin, Gill wrote that he had succeeded in collecting upwards of 50 chronometers for the expedition and these were now in the hands of Mr. Hartnup of the Liverpool Observatory to have their rates ascertained at all temperatures. He had studied the circumstances of the opposition of Juno with considerable care, determining the differences in parallax for observation altitudes of 20–40° and making a catalogue of stars close to the predicted path of Juno and to be observed with it for every day from the 10th October, finding that on every night there were sufficient suitable stars for comparison. Such observations would provide an alternative determination of the solar parallax. These preparations were also communicated[15] to the RAS. Gill wrote[16] to Airy in May expecting to confirm the cooperation with the British Transit group in Egypt in determining the longitude of Aden using telegraphic exchange of signals, but was dismayed to learn that this would not now occur. In another letter to Auwers[17], who was Secretary of the German Transit of Venus Commission, Gill expressed his disappointment with Airy's decision and asked for his assistance.

We do not know at what stage Ralph Copeland, then assistant astronomer at Dunsink, was invited to join the expedition, but when Gill learnt of it, he wrote[18] welcoming him. He asked him to acquire a number of books and then proceeded to give him advice on suitable clothing! This included, for observing, trousers with a scarf to "protect the abdomen from cold drafts at night", a light suit or two of tweed, a light coat or two, and white duck trousers and a solar topee or pith hat. This may have been a joke, but perhaps Gill was unaware that Copeland had previously worked in the Australian gold fields and on a sheep farm, in the Arctic during winter, and had observed with the Leviathan of Parsonstown perched 30 ft above the ground (ref. 6). He then went on to describe the instrument Copeland would use for the transit and a detailed plan of the observations he was expected to make. In his next letter to Copeland[19] three days later, he wrote: "Airy has done his best to stump us, after leading us to imagine that he w^{d} be prepared to exchange signals from Suez with me at Aden in Jan^{y}. Now he says that as the telegraphic determination of the longitude of Alexandria is likely to be successful, the work of the British Egyptian Station will be over immediately after the transit and it will be out of the question to keep the instrument and observers there until January." He described his proposal to Auwers for the cooperation with the German observers on Mauritius on their return journey and also to van der Sande Bakhuizen of Leiden regarding the junction of the longitudes of the Dutch station on Réunion and Mauritius.

After the transit and work in Egypt, Gill returned to Dun Echt almost exactly a year later. A letter to John Russell Hind[20], Superintendent of the Nautical Almanac, shows that Gill as busy as ever: "I have now returned home. I had intended to call for you in London but had so much time clearing my goods and chattels at the Docks, that I had only time to make a few visits to Chronometer makers that were absolutely necessary, see Simms and attend the Greenwich Visitation, when I hoped to meet you — and be off to meet Lord Lindsay here depositing my chronometers by the way at Liverpool, to have their temp[tr] coefficients redetermined." In Dun Echt, however, he found that the climate had changed. Lady Crawford, Lindsay's mother, had insisted that the Gills made over a larger portion of the Astronomer's House to Henry Carpenter and his family (Haley, ref. 9). Carpenter, who had started at Greenwich as Boy Computer and rose to be an observer, was taken on by Lindsay in 1874 as First Assistant to Gill and took care of the observatory while Lindsay and Gill were away on the transit expedition. Also, Lady Crawford objected to the use of her stables for the carriages and horses of Gill's visitors, so that when Henry Russell, Director of the Sydney Observatory, was expected to visit, Gill asked Mr. Walker in Aberdeen[21] to direct his visitor to the appropriate coach to Echt or, if hiring a carriage, to ensure that the horses were put up at the inn and not the farm stables. Matters came to a head after Gill had given a talk to the Aberdeen Philosophical Society against the wishes of Lord Lindsay, causing the latter to give Gill six months notice of dismissal (ref. 9). Despite this, the two men remained very good friends.

During the notice period, Gill continued correspondence regarding reduction of the transit expedition observations, with one significant change: from 1876 January 28 he wrote frequently, almost twice a week, to Henry Carpenter, implying that the latter had moved away from Dun Echt. Gill's letters seldom give the recipients' addresses, but when Copeland took over from Gill later in the year, and also wrote frequently to Carpenter, he used an address in Leatherhead, Surrey. Carpenter was the principal computer, but the work was spread out amongst others: Gill sent a cheque for £12 in a letter[22] to Hind for payment of his computer and, responding to some calculations done by a J. Harding[23] of Trafalgar Rd., Greenwich, added that there was a great deal of work to follow and asked if Harding knew anyone who would be suitable for some easy computing. Although the letters to Carpenter were necessarily very detailed, they were not impersonal: Gill writing at the end of one letter[24] "We are much concerned to hear Mrs Carpenter does not do as well as you wish. Let us always hear how she and baby are doing and give our kindest regards." There were also frustrations; in one of his many letters to Copeland, Gill wrote[25], "I have yr note, and much regret to hear that such a hash has been made of the daily stars places. I have not looked into mine yet for I thought Carpenter wd have been perfectly reliable in such work." Such problems were probably inevitable for remote working without the chance to clarify possible misunderstandings in person.

Encouraged by the results of his Juno observations, Gill wrote to Airy[26], proposing a scheme to be submitted to him. This would be the observation of one of the minor planets discovered by Watson* whose eccentricity was so small that in April '78 its distance from the Earth would be 0·65 AU. From what he remembered Watson telling him when they were in Egypt together the previous April, the planet would be in opposition in April 1877, at 8th mag and –30° declination. Should the Juno observations show the accuracy of the method (for determination of the solar parallax), would Airy be disposed to sanction the application of the method also to this minor planet? From a latitude of about –19° this planet as well as Mars could be observed with great advantage — obtaining independent determinations of the parallax from each. For an observing station, Gill suggested the Table Land of N Queensland, in latitude –19° and with excellent communication with Brisbane by steamer and good road by bullock drays, and according to Gill's two brothers, a cloudless sky every night excepting in December–February.

Later letters to Copeland included reference to the transition between the two at Dun Echt. For example, on 1876 May 16 Gill wrote[27] that he would be moving out on the 23rd June and would stay a few weeks in Aberdeen after he left, so that he could be able to give Copeland any assistance in explaining matters — and then he meant to "take a little house in some quiet country place for a month or two, and stick at the book until it was finished". He was confining himself to doing only what could not be done away from the observatory — "and this with my lameness (for I still come to the Observatory in y[r] Belmont Observing Chair with a bit added mounted in a wheelbarrow) will prevent my leaving the Observatory in the apple-pie order I would have wished".

Gill's correspondence shows that he was on easy terms with the leading astronomers of the day, such as Airy, Auwers, and van der Sande Bakhuizen; there is banter and humour in letters to his friends. He was probably closest to Grubb, to whom he wrote a letter[28] of condolence after a family tragedy, and to whom he disclosed ambition in another[29] commenting on Piazzi Smyth's tribulations: "Poor Piazzi — still more Mrs Piazzi !!! — I draw a veil over a scene so harrowing. He won't resign tho — & I'm not ready for the post yet — if he[d] hold on for another ten years I should like it very well."

Letters from the first years of Copeland's tenure 1876–1877

The first of Ralph Copeland's letters in the archive[30] was to Professor Klinkerfues at Göttingen, under whom he had studied for his PhD, and a few days later he wrote[31] the first of his many letters to the bookseller Robert Peppmüller, also in Göttingen and written in German, ordering scientific books for Lord Lindsay. In this, Lindsay was following the interests of his father, the 25th Earl of Crawford, who had built up a famous library of beautiful and rare books[32], which became complemented by Lindsay's collection. The letter books are full of orders to Continental and British booksellers, mostly to Peppmüller, who sometimes acted as agent for purchases from other German dealers[33]. Other dealers were used, such the London dealer in rare books, Bernard Quaritch, who supplied a first edition of Flamsteed's *Historia Coelestis*[34].

He also wrote[35] to William Yeats of the Aberdeen firm of Yeats & Spottiswood, who handled the observatory's legal and financial matters, with a list of Lindsay's valuations of his instruments, for insurance. Copeland followed this with a letter[36] which included a sketch of the observatory showing the locations of the instruments to be insured (Fig. 1). The following year, he wrote concerning insurance of the buildings[37] and arrangements for the Fire Engine[38].

*James Craig Watson (1838–80) of Ann Arbor discovered 22 minor planets, 16 before 1875.

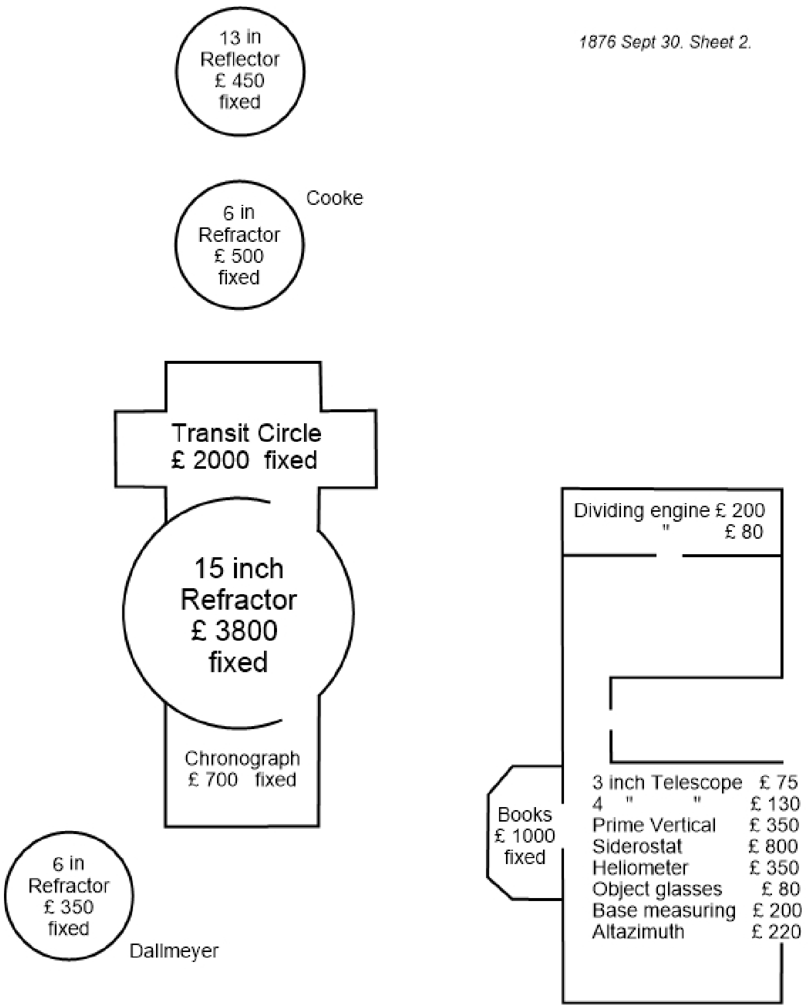

Fig. 1

Re-drawing of sketch in Copeland's letter (ref. 36) to Yeats & Spottiswood showing locations of the fixed instruments and listing the others, together with their values for insurance. This can be compared with the view in Plate C of ref. 1.

Yeats needed some reassurance about storage of photographic chemicals — but apparently not for the gunpowder which Copeland periodically ordered for the time gun[39] operated by the observatory.

Also in 1876, Lindsay wrote[40] that Lord Crawford (his father) had approved the appointment of Mr. R. Copeland as a computer. We know this to be Copeland's nephew Robert from a letter[41] regarding the Belmont time reductions addressed to "My dear Nephew". The initial appointment was for the winter or until Mr. Lohse (J. Gerhard Lohse, to be assistant astronomer) could be appointed. From a letter[42] by Copeland to Yeats we learn that Robert Copeland was paid £9 for the winter and that Mr. Lohse started on 1877 April 1 at £120 per annum; but from later correspondence it is evident that Robert's employment continued more or less continuously for many years.

In 1877 April, Lindsay wrote[43] that the council of the RAS had decided to give Gill £500 for his opposition-of-Mars expedition and asked Copeland to arrange for the cases of the Heliometer, the 6-inch equatorial mounting, and the iron work of the 4″ which Lindsay had used in Mauritius to be got out and packed for Gill's expedition. Ten days later, Copeland wrote[44] to Gill that the traction engine had left that morning with the equipment, giving a full inventory.

Not listed here are Copeland's many letters to Henry Carpenter regarding reduction of the Transit-of-Venus data and to Thomas Cooke & Sons and other suppliers regarding the observatory's instrumentation as he familiarized himself with it.

The 1878 Transit of Mercury and visiting astronomers

Lord Lindsay organized a coordinated series of observations of the 1878 May 6 Transit of Mercury from Dun Echt. In a letter[45] to Copeland he wrote that he planned to participate in it himself if at all possible and listed the instruments available, allocating observers to them, *e.g.*, Copeland to the Dallmeyer 6″ with micrometer, Mr. Lohse (Copeland's assistant) to the 4″ Cooke, himself to the 6″ Cooke, and so forth. He would get Davis, his photographer, and Carpenter to join them at Dun Echt, and considered asking Ranyard (Arthur Cowper Ranyard, lawyer and astronomer) and perhaps another astronomer to join them. Ranyard did participate, and the observations were reported to the RAS and published in the *MNRAS*[46,47].

On June 28th, the Rev James Virtue of Dumfries observed Jupiter with Copeland at Dun Echt[48]. In July, Copeland wrote[49] to Virtue regarding the latter's possible discovery of nebulae, patiently giving advice on observing techniques. We read of an intriguing caution to visitors to the observatory in Copeland's letter[50] to the secretary of the Aberdeen Philosophical Society regarding their proposed visit on June 8th: as he had made preparations for working the large magnet, members of the proposed party should leave their watches at home because he had found that the magnet deranged any watches brought within its range.

Copeland wrote to more amateur astronomers who had contacted the observatory, such as John Birmingham of Tuam, regarding possible duplicity of one of his red stars[51], reporting his own spectroscopic observations of it[52] (which showed nothing exceptional) — but determination of the longitude of the Belmont observing station *via* Moon culminations remained a problem. He asked[53] Professor Peters of the Kiel Observatory to place a notice in the *Astronomische Nachrichten*, which he edited, requesting astronomers who may be in possession of unpublished meridian observations of the Moon or of occultations of fixed stars in the months of November and December 1874, made at observatories the longitudes of which had been determined by telegraph, to let Copeland have copies of the data.

In 1879 February, Gill was appointed Her Majesty's Astronomer at the Cape. Some days later, Lindsay wrote[54] to Copeland telling him that Gill had bought the Heliometer for £200 and asking Copeland to pack it up and send it to Grubb, at Gill's expense. Grubb made an equatorial stand for it and the instrument was used by Gill at the Cape for measuring stellar parallax[55].

Dun Echt Circulars and Copernicus

In 1879 November, Lindsay initiated the series of *Dun Echt Circulars* to inform astronomers of the appearance of comets and other phenomena requiring prompt communication to other observers. His announcement in *Nature*[56] must have drawn an unfavourable response from the Smithsonian Institution, causing Copeland to draft a reply[57] which he initially sent to Lindsay[58] for approval[59] before posting it. He made the point that the *Circulars* were intended to supply information on astronomical discoveries to every owner of a telescope in the British Islands who communicates an address for the purpose, more especially to all those amateurs who may not be in communication with a government observatory. The Smithsonian scheme, on the other hand, guaranteed communication of astronomical discoveries between the United States and five European government observatories, but with no provision for wider distribution this side of the Atlantic.

The first *Dun Echt Circular* reported the discovery of a new planetary nebula or nebular star by the Rev. Thomas W. Webb. After a delay caused by bad weather, Copeland wrote[60] to Webb on 24th November identifying his object as Durchmusterung +41° No 4004, reporting that its spectrum was sensibly monochromatic seen through a low-powered spectroscope and commenting that there seemed to be a link between the last stage of Nova Cygni and the smaller planetary nebulae. On the same date, *Dun Echt Circular No 1* was issued reporting the discovery and giving the identification, position, and spectral information. Also on the 24th, Copeland wrote[61] giving the same information to J. L. E. Dreyer at Dunsink, who included the object in his catalogue of nebulae[62] as NGC 7027, the name by which it is generally known today.

At first the *Circulars* were intended chiefly for amateur astronomers. When the journal *Copernicus* (initially called *Urania*) was started by Copeland and Dreyer in 1881, Lord Crawford (as Lindsay had now become) agreed to a plan by which any urgent communication to the journal appeared forthwith in a *Circular*[63]. Hence *Circulars* were distributed to *Copernicus* subscribers. Although it included papers by the Dun Echt observers, *Copernicus* was an international journal, publishing a wide variety of contributions, some written in French and German. Unfortunately, the editors appear to have had difficulty in filling the issues: as Copeland wrote[64] to Ranyard "Can you by any possibility let us have a paper, long or short, for 'Copernicus'? We are somewhat badly off for contributions", and as *Copernicus* was not financially viable, it ceased publication after three years.

The *Circulars* continued for the life of the observatory and were printed on site using a Squintani 'Model No. 3' printer. Specialized fonts were an issue; on 1881 May 16 Copeland wrote to Squintani[65] ordering large quantities of type including accented characters, remarking that when he had printed some German, he had had to put in all the ö and ä by hand with a colon. He enclosed the latest *Dun Echt Circular* as a specimen of "work with one of your old No 3s". Lindsay appreciated his efforts, writing[66] "you are really becoming a first rate compositor".

A total of 179 *Circulars* were issued, the last being on 1890 January 29. The mailing list[67] included about 200 recipients, and many *Circulars* also appeared in the *Astronomical Register*. The effort and cost of distribution must have caused some concern because in 1886 January, Copeland wrote to a number of recipients, *e.g.*, to Mr. Cattermole[68] of Norwich, along the following lines: in accordance with Lord Crawford's scheme of 1879 November 1 the Dun Echt circulars are distributed gratis to all applicants "who would be likely to make useful observations". It had become obvious that this could not practically be made to include everyone interested in astronomy; but pending any arrangement for a wider distribution, the recipient was invited to send, say, a score of addressed wrappers in which to enclose a corresponding number of circulars as they appeared.

Astronomical correspondence 1879–1882

At this time, the subject matter of the astronomical correspondence from Dun Echt was becoming much broader than that concerned with the Transit-of-Venus reductions. For example, Copeland corresponded with Professor Edward Pickering of Harvard regarding emission-line spectra[69] and giving details of his observations[70] of Nova Cygni. Nearer home, he sent detailed observations of two bright meteors[71,72] to William Denning of Bristol, asking for details of any observations of these. The 'Great Southern' Comet of 1880 led to a flurry of correspondence: Copeland wrote[73] to the watchmaker-astronomer Henry Pratt of Brighton drawing attention to telegraphed reports of it, estimating its position and motion, and asking Pratt to try and observe it on the southern horizon in the early evening twilight. He also corresponded[74] with Hind regarding the latest reported observation and its discrepancy with previously determined elements. Hind must have computed new elements and sent them to Copeland who reported[75] that he had tried to observe the comet from Dun Echt but was thwarted by the hazy sky and long twilight, so he had sent a predicted place to Dr. Schmidt, Director of the National Observatory at Athens.

In parallel was correspondence with Joseph Baxendell of Southport, who had contacted Lindsay with a query, possibly from learning of the *Dun Echt Circulars*. Copeland wrote[76] that he observed his suspected nova with the spectroscope but saw nothing very striking. He was uncertain whether it was advisable to send out a *Circular* respecting the new variables if they were not actual novae but would hesitate no longer if Baxendell noted anything particularly remarkable, writing "Such discoveries seem to me to be infinitely more interesting than the discovery of a small asteroid". After receiving Baxendell's paper on U Sagittae, Copeland wrote[77] that he would like to get out a *Circular* on his two new variables — which he did: *Dun Echt Circular No. 6*. Their correspondence included discussion of comets, Copeland writing[78] in October thanking Baxendell for a telegram helping him to pick up the new comet (1880d) without delay and observe its spectrum[79]. Other correspondents introduced through their queries were William Franks of Leicester, to whom Copeland sent[80] the positions of five double stars he was interested in, and James Robertson of Coupar Angus regarding a variable star[81]. In both cases, their correspondence continued for some years, latterly about comets. In other cases, we have only a single letter, such as that[82] to James Skinner of Inverurie giving extended advice on the use of his spectroscope. Sadly, we do not know how Mr. Skinner used his instrument — there appears to be no more correspondence.

Astronomical Telegrams and the Science Observer Code

Astronomers used telegrams for exchanging information on discoveries but the telegram format was not suitable for numerical data and there were attempts to overcome this. One plan was presented to the RAS at its 1880 December meeting[83], but in a letter[84] to Ranyard, who was on the RAS Council at the time, Copeland was very critical "… in spite of the high authority supporting it, contains all the worst features of the old order which have led to so much blundering and sheer waste of observing time." He went on to give an example of the blunder the plan would introduce.

At about this time, Seth Chandler and John Ritchie Jr. of the Boston Scientific Society developed a code ('The Science Observer Code') for the telegraphic transmission of cometary orbits, tailored to the transmission of numerical data. This was quite separate from the Smithsonian scheme mentioned above. To test the usefulness of the code, which was based on the location of words in a particular dictionary — *Worcester's Comprehensive Dictionary*, Boston, 1876 — to convey each set of five digits[85], Chandler and Richie arranged with Lord Crawford for the receipt and publication of cable messages containing orbits computed in the United States and *vice versa*. For example, *Dun Echt Circular No. 17* quoted the elements and ephemeris of Swift's Comet received by cable from Boston using the Science Observer Code, followed by new observations from Dun Echt and revised elements and ephemeris derived by Lohse and Copeland[86]. At the meeting of the *Astronomische Gesellschaft* in 1881 September, Chandler and Ritchie[87] drew attention to the tests between Boston and Dun Echt, and Copeland gave an exposition of the code, including examples for communicating cometary elements and ephemerides.[88] As further demonstrations of the usefulness of the code, the *Dun Echt Circulars Nos. 45–48*[89] quoted positions, elements, and ephemerides of Comet Wells (1882a) received from Boston or Vienna where it was used.

Copeland was enthusiastic about extending the use of the code: in a letter[90] to Ritchie he suggested there could be support at the Cape, Australia, and Brazil. He also wrote[91] to Professor Edmund Weiss, Director of the Vienna Observatory, accepting his offer to exchange astronomical telegrams, commenting that the Smithsonian telegrams never reached Dun Echt directly but occasionally were sent on from Greenwich — which was not satisfactory, *e.g.*, a most important telegram from the Cape giving particulars of Comet 1881b was merely communicated to the *Times*, a journal seldom seen at Dun Echt. He then gave a detailed exposition of the Science Observer Code.

The Brazilian connection may date back five years to a conversation between the Emperor of Brazil and Otto Struve, when the former said that he intended to visit the observatory at Echt[92]. The visit seems not to have occurred, and the exchange of telegrams was initiated by a letter from Luis Cruls, recently appointed Director of the Imperial Observatory, to Lord Crawford. In his reply on Crawford's behalf, Copeland[93] raised the question of their telegraphic address. He then wrote[94] to the agents in Aberdeen who handled the Dun Echt telegram traffic, explaining that the observatory would wish to send telegrams to the Imperial Observatory but that the latter had proposed a telegraphic address of six words. This would cost 39/4 (£1·97) to transmit, making a serious inroad on the £25 which the Brazilian government proposed to remit as prepayment for their messages, so he asked his agents to enquire at the telegraph office as to what would be the shortest address they could use with safety. In a further letter to Cruls[95], he wrote that he had written to Boston, asking Mr. Ritchie to send two sets of instructions and two dictionaries to him and asking him if he could register a short address with his telegraph station. The arrangements worked well when Cruls observed Comet Wells (1882a) the night after receiving a telegram[96], and telegraphed his discovery of a comet in September[97].

Co-ordination of comet hunting

In a more organized engagement with the amateur observers, Copeland sought to enlist the aid of a number of his correspondents in a systematic search for new comets. This arose from a letter from William Denning in 1882 May, in which he wrote that he would have to give up searching for comets. Copeland replied[98] that he felt that Lord Crawford would be glad for Dun Echt observatory to take in hand the organization of comet seeking but pointed out the difficulty of comet seeking from Dun Echt in the summer months owing to the lightness of the sky. After suggesting comet seeking in postscripts to letters about Comet Wells to James Robertson[99] and Isaac Ward[100], Copeland wrote again[101] to Denning asking for names of astronomers who might be interested in searching for comets.

On 1882 August 14, Copeland wrote to sound out astronomers whose names had been given to him. In his letter[102] to Miss Mary Ashley, for example, Copeland wrote that he was anxious to make Dun Echt a central station where every effort would be made to determine places of any object discovered, whether comet or nebula. They would also keep a constant appendix to the Gen. Cat. of nebulae and Mr. Dreyer's supplement. If Miss Ashley's local surroundings permitted it, he would be glad if she could watch some southern part of the heavens, as she was nearly 6° further south than Dun Echt (she lived in Bath, coincidentally in King William Street, only a few doors away from the house occupied by William and Caroline Herschel a century earlier). He wrote similarly to A. S. Williams[103], living in Brighton, also asking him to consider a southerly region given his location, and to W. S. Franks[104] of Leicester and Rev. J. J. M. Perry[105] of Alnwick (St Paul's Vicarage, not to be confused with Father Perry of Stonyhurst). The responses must have been positive because he wrote again[106] on September 7 setting out the distribution of fields set out in Table I as likely to suit the observers and asking for a response if any region was inconvenient. In response to a query from Miss Ashley, Copeland explained[107] that the extra space WSW to SSW in her field was to cover the gap in Mr. Williams's field.

TABLE I

Proposed distribution of fields for comet hunting

Field	*Observer*
26°S – 5°S (partly obstructed in SW)	A. S. Williams (West Brighton)
5°S – 10°N (& down to horizon WSW–SSW)	Miss M. Ashley (Bath)
10°N – 25°N	Rev. J. J. M. Perry (Alnwick)
25°N – 45°N	W. S. Franks (Leicester)
45°N – 55°N	J. Robertson (Coupar Angus)
55°N – 65°N	I. W. Ward (Belfast)
65°N – pole, + low down to North	Dun Echt observers

The 1882 comets and Transit of Venus expedition

In parallel with this activity, Copeland was engaged in extensive correspondence[108] with T. Cooke & Sons regarding the design of a new spectrograph for Dun Echt and was also immersed in preparations for his expedition to Jamaica to observe the Transit of Venus on 1882 December 6, preparing and packing equipment, arranging transport, *etc.* Spectroscopic observations of Comet Wells approaching perihelion caused him to postpone a visit to Oxford to meet with Edward Stone FRS[109], organizer of British government expeditions to observe the 1882 transit, and his co-observer Captain Mackinlay[110]. In letters to Professor Bredichin[111] of Moscow and Thomas W. Backhouse[112] of Sunderland, Copeland described how on June 6th before sunrise he and Lohse observed spectacular sodium-*D* emission lines in the spectrum of the comet. Full details of the observations were published in *Copernicus*[113], as were those of the 'Great Comet', almost certainly[114] that discovered by Cruls. Copeland's observation of this was only made possible with a recently telegraphed position from the astronomer and telescope maker A. A. Common[115].

After Copeland's departure for Jamaica in October, Gerhard Lohse took over the correspondence and issue of the *Dun Echt Circulars*. To extend the network of observatories exchanging telegrams, he wrote[116] to Dr. Sergei Glasenapp, Director of the St. Petersburg University Observatory, regarding routing, short telegraphic addresses, transmission costs, and advantages of the "Science Observer Code". He also wrote[117] to Ritchie in Boston informing him of the contact and asking for copies of the code and dictionaries to send to Glasenapp.

A letter[118] to John Robertson of Coupar Angus regarding his proposed visit to Dun Echt gives a view of the limited options for public transport to and from the observatory. He was advised to take the 'Cluny Coach' leaving Aberdeen each afternoon and taking two hours to reach Waterton of Echt, where there was an inn and where he could ask directions for the 20-minute walk through the park to the observatory. If he stayed two nights there would be opportunities of viewing the stars and time to look over the observatory during the day between, taking the coach back to Aberdeen on the third morning.

The next topic to feature in Lohse's correspondence was Copeland's extension of his Transit of Venus trip to visit Quito in order to test its suitability for astronomical observations. Lohse wrote to Copeland[119] regarding the packing and shipping of the additional equipment he had requested for his observations — as well as his passport. Other correspondents included A. A. Common regarding a possible double star, and Miss Ashley, regarding identification of a nebula she had observed. In each case, Lohse reported observations he made aiming to resolve their queries — continuing the Dun Echt tradition of responding to and helping amateur astronomers. He wrote to W. S. Franks, one of the 'comet seekers', regarding his difficulties in covering his zone (Table I) and to a new correspondent, the Rev. H. Dowsett of Ramsbottom, regarding identification of an occulted star he had observed.

Copeland's correspondence after his return from the Americas

Copeland returned home on September 1: he had started on his return journey on July 3rd but, missing the Royal Mail steamer at Colon, went on to New York and spent 17 days in the northern states[120], where he visited a number of observatories, examining their instrumentation[121]. Amongst his first letters written after his return was one to Messrs Cooke & Sons asking about the state of the spectrograph they were building for Dun Echt. He also mentioned that he had a few beetles from Bolivia for one of their staff[122].

His astronomical correspondence focussed on comets, with letters to Annibale Riccò of Palermo[123], regarding the spectrum of the Great Comet (of 1882), and to John Rand Capron of Guildford[124] and Charles Prince of Crowborough[125] regarding the comet whose discovery by Brooks had been reported in *Dun Echt Circular No. 78*, giving his own measured coordinates. Copeland issued a stream of *Circulars*, giving elements, ephemerides, new positions and, in *No. 81*, noted that the elements showed great resemblance to those of Comet Pons of 1812, the return of which had been expected[126]. Early in 1884, he replied to two 'new' correspondents, the Rev. A. F. Hill of Aberdeen[127] and the pioneering astrophotographer Isaac Roberts[128], regarding their observations of this comet and inviting the former to visit Dun Echt when the large refractor was again available.

He also had to expand the team of 'comet seekers' (Table I) following the news from W. S. Franks that he was having difficulties covering his zone, beginning by sounding out G. D. Harding of Fishponds, near Bristol, who had applied to receive the *Circulars*[129]. After further correspondence with Franks[130], it was agreed that his zone would be reduced to 39°N–45°N. The new 25°N–32°N and 32°N–39°N zones were allocated to the Rev. W. J. Roome of Aldershot[131] and G. D. Harding[132].

At around this time, the Rev. T. E. Espin, then of Birkenhead, telegraphed with coordinates of a possibly new nebulous object. Copeland and Lohse were unable to see anything from Dun Echt nor find anything in the catalogues at the place telegraphed, but gave details, including sketches[133], of a previously observed nebula, now known as NGC 1999, about 15′ away. Another detailed response was to Miss Ashley[134] about her observation of the nucleus of M61. Copeland summarized the findings of different observers, including John Herschel, who described it as bi-nuclear, and undertook to have a good look at it in a few months' time. Evidently, Dun Echt was becoming known as the observatory ready and willing to check possible discoveries using the telescope or the library, and disseminate them if appropriate

Arising from his South American travels, Copeland wrote to Lazarus Fletcher[135] at the British Museum, Keeper of Minerals, enclosing a small fragment of a meteorite for his inspection. If it proved to be genuine, Copeland would like it back to make some spectroscopic experiments. He had a piece weighing about 5 lbs at Dun Echt and estimated the parent block to weigh 70 lbs. He concluded "If there has been no confusion about picking up the right stone, it will be necessary to proceed quietly & cautiously to secure the part now in South America." In response[136] to a letter from Edward Pickering of Harvard about 'Mountain Astronomy', he gave positions of two of the most striking emission-line objects he had discovered in his experiments with the prism in the Andes, and wrote that he would be publishing a full account in *Copernicus*. The following year[137], he asked Pickering to forward a set of his Notes and Suggestions about Variable Stars to John Robertson, Coupar Angus, Scotland. He wrote that, with next to no means, Robertson had purchased a telescope and observed sun-spots on every fine day for more than seven years and asked Pickering for advice on the best line Robertson should take having 1 to 2 hours available each evening using a telescope without an equatorial mount. As Pickering's plans for 'Mountain Astronomy' progressed, Copeland wrote again[138] with copies of his papers on his experiences in the Andes and remarked on the range of heights accessible on the Mollendo–Puno railway. In a subsequent letter[139], he gave the names of people connected with the railway — Mr. McCord, General Supervisor of Traffic, station-masters, line inspectors, *etc.* — who could collect meteorological data in the region to aid selection of an observing site.

This correspondence was interspersed with the continued stream of orders to booksellers and letters tying up loose ends of the reductions of the 1874 Transit observations, *e.g.*, to Oudemans[140] of Utrecht regarding the exact location of his station in Aden and including exchanges with David Gill[141] regarding Vol III of the *Dun Echt Publications* which described the determination of the positions of the various observing stations. Copeland wrote appreciably to A. A. Common[142] regarding his silvering of the siderostat mirror, but most of the instrument-related correspondence was to Thomas Cooke & Sons concerning the new spectroscope for the 15-inch. Some letters concerned details of the design but as time went on the date of delivery became ever more pressing[143] as he and Lord Crawford wanted it to be available at Dun Echt for the British Association meeting being held in Aberdeen in 1885 September.

This was a busy time for astronomers: what we now know to be a supernova (S And) erupted in the Andromeda nebula. Copeland observed it on September 1 but was disappointed by its spectrum: it showed no striking lines like those seen in previous 'new' stars[144]. Earlier that day he had received notice of the new star by telegram from Kiel, had written a report on the announcement, together with background information, which he sent[145] to the editor of *The Scotsman* and also issued *Dun Echt Circular No. 97*. Following an exchange of communications[146] with Isaac Ward of Belfast, who had first observed the new star on August 19th, and the measurement of its position relative to the nucleus of the nebula by Crawford and himself, Copeland issued *Circular No. 98* reporting these results. He remained puzzled by the spectrum, *e.g.*, to the Rev. J. M. Perry, he wrote[147] "The spectrum is indeed very difficult to deal with, being quite unlike that of a genuine nova like Schmidt's".

Catalogue of the Library and an eclipse expedition

In 1887 January, Copeland wrote to Edmond & Spark[148] of Aberdeen accepting their tender for the printing of the *Observatory Catalogue*. Over the previous decade or so, a catalogue on cards was gradually built up by many hands, including for a while a James Mitchell of the Academy of the Paulines at Catterick, to whom Copeland wrote[149] giving very detailed instructions as to the index-card format. The printed *Catalogue* took about two years to produce with numerous letters from Copeland to Edmond & Spark regarding format, proofs, and corrections, leading to a comprehensive publication[150].

Also in 1887, Copeland wrote to the Secretary of the RAS, Edward Knobel[151], offering himself as one of the Society's two candidates for Prof. Bredichin's hospitality to observe the forthcoming solar eclipse from his country seat Pogoste, near Kineshma on the Volga, which lay very close to the central line of totality[152]. The RAS Council accepted Copeland's offer and nominated Father Stephen Perry of Stonyhurst as their other observer. Copeland wrote[153] to Perry, who was an experienced eclipse observer, asking him to suggest the most promising lines of investigation and listing the equipment which he could draw upon. Copeland made arrangements for the shipping of equipment and wrote again to Bredichin[154] giving the dimensions of the equipment he was bringing and his plans to travel with it *via* Hull and St Petersburg. Unfortunately, bad weather at the critical time prevented him from getting useful observations (ref. 152).

Connections with the observatory continued to expand, with new correspondents including Lord McLaren in Edinburgh, Kenneth Tarrant at Pinner, and C. W. Tweedale at Crawshawbooth. Lord McLaren visited the observatory at Dun Echt at least twice and Copeland gave advice on instrumentation[155]. He also attempted to acquire a set of Argelander's star maps for McLaren[156]. The connection continued: in 1889, when Copeland became Director of the Royal Observatory Edinburgh, he and McLaren viewed potential sites for the new observatory together and were on the committee that finally chose the Blackford Hill site[157]. Tarrant was an experienced observer and the correspondence centred on measures of close double stars[158]. Tweedale, on the other hand, was inexperienced and the correspondence was sparked by his supposed discovery of a comet which turned out, after detective work by

Copeland, to be a ghost image inside his telescope[159]. What is striking about these letters is Copeland's friendliness and encouragement despite the wild-goose chase. At the same time, Copeland was in correspondence with Miss Agnes Clerke[160] regarding variations in the emission-line spectrum of γ Cas. Of the long-standing correspondents, the Rev. T. E. Espin, now at Wolsingham (Tow Law observatory), was most frequent, initially about red stars he had observed[161], and latterly about emission-line stars[162].

Conclusions

Copeland's letters are more formal in style than Gill's, with none of the banter amongst friends, but very supportive and patient with inexperienced observers. The only personal touch occurs in a letter to John Hind reporting observations of a comet received from Rome and remarking "there would seem to be traces of a nucleus at the centre: but as we have a little daughter 36 hours old I cannot ask Mrs Copeland to puzzle out the somewhat illegible Italian."

The letters show that the Dun Echt Observatory, despite its relative geographic isolation, to be closely linked with the astronomical community. Reduction of the 1874 transit observations strengthened connections with major Continental observatories while active prosecution of the use of the Science Observer Code for astronomical telegrams developed connections further afield. While producing professional-level astronomy, the observatory was embedded in the amateur community — letters often refer to incoming reports of observations as well as queries, promptly answered by means of new observations or reference to the comprehensive library at Dun Echt. The *Dun Echt Circulars*, aimed squarely at observers, must have been invaluable to many of them.

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(References to letters in the Archives are abbreviated thus: "ROE A27.186, 19" for "ROE Archives Box 27, Book 186, letter (beginning) on p. 19". Dates of letters are given in uniform style.)

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 17: THE F-TYPE TWIN SYSTEM CW ERIDANI

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CW Eri is a detached eclipsing binary system of two F-type stars with an orbital period of 2·728 d. Light-curves from two sectors of observations with the *Transiting Exoplanet Survey Satellite* (*TESS*) and previously published radial-velocity data are analysed to determine the system's physical properties to high precision. We find the masses of the two stars to be $1{\cdot}568 \pm 0{\cdot}016\ M_{\odot}$ and $1{\cdot}314 \pm 0{\cdot}010\ M_{\odot}$, the radii to be $2{\cdot}105 \pm 0{\cdot}007\ R_{\odot}$ and $1{\cdot}481 \pm 0{\cdot}005\ R_{\odot}$ and the system's orbit to have an eccentricity of $0{\cdot}0131 \pm 0{\cdot}0007$. The quality of the *TESS* photometry allows the definition of a new high-precision orbital ephemeris; however, no evidence of pulsation is found. We derive a distance to the system of $191{\cdot}7 \pm 3{\cdot}8$ pc, a value consistent with the *Gaia* DR3 parallax which yields a distance of $187{\cdot}9^{+0{\cdot}6}_{-0{\cdot}9}$ pc. The measured parameters of both stellar components are found to be in agreement with theoretical predictions for a solar chemical composition and an age of 1·7 Gyr.

Introduction

Detached eclipsing binaries (dEBs) are a vital source of stellar parameters as they allow direct measurement of the component stars' physical properties when combining light-curves and radial-velocity (RV) observations[1–3]. Detached systems are particularly useful as, in the absence of mass transfer, the components are representative of single stars and are therefore an invaluable source of data for testing and refining stellar-evolution models[4,5].

The volume and quality of light-curve data has increased enormously in recent years[6], especially from space-based exoplanet surveys such as *CoRoT*[7] and NASA's *Kepler*[8], *K2*[9], and *TESS*[10] (*Transiting Exoplanet Survey Satellite*) missions. This work is one of a series where we revisit known dEBs in order to refine their characterization with the benefit of this new era of photometry. Here we analyse CW Eridani using *TESS* light-curves alongside previously published RV data.

The dEB CW Eridani

HD 19115 was categorized as photometrically variable in 1967 by Strohmeier & Ott[11]. Popper[12] reported that the spectrum was double-lined and it was given the designation CW Eri by Kukarkin *et al.*[13]. Chen[14] reported on *UBV* photometric observations made at the Rosemary Hill Observatory between 1970 and 1972, publishing an ephemeris and relative sizes for the components. Further photometric observations were made by Mauder & Ammann[15] and, with the addition of spectroscopic observations made available to them by Popper, they recorded masses and radii for both components to 2–3% confidence and assigned a spectral type of F0.

Popper & Dumont[16] included CW Eri in their programme of *UBV* photometric observations at the Palomar and Kitt Peak observatories with the *B*- and *V*-band magnitudes given in Table I being recorded over 11 nights. Brancewicz & Dworak[17] included it in their catalogue of eclipsing binaries where they used numerical methods to characterize the system, giving a spectral type of F0+ and physical parameters to ~5% confidence.

Table I

Basic information on CW Eri.

Property	*Value*	*Reference*
Right ascension (J2000)	$03^{h}03^{m}59^{s}{\cdot}95$	22
Declination (J2000)	$-17^{\circ}44'16''{\cdot}06$	22
Henry Draper designation	HD 19915	23
Hipparcos designation	HIP 14273	24
Tycho designation	TYC 5868-881-1	25
Gaia DR3 designation	5152756553745197952	22
Gaia DR3 parallax	5·2380 ± 0·0198 mas	22
TESS Input Catalog designation	TIC 98853987	26
B magnitude	8·79 ± 0·07	16
V magnitude	8·43 ± 0·07	16
G magnitude	8·306 ± 0·003	22
J magnitude	7·799 ± 0·020	27
H magnitude	7·659 ± 0·034	27
K_s magnitude	7·626 ± 0·023	27
Spectral type	F2 V	28

The most complete investigations were carried out by Popper[12,18] based on spectrograms taken at the Lick Observatory between 1967 and 1974 along with photometry from Chen[14] and Mauder & Ammann[15]. Popper determined the spectral types of the components as F1 and F4, gave their masses to 2% confidence, and determined their radii to 2·5% and 4·5% for the primary and secondary components, respectively.

Outside automated surveys, in the years since Popper few observations have been made. Wolf & Kern[19] recorded three observations as part of their photometric survey of the southern hemisphere, giving a *V*-band magnitude ranging from 8·39 at quadrature to 8·90 during primary eclipse. Perry & Christodoulou[20] included it in their *uvbyβ* interstellar-reddening survey of the southern hemisphere. Nordström *et al.*[21] made three spectroscopic observations as part of their RV survey of early F-type dwarfs.

Table I shows basic information for CW Eri. The *B* and *V* magnitudes are those recorded by Popper & Dumont[16]. These were explicitly based on observations made outside of an eclipse and have since been widely used. The *J*, *H*, and K_s magnitudes are those reported by 2MASS from observations made at JD 2451052·9027±30 sec. At this time the system will have been within a secondary eclipse so these will be below the system's maximum brightness. The spectral type of F2 V is given by Houk & Smith-Moore[28] as part of the *Michigan Catalogue of HD Stars*, Vol 4.

Observational material

CW Eri was observed twice by the *TESS* mission[10], first in sector 4 from 2018/10/19 to 2018/11/14 and again in sector 31 from 2020/10/22 to 2020/11/18, each in short-cadence mode with a 120-s sampling rate. Both sectors show light-curves covering a period of approximately 25 days with a break near the midpoint for data download. Unambiguous primary and secondary eclipses are seen in addition to a sinusoidal variation resulting from the ellipsoidal effect (Fig. 1).

The *TESS* time-series data for the two sectors were downloaded from the MAST archive* and subsequently processed using the LIGHTKURVE[29] and ASTROPY[30] Python packages. These data consist of simple aperture photometry (SAP) and pre-search data conditioning SAP (PDCSAP) flux measurements[31]. We based our analysis on the SAP data as they are well-behaved whereas extraneous variability was seen in the PDCSAP data from sector 4. Data points with no flux value recorded (NaN) and those with a non-zero QUALITY flag were cut, as were those within a distorted secondary eclipse within sector 4 from BJD 2458420·0 to 2458423·0. A total of 13841 data points from sector 4 and 16671 from sector 31 were considered for subsequent analysis.

The *Gaia* DR3 database† was queried for potential sources of third light within 2 arcmin of CW Eri. Six of the seven objects found are at least 10 mag fainter than CW Eri in the *G*-band so contribute negligible light. The remaining object, TYC 5868-428-1, has a *G*-band magnitude of 11·053 mag with the resulting flux ratio of 0·080 being adopted as the initial value of the fitted third-light parameter in the following analysis.

Light-curve analysis

The remaining SAP flux data were converted to magnitudes then rectified to zero and detrended by fitting and subtracting a quadratic polynomial across the whole of each sector. This was refined after initial attempts at fitting, with the best results achieved by subtracting a second quadratic fit from those data in sector 4 following the mid-sector break. The resulting light-curves, shown in Fig. 1, consist of four isolated half-sectors over a time interval of ~759 d. We adopt the standard definition of the primary eclipse as being the deeper of the two which occurs when the larger and brighter component, which we label star A, is eclipsed by the smaller star B.

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

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

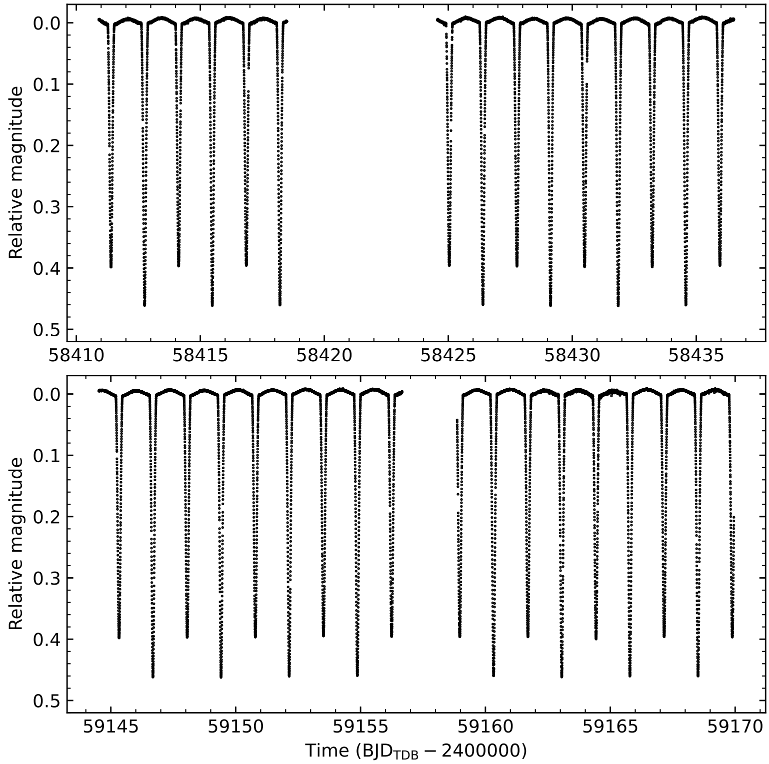

FIG. 1

TESS short-cadence SAP photometry of CW Eri from sectors 4 (top) and 31 (bottom). The flux measurements have been converted to magnitude units then rectified to zero magnitude by the subtraction of low-order polynomials.

The data were fitted using version 43 of the JKTEBOP* code[32,33] with a total 30 512 data points fitted as the four separate half-sectors. Each light-curve was fitted for the orbital period (P) and the time of mid-primary eclipse (T_0) with our reference time being the primary eclipse closest to the midpoint of the data. Also fitted were the sum ($r_A + r_B$) and ratio ($k = r_B/r_A$) of the fractional radii, the orbital inclination (i), the orbital eccentricity (e) and argument of periastron (ω) through the Poincaré elements $e \cos \omega$ and $e \sin \omega$, the stars' central-surface-brightness ratio ($\mathcal{J}$), the amount of third light ($L3$), and each star's reflected light.

We adopted the power-2 limb darkening (LD) law with *TESS*-specific coefficients taken from Claret & Southworth[34]. The coefficients were interpolated for star A ($T_{\rm eff} = 6840$ K and $\log g = 4{\cdot}0$) and star B ($T_{\rm eff} = 6560$ K and $\log g = 4{\cdot}2$), each with a solar metallicity ([Fe/H] $= 0{\cdot}0$). For both stars, the scaling coefficient c was left free to fit and α was fixed.

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

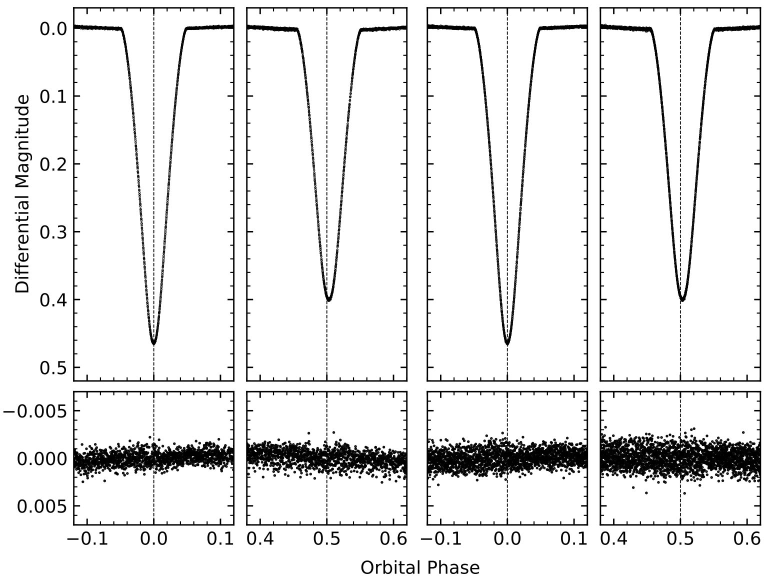

FIG. 2

Best fit to the full *TESS* sector-4 light-curve of CW Eri using JKTEBOP. The primary and secondary eclipse of the first half-sector are shown to the left and those for the second half-sector to the right. The residuals are shown on an enlarged scale in the lower panels.

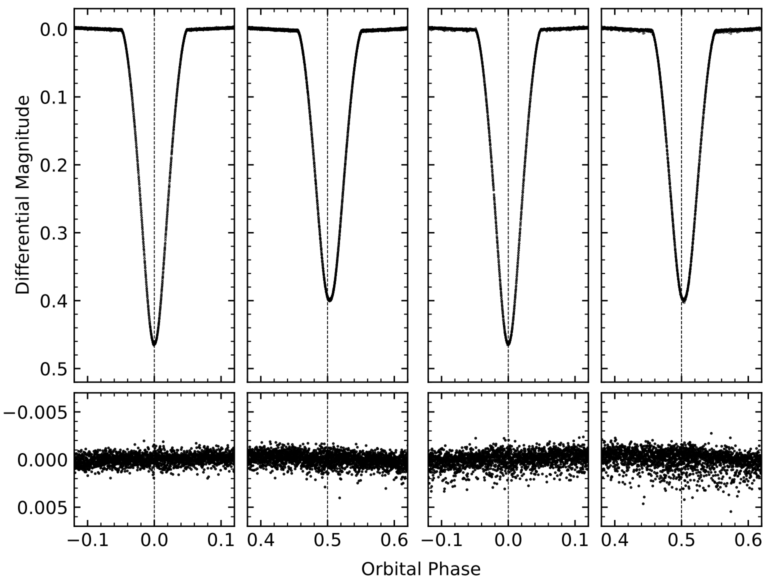

FIG. 3

Same as Fig. 2 but for *TESS* data from sector 31.

The best fits to the light-curves are shown in Figs. 2 and 3 where it can be seen that the secondary eclipse is slightly offset from phase 0·50, confirming a small orbital eccentricity. As F-type stars may exhibit γ Doradus or δ Scuti pulsations[35] the residuals of the fits were analysed with Lomb–Scargle periodograms, but no evidence of pulsation was found.

The final values and uncertainties for the fitted parameters of each half-sector were separately determined with 10 000 Monte Carlo (MC) simulations[32] and a residual permutation (RP) algorithm[36], as implemented by JKTEBOP tasks 8 and 9, respectively. The latter method successively shifts the best-fit residuals along the light-curve until they are cycled back to their initial position. With each shift a new fit is made and the final distribution of each fitted parameter gives an estimate of its uncertainty. While the MC simulations are sensitive to Poisson noise, the RP algorithm is additionally sensitive to correlated noise[36]. The fitted parameters for each half-sector are given in Table II with the uncertainties being the 1σ values of either the MC or RP simulations. The selection of uncertainties for each parameter is based on the method which yields the larger weighted mean error bar. The adopted parameters for CW Eri, as given in Table III, are the weighted mean and uncertainty of the corresponding fitted parameters across the four half-sectors.

Orbital ephemeris

With the light-curve analysis yielding consistent orbital parameters, we sought to derive a high-precision orbital ephemeris for the system. In order to base this on the longest possible dataset, historical minima-timing data for CW Eri were obtained from the TIming DAtabase at Krakow (TIDAK) team[37]. While the majority of minima timings were given without an uncertainty, all included a weight value between 1 and 10. Where missing, estimated uncertainties were generated by scaling a base estimate of 0·004 by the reciprocal of the observation's weight. To these data were added the primary epoch and period from fitting each of the four half-sectors of *TESS* data with their uncertainties scaled up by a factor of 5 to cover any scatter.

The existing TIDAK ephemeris* was used to calculate cycle numbers and assign minima types (primary or secondary) to the eclipses after which linear, quadratic, and cubic polynomials were fitted to reveal trends in the timings. Initial attempts at fitting the data revealed excessive scatter from a number of sources and the final fitted ephemeris is based only on the *TESS* observations and those from TIDAK with a weight of 10. With the fitting complete the quadratic and cubic fits were discounted, as they were poorly constrained by the data, and the following linear ephemeris was adopted:

$$\text{Min I} = \text{BJD}_{\text{TDB}}\ 2452500{\cdot}37624(69) + 2{\cdot}72837024(27)E \qquad (1)$$

with E being the cycle number since the reference time and the bracketed values being the uncertainties in the last digit of the preceding values. The final eclipse timing data used in this analysis are given in Table IV and the residuals of the linear fit are shown in Fig. 4.

Radial velocities

The RV measurements originally published by Popper[12] were reanalysed. The observations were made between 1967 and 1974 at the Lick Observatory and consist of 38 RVs for star A and 35 for star B. Popper's data gives RVs to

*https://www.as.up.krakow.pl/minicalc/ERICW.HTM

TABLE II

The fitted parameters of CW Eri for each of the four TESS half-sector light-curves using the JKTEBOP code. The uncertainties are 1σ values derived from either Monte Carlo or residual-permutation simulations. For each parameter the uncertainties given are from the method yielding the larger weighted mean uncertainty across the half-sectors. A value of 2400 000 has been subtracted from the eclipse times to save space.

Parameter	*Sector 4.1*	*Sector 4.2*	*Sector 31.1*	*Sector 31.2*
Fitted parameters:				
Primary eclipse time (BJD_{TDB})	58415·482929 ± 0·000022	58431·853144 ± 0·000015	59152·142894 ± 0·000015	59163·056373 ± 0·000020
Orbital period (d)	2·7283891 ± 0·0000157	2·7283696 ± 0·0000092	2·7283737 ± 0·0000065	2·7283805 ± 0·0000117
Orbital inclination (°)	86·366 ± 0·037	86·373 ± 0·033	86·412 ± 0·022	86·313 ± 0·040
Sum of the fractional radii	0·30659 ± 0·00021	0·30676 ± 0·00019	0·30651 ± 0·00013	0·30682 ± 0·00023
Ratio of the radii	0·7042 ± 0·0017	0·7033 ± 0·0011	0·7048 ± 0·0010	0·7026 ± 0·0012
Central-surface-brightness ratio	0·9262 ± 0·0065	0·9203 ± 0·0061	0·9309 ± 0·0041	0·9203 ± 0·0068
Third light	−0·0025 ± 0·0019	−0·0014 ± 0·0017	0·0024 ± 0·0012	−0·0036 ± 0·0021
LD c coefficient of star A	0·592 ± 0·027	0·622 ± 0·025	0·573 ± 0·017	0·611 ± 0·028
LD c coefficient of star B	0·614 ± 0·019	0·601 ± 0·018	0·620 ± 0·012	0·608 ± 0·021
LD α coefficient of star A		0·4676 (fixed)		
LD α coefficient of star B		0·4967 (fixed)		
$e \cos \omega$	0·00492 ± 0·00002	0·00491 ± 0·00001	0·00513 ± 0·00001	0·00513 ± 0·00002
$e \sin \omega$	−0·01181 ± 0·00108	−0·01290 ± 0·00069	−0·01135 ± 0·00066	−0·01229 ± 0·00082
Derived parameters:				
Fractional radius of star A	0·17990 ± 0·00026	0·18010 ± 0·00017	0·17979 ± 0·00016	0·18021 ± 0·00018
Fractional radius of star B	0·12669 ± 0·00016	0·12666 ± 0·00011	0·12672 ± 0·00010	0·12661 ± 0·00012
Orbital eccentricity	0·01279 ± 0·00099	0·01381 ± 0·00064	0·01245 ± 0·00060	0·01332 ± 0·00075
Light ratio ℓ_B/ℓ_A	0·4535 ± 0·0014	0·4537 ± 0·0010	0·4542 ± 0·0009	0·4510 ± 0·0010

TABLE III

The adopted parameters of CW Eri derived from the four TESS half-sector light-curves fitted with the JKTEBOP code. Other than the time of primary eclipse each is the weighted mean of the corresponding fitted parameter values and 1σ uncertainties for each fitted half-sector given in Table II.

Parameter	*Value*
Fitted parameters:	
Time of primary eclipse (BJD_{TDB})	2458415·482929 ± 0·000022
Orbital period (d)	2·7283751 ± 0·0000068
Orbital inclination (°)	86·381 ± 0·042
Sum of the fractional radii	0·30662 ± 0·00015
Ratio of the radii	0·7037 ± 0·0011
Central-surface-brightness ratio	0·9262 ± 0·0057
Third light	−0·0002 ± 0·0030
LD c coefficient of star A	0·593 ± 0·024
LD c coefficient of star B	0·613 ± 0·009
LD α coefficient of star A	0·4676 (fixed)
LD α coefficient of star B	0·4967 (fixed)
$e \cos \omega$	0·00502 ± 0·00013
$e \sin \omega$	−0·01210 ± 0·00076
Derived parameters:	
Fractional radius of star A	0·18000 ± 0·00020
Fractional radius of star B	0·12667 ± 0·00005
Orbital eccentricity	0·01310 ± 0·00067
Light ratio ℓ_B/ℓ_A	0·4532 ± 0·0015

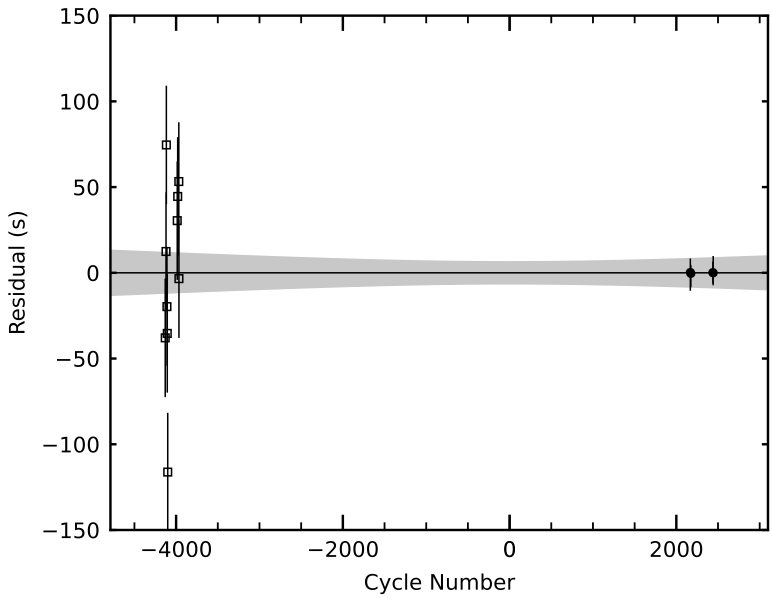

FIG. 4

Observed minus calculated ($O-C$) diagram of the times of primary minimum *versus* the fitted linear ephemeris. Timings from the *TESS* data are shown with with filled circles and those from the literature are shown as open squares where uncertainties have been estimated. The shaded areas indicate the 1σ uncertainty in the ephemeris determined from these data.

TABLE IV

Times of published mid-eclipse for CW Eri and their residuals versus the fitted ephemeris.

Orbital cycle	*Eclipse time* (BJD_{TDB})	*Uncertainty* (*d*)	*Residual* (*d*)	*Reference*
−4130·5	2441230·842503	0·000400	−0·000439	14
−4121·0	2441256·762604	0·000400	0·000144	14
−4117·0	2441267·676804	0·000400	0·000863	14
−4110·0	2441286·774304	0·000400	−0·000228	14
−4106·0	2441297·687604	0·000400	−0·000409	14
−4100·5	2441312·692704	0·000400	−0·001345	14
−3986·5	2441623·728610	0·000400	0·000352	14
−3981·0	2441638·734809	0·000400	0·000515	14
−3967·5	2441675·567908	0·000400	0·000616	14
−3966·0	2441679·659808	0·000400	−0·000039	14
2168·0	2458415·482929	0·000109	0·000003	This work
2174·0	2458431·853144	0·000075	−0·000004	This work
2438·0	2459152·142894	0·000074	0·000002	This work
2442·0	2459163·056373	0·000099	−0·000000	This work

one decimal place and HJD time-stamps to three decimal places and, in the absence of uncertainties, we applied equal weighting to all measurements. The RVs were analysed with JKTEBOP based on the ephemeris and orbital parameters derived from the photometric fitting with the uncertainties of the fitted results determined using Monte Carlo simulations (see Paper VI, ref. 38).

Initial fitting was carried out with fixed values for T_0 and P which yielded results very similar to Popper's with slightly worse r.m.s. residuals for star B. Given the low temporal resolution of the observations, we investigated whether allowing these parameters to be varied when fitting the RV orbits would yield an improved fit. It was found that allowing T_0 to vary yielded a demonstrable improvement in the fitted RV orbits with lower uncertainties and r.m.s. residuals; these are the results reported here.

The fitted orbits are shown in Fig. 5. Parameters for the spectroscopic orbits are given in Table V which shows them to be in good agreement with Popper[12] while having lower uncertainties and residuals. Nordström *et al.*[21] give only an overall systemic velocity of $V_\gamma = 37{\cdot}16 \pm 2{\cdot}94$ km s^{-1}, based on three observations, which also agrees well with our findings. Few works have published any further RV data on CW Eri, with Duflot *et al.*[39] giving $V_\gamma = 36{\cdot}4$ km s^{-1} in their Wilson-Evans-Batten catalogue and Gontcherov[40] giving a value $V_\gamma = 36{\cdot}8 \pm 2{\cdot}1$ km s^{-1}, potentially based on the values published by Nordström and Duflot, with both showing some overlap with our individual RVs.

TABLE V

Spectroscopic orbits for CW Eri from the literature and from the reanalysis of the RVs in the current work. All quantities are in km s^{-1}.

Source	K_A	K_B	$V\gamma_A$	$V\gamma_B$	*r.m.s residual*
Popper[12]	98·9 ±0·3	118·0 ±0·6	36·4 ±0·3	35·7 ±0·5	1·70, 2·80
This work	98·7 ±0·3	117·7 ±0·5	36·1 ±0·3	36·2 ±0·4	1·55, 2·55

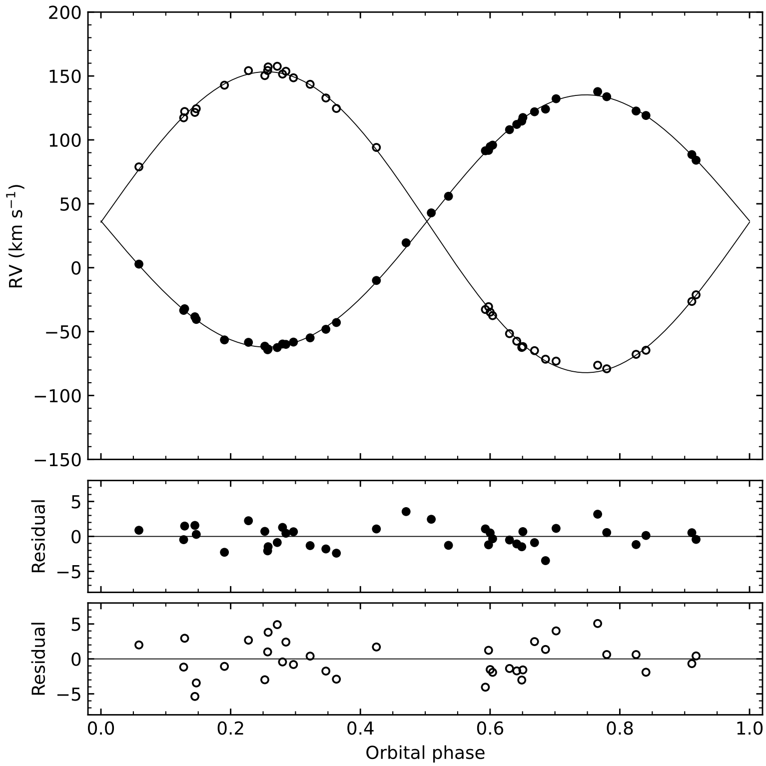

Fig. 5

RVs of CW Eri measured by Popper[12] (filled circles for star A and open circles for star B) compared to the best-fitting spectroscopic orbits from JKTEBOP (solid curves). The residuals are given in the lower panels separately for the two components.

Physical properties of CW Eri

The physical properties of CW Eri were calculated based on the parameters derived from the light-curves (Table III), the RV fitting (Table V), and the new ephemeris calculated above. The uncertainties for r_A and r_B were increased to 0·2% following the recommendation from Maxted *et al.*[41]. Effective temperature values were taken from Popper[12] where a value for both components has been given with accompanying uncertainty. The JKTABSDIM code[42] was used to calculate the system's properties given in Table VI with uncertainties propagated using a perturbation approach. Standard formulae[43] and the reference solar values from the IAU[44] were used.

The results show that the masses and radii are determined to a precision of better than 1·0%, meeting the criteria for inclusion in the *Detached Eclipsing Binary Catalogue* (*DEBCat**, ref. 3). The mass measurements are in agreement with the original values published by Popper[12], as expected as they are based

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

TABLE VI

Physical properties of CW Eri defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 44).

Parameter	*Star A*	*Star B*
Mass ratio	$0{\cdot}8385 \pm 0{\cdot}0047$	
Semi-major axis of relative orbit ($\mathcal{R}^{\rm N}_{\odot}$)	$11{\cdot}694 \pm 0{\cdot}034$	
Mass ($\mathcal{M}^{\rm N}_{\odot}$)	$1{\cdot}568 \pm 0{\cdot}016$	$1{\cdot}314 \pm 0{\cdot}010$
Radius ($\mathcal{R}^{\rm N}_{\odot}$)	$2{\cdot}1048 \pm 0{\cdot}0074$	$1{\cdot}4812 \pm 0{\cdot}0052$
Surface gravity (log[cgs])	$3{\cdot}9869 \pm 0{\cdot}0026$	$4{\cdot}2156 \pm 0{\cdot}0022$
Density ($\rho_{\odot}$)	$0{\cdot}1681 \pm 0{\cdot}0011$	$0{\cdot}4045 \pm 0{\cdot}0027$
Effective temperature (K)	6839 ± 87	6561 ± 98
Luminosity $\log(L/\mathcal{L}^{\rm N}_{\odot})$	$0{\cdot}941 \pm 0{\cdot}022$	$0{\cdot}564 \pm 0{\cdot}026$
$M_{\rm bol}$ (mag)	$2{\cdot}387 \pm 0{\cdot}056$	$3{\cdot}330 \pm 0{\cdot}065$
Distance (pc)	$191{\cdot}7 \pm 3{\cdot}8$	

on the same RV data. The measured radii are consistent with those from Popper ($2{\cdot}08 \pm 0{\cdot}05$ and $1{\cdot}56 \pm 0{\cdot}07$ $R_{\odot}$) but are much more precise due to the availability of the *TESS* photometry.

We determined the distance to the system based on the *B* and *V* apparent magnitudes from Popper & Dumont[16] and those in the *J*, *H*, and K_s-bands from 2MASS[27] (Table I). The 2MASS magnitudes are based on observations made during a secondary eclipse which were corrected for by subtracting the fitted light-curve model at the corresponding phase to find revised values of $J = 7{\cdot}658 \pm 0{\cdot}022$, $H = 7{\cdot}518 \pm 0{\cdot}035$, and $K_s = 7{\cdot}485 \pm 0{\cdot}025$ mag. We searched for reliable observations made in the Cousins *R* and *I* bands but found none. An interstellar extinction value of $E(B–V) = 0{\cdot}013 \pm 0{\cdot}015$ was adopted from the STILISM tool* and bolometric corrections from Girardi *et al.*[45] were used.

The *Gaia* DR3[22] parallax yields a distance of $187{\cdot}9^{+0{\cdot}6}_{-0{\cdot}9}$ pc for CW Eri, with the renormalized unit weight error (RUWE) of 1·029 indicating a reliable astrometric solution. This is in agreement with distances based on the bolometric corrections of Girardi *et al.*[45] when applied to the *B*, *V*, and *J*-band magnitudes, with the *J*-band yielding the best match at $188{\cdot}4 \pm 3{\cdot}0$ pc. A similar pattern is seen when using the passband-specific surface brightness–$T_{\rm eff}$ relations of Kervella *et al.*[46]. Both methods yield slightly larger distances than *Gaia* using the *H* and K_s-band magnitudes; however, the weighted mean of all of the derived distances is $191{\cdot}7 \pm 3{\cdot}8$ pc which is in agreement with the *Gaia* value.

Comparison with theoretical models

To test our results, the measured properties of the components of CW Eri were compared with predictions of PARSEC theoretical stellar-evolutionary models[47] in plots of mass *versus* radius, $T_{\rm eff}$, and luminosity. The best agreement was found for models based on a solar composition (fractional metal abundance of $Z = 0{\cdot}017$) and an age of 1·7 Gyr. This gives a very good fit to star A with star B appearing slightly larger and more luminous than the model predictions. Choosing a model with lower metallicity gives a closer fit to star B's radius and luminosity but at the expense of star A which now appears slightly smaller and less massive than predicted, and both components are cooler than the model. The converse is found when higher-metallicity models are used with the $T_{\rm eff}$ being most sensitive to any change. Fig. 6 shows models ranging from slightly sub-solar ($Z = 0{\cdot}014$) through solar to slightly super-solar metal abundance ($Z = 0{\cdot}020$).

*https://stilism.obspm.fr

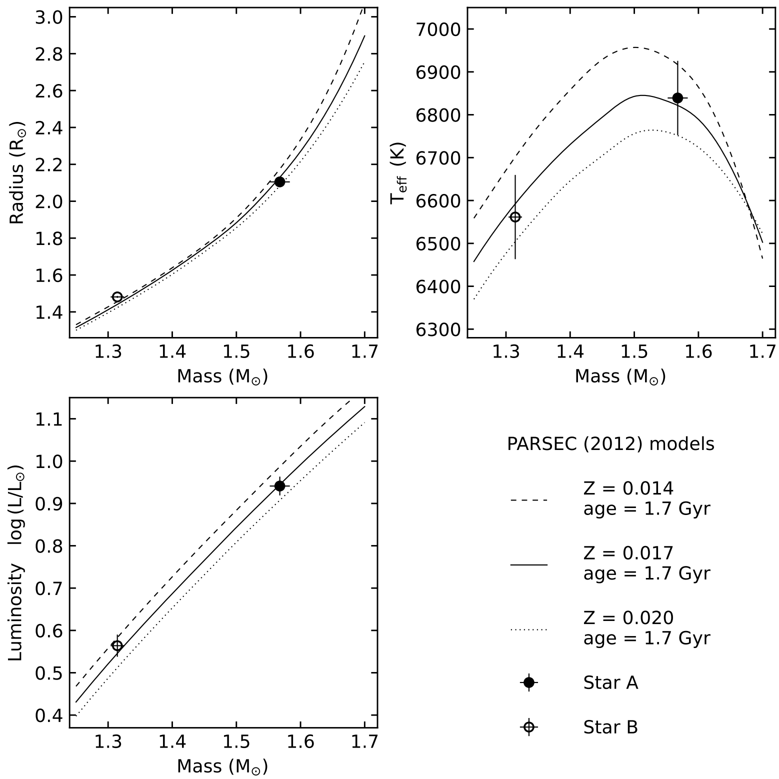

Fig. 6

Comparison between the theoretical predictions of PARSEC models[47] and the measured properties of CW Eri presented here for stellar mass *versus* radius, $T_{\rm eff}$, and luminosity. The ages and metal abundances of the chosen theoretical models are given in the legend within the lower right quadrant.

This choice of age and metallicity is further supported with a Hertzsprung–Russell diagram showing the evolutionary tracks of PARSEC model stars of $Z = 0{\cdot}017$ and masses 1·3, 1·45, and 1·6 $M_\odot$ (Fig. 7). Both components of CW Eri are consistent with model stars of similar mass which have evolved away from the ZAMS line into the upper half of the main sequence. Comparisons were also made with equivalent MIST[48,49] models and evolutionary tracks, with broadly similar results except that the star A is hotter than predicted.

While the chosen PARSEC model has a good fit to the mass, radius, and $T_{\rm eff}$ of the components, we note that the metallicity is in disagreement with published values. Perry & Christodoulou[20] give [Fe/H] = –0·32 in their *uvbyβ* survey of southern hemisphere A and F-type stars. A value of [Fe/H] = –0·39 was published in the *Geneva-Copenhagen Catalogue* by Holmberg *et al.*[50] and subsequently recalculated as –0·26 by Casagrande *et al.*[51]. A plausible answer to this discrepancy is that the metallicity was calculated assuming that the photometry of the system represents that of a single star rather than the combined light of two stars of different colours.

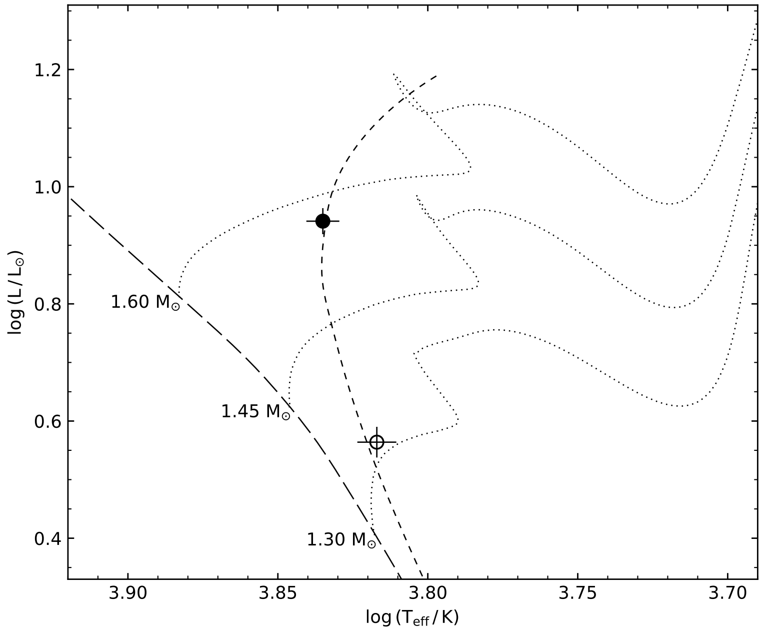

FIG. 7

Hertzsprung–Russell diagram showing the components of CW Eri (filled circle for star A and open circle for star B) and selected predictions from the PARSEC models[47] (dotted lines). The zero-age main sequence is shown with a long-dashed line, and an ioschrone for an age of 1·7 Gyr with a short-dashed line. Models for 1·30, 1·45, and 1·60 $M_{\odot}$ are shown (labelled) with a metal abundance of $Z = 0{\cdot}017$.

Summary

CW Eri is a dEB consisting of a pair of F-type stars that has remained largely ignored since it was last studied by Popper in 1983[12]. We have revisited the system, making use of two sectors of *TESS* photometry, and determined its photometric parameters to high precision. By combining these results with Popper's original RVs we refined the spectroscopic orbits and subsequently obtained high-quality measurements of the physical properties of the system. The residuals were analysed for evidence of pulsations with none being found. By combining eclipse timings from the four fitted *TESS* half-sectors with archival eclipse-timing data we defined a new high-precision orbital ephemeris.

The properties of both stars were found to be consistent with PARSEC models for a solar metallicity and an age of 1·7 Gyr. The evolutionary tracks show the stars to be in the second half of their main-sequence lifetime with the more massive star A having evolved farther from the ZAMS. With two stars of well-constrained properties and age this system lends itself to the calibration of future stellar models, a role which could be further enhanced by the analysis of follow-up spectroscopy to constrain their atmospheric characteristics better.

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CORRESPONDENCE

To the Editors of 'The Observatory'

Willem Henri Julius (1860–1925)

In her retrospective review[1] of Charles Abbot's 1911 book *The Sun*[2], Virginia Trimble notes that 'W. H. Julius' is mentioned and wonders who he was and what his contributions to solar physics were. Andrew Young has already briefly outlined Julius' contributions[3] but I have unearthed a few more details which I thought might also be of interest. As Prof. Trimble notes, Julius is not included in the *Biographical Encyclopedia of Astronomers*[4], at least in the edition to which I have access. However, Brüggenthies & Dick's *Biographical Index of Astronomy*[5] does have an entry for one 'Julius, Willem Henri' which gives further entries in the *Dictionary of Scientific Biography* (*DSB*; by Marcel Minnaert)[6] and the on-line *Finding List of Obituary Notes of Astronomers*[7] (*ONA*) compiled by Duerbeck, Ott & Dick. The *ONA*, in turn, gives three obituaries, of which I was able to locate two[8,9], including one in this *Magazine*. A further search of the NASA ADS Bibliographical Database for items about Julius published in the years shortly after his death found one by Einstein that appeared in *ApJ*[10]. It is not a conventional obituary but a recap of some of Julius' ideas and an appeal that they not be overlooked.

The two obituaries[8,9] are both anonymous, single, short paragraphs and do little more than note Julius' death. Most of what follows is based on the entry by Minnaert in the *DSB* and Einstein's paper in *ApJ*. Minnaert was Julius' research student[11] and later occupied the Chair that Julius had held (though Minnaert was not the immediate successor). Einstein was a long-standing friend.

Willem Henri Julius (his forenames were sometimes Anglicised to William Henry; Fig. 1) was born in Utrecht on 1860 August 4. He enrolled at the University of Utrecht in 1879, where he studied mathematics and physics, gaining a doctorate under the supervision of Buys Ballot. (Christophorus Buys Ballot, 1817–90, is primarily remembered as a meteorologist, but at the time he supervised Julius he held Chairs in Physics and Mathematics, having initially been appointed to teach Mineralogy and Geology and then holding a Chair

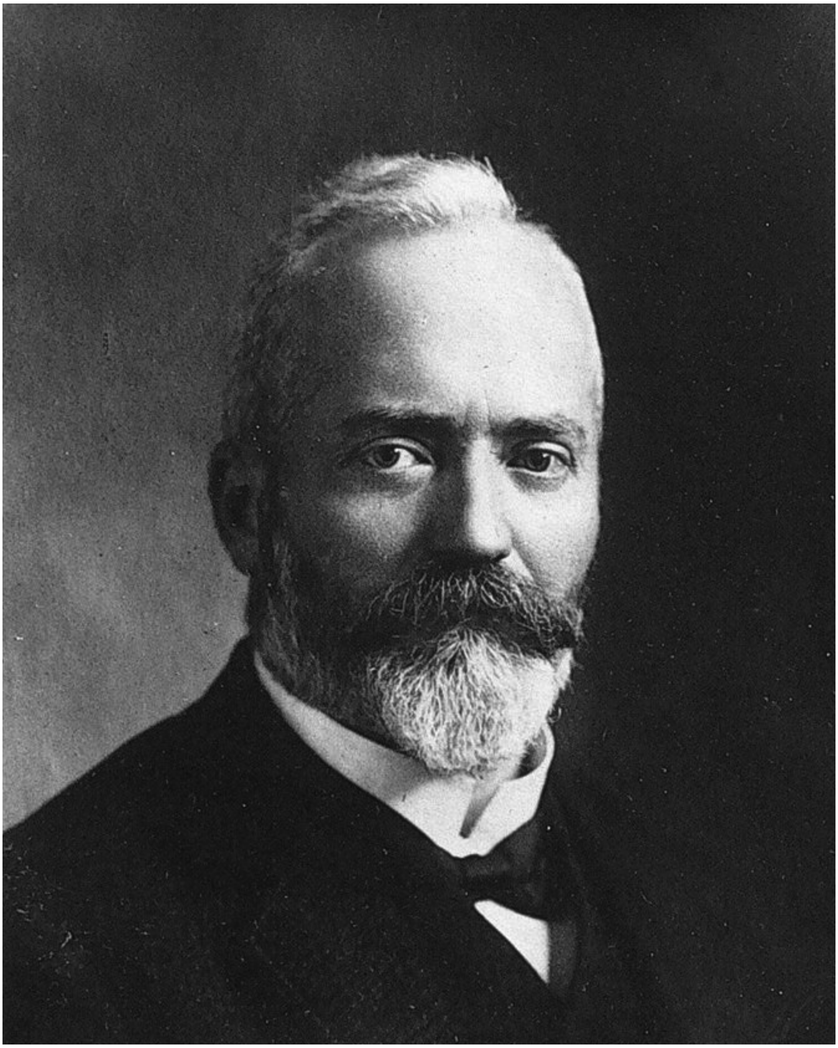

Fig. 1

William Henry Julius (1860–1925). Photograph extracted from the on-line genealogical database geni.com where it is included in an album compiled by Ms. Marije Walbeek, a descendent. It is reproduced courtesy of Ms. Walbeek.

in Chemistry[12].) In 1890 Julius was appointed a Professor at the University of Amsterdam but in 1896 moved back to Utrecht to take up a Chair there. He remained at Utrecht for the rest of his career and later became Director of the University's Physical Laboratory, within which he subsequently established a Heliophysical Observatory[13]. Julius died on 1925 April 15 at the age of 64.

Julius' career divides into two parts. In the first he worked primarily on laboratory physics, specifically using radiometers to study the infrared emission and absorption spectra of gases. In order to improve the stability of his radiometers he developed the 'Julius suspension' in which the radiometer is supported directly below its centre of mass in order to reduce vibration.

Around 1890–1900 Julius' work underwent a change of direction. Einstein places this change in 1891 and attributes it to Julius reading August von Schmidt's study of refraction in the solar atmosphere[14]. Conversely Minnaert places it in 1901 when Julius was involved in observing the eclipse of that year. These assertions can be reconciled, at least to some extent, if Julius read Schmidt's book some years after its publication in 1891 and in preparation for the eclipse. The earliest astronomical publication by Julius recorded in the NASA ADS is from 1899[15] and concerns what became his principal astrophysical interest: extending Schmidt's ideas about refraction in the solar atmosphere.

Julius was heavily involved in the Dutch expedition to observe the 1901 total solar eclipse from Karang Sago, then in Dutch Sumatra, now in Indonesia. He was a member of the organizing committee for the expedition, wrote (with J. C. Kapteyn, J. P. van den Stok and A. A. Nijland) a pamphlet offering advice to amateur astronomers about observing the eclipse, and participated in the expedition itself[16,17]. He also observed the 1905 and 1912 eclipses[18].

However, most of Julius' solar work was concerned with extending Schmidt's ideas on refraction due to density inhomogeneities in the solar atmosphere and anomalous refraction close to the central wavelength of absorption lines. He used these ideas to explain aspects of the appearance of sunspots and prominences and the broadening of Fraunhofer lines. Starting in 1899 he published many papers on this topic.

Julius' ideas initially received a mixed reception, for example, being criticised by St. John[19–22] and Royds[23] but treated more favourably by Albrecht[24] and Croze[25]. Anomalous dispersion is an established phenomenon, demonstrated in laboratory experiments (see the discussion of theories of optical dispersion between the 1870s and 1920s by Taltavull[26] and references therein). At the time of Julius' work the pressure in the solar atmosphere had not been measured but was assumed to be much higher than turned out to be the case. In 1923 Fowler & Milne[27] measured the electron pressure in the solar atmosphere to be 10^{-4} atm, far too tenuous for anomalous dispersion to play a significant role in solar phenomena. From this point Julius' theories were untenable. Forbes[28] gives a succinct summary of these developments. In his *DSB* entry Minnaert judiciously describes the importance that Julius attached to anomalous dispersion as 'vastly exaggerated' (Minnaert's thesis under Julius had been on 'Irregular ray curvature'). In his paper Einstein merely suggests that Julius' ideas are worth considering and discusses them in the context of the radial velocities observed in the photosphere; he does not endorse them. More recently Julius' ideas are briefly discussed by Taltavull[29] and at greater length (and in German) by Hentschel[30].

By the mid-19th Century astronomy was well-established at Utrecht, the University Observatory having been founded in 1642, just six years after the University was founded in 1636[31]. However, there had been no solar work before

Julius[32]. His own work, founding the Heliophysical Laboratory and the several doctoral students that he supervised[33], were the start of the Utrecht solar physics group, which became well-known and well-respected later in the 20th Century. Julius also supervised doctoral students in mathematics[34] and meteorology[35].

Some correspondence by Julius is extant. George Ellery Hale (1868–1938)[36] is mostly remembered as the founder of the Yerkes, Mount Wilson, and Palomar Observatories, for his rôle in the establishment of scientific organizations, including the International Union for Co-operation in Solar Research (a precursor of the IAU), and for co-founding *ApJ*. His own research was primarily in solar astronomy and, of course, the Mount Wilson Observatory included extensive, indeed preeminent, instrumentation for solar work. An extensive correspondence between Hale and Julius during the years 1903–25 has survived[37]. The greater part of it concerns anomalous dispersion, though other topics include the submission and discussion of papers (in Hale's editorial rôle for *ApJ*), instrumentation for Julius' Heliophysical Observatory, and a visit by Julius to Mount Wilson. While the Director at Mount Wilson, Hale encouraged a number of eminent European astronomers to visit the Observatory, use its facilities and collaborate (Kapteyn is a well-known example), and Julius duly visited in the summer of 1907. The correspondence shows Hale as initially open-minded about the importance of anomalous dispersion and he collaborated with Julius in the design of instruments and experiments to test these ideas at Mount Wilson. He largely maintains this open mind throughout the correspondence, though his attitude seems to cool somewhat as convincing evidence proves elusive. The final item in the correspondence is a printed announcement of Julius' death sent by his wife and children.

In the autumn of 1911 there was a complicated correspondence between Julius, Henderick Lorentz (Professor at Leiden), and Einstein, offering the latter a chair at Utrecht, which had become vacant following the death of Cornelis Wind (1867–1911) earlier in the year. Julius made an informal approach on August 20 and on November 15 Einstein sent his final refusal, declining in favour of the offer of a chair at Zurich, for which he had also been in negotiation and had probably preferred all along. During this period Einstein visited Julius in Utrecht on his way home from the First Solvay Congress, held in Brussels during October. This episode is briefly described by Fösling[38], in more detail by Clark[39], and at greater length (and in Dutch) by van Herwaarden[40]. A few years later Julius joined Lorentz, Pieter Zeeman, and Heike Kamerlingh Onnes in sending a letter of support for Emil Warburg's fourth (and unsuccessful) nomination of Einstein for a Nobel Prize[41].

The extant correspondence between Julius and Einstein is included in the Einstein *Collected Papers*[42]. In addition to letters about the proposed appointment at Utrecht there is various other correspondence from the turn of the century to a few months before Julius' death. Some additional material pertaining to Julius is held in the Archives of the University of Utrecht.

A search of the NASA ADS bibliographic database[43] finds 53 publications by Julius, of which it considers 24 to be refereed. Julius published primarily in the *Proceedings* of the Royal Netherlands Academy of Arts and Sciences (*KNAB; Koninklijke Nederlandse Akademie van Wetenschappen*, Proceedings Series B, Physical Sciences; 24 papers) and *ApJ* (16 papers), together with a few publications in other journals, including one in this *Magazine*[44]. He mostly published in Dutch or English, but also wrote a few papers in German or French. Following normal practice at the time all but two of his papers are single-author. However, these numbers should be regarded with a certain degree of circumspection. Andrew Young's *Annotated Bibliography of Atmospheric Refraction*[45] lists two papers on anomalous dispersion that Julius published in the *Physikalische Zeitschrift* (a German physics journal that ran during the first half of the 20th Century) which do not appear in the ADS list. Also, many of the papers listed by the ADS are duplicates, with the same paper published in *ApJ*, *KNAB*, and in some cases other publications (such duplication, to give papers a wider international readership, was another practice more common then than now). Finally, the figures do not include Julius' non-astronomical publications on laboratory studies of infrared emission and absorption. A search of the *WORLDCAT* global on-line union catalogue of library holdings lists 28 books by Julius, but inspection reveals that some of the entries are bound copies of reports or reprints of papers (again, the circulation of reprints was common at the time). Removing these entries whittles the list down to five titles, all of which are in Dutch. They are summarized in Table I.

A simple on-line search (unsurprisingly) found entries for Julius in the on-line *Biographical Dictionary of the Netherlands*[46] maintained by the Huygens Institute, and in the Dutch Wikipedia[47]. The latter includes a scan of a portrait of Julius by Mrs Antonie Lewin dating from 1916. He would have been 56 when it was painted but looks older. The search also found an entry in the *Lucerna* on-line database of magic-lantern images hosted by the University of Exeter[48]. It refers to three sets of magic-lantern slides of Dutch eclipse expeditions of 1901, 1905, and 1912, with low-resolution images available, some of which clearly show Julius.

Finally, Julius' posthumous *Leerboek der zonnephysica*[49] (which was brought to publication by Minnaert) includes a summary biography of Julius and a complete list of his publications. Minnaert's *DSB* entry locates this biography and bibliography in a book entitled *De Natuurkunde van de Zon*, of which I can

TABLE I

Books published by W. H. Julius. In all cases they are in Dutch and Julius is the sole author.

Date	*Title*	*Title* (*English*)	*Publisher*	*Location*	*Notes*
1888	*Het warmtespectrum en de trillingsperioden der moleculen van eenige gassen*	The heat spectrum and the vibration periods of the molecules of some gases	J. van Boekhoven	Utrecht	Doctoral Thesis.
1891	*De methoden van onderzoek in de natuurkunde*	The methods of research in physics	Clausen	Amsterdam	Inaugural lecture at the University of Amsterdam.
1896	*Kritiek in de natuurkunde*	Criticism in physics	Kemink	Utrecht	
1908	*Energievervoer in de electronenwereld*	Energy transport in the electronics world	J. van Druten	Utrecht	Speech delivered on the 272nd anniversary of the Utrecht high school, 26 March 1908.
1928	*Leerboek der zonnephysica*	Textbook of solar physics	Noordhoff	Groningen	Posthumous. Published in the series *Natuurkundige Bibliotheek.*

find no trace; if it exists it has left a remarkably light bibliographic footprint. Minnaert had published a paper[50] and a book[51] with very similar titles at around the same time and it seems plausible that he was simply mis-remembering the title when he wrote the *DSB* entry.

In summary, Willem Henri Julius was a physicist who later turned to solar physics and was active in that field in the early decades of the 20th Century, so his being mentioned in Abbot's 1911 book about the Sun is not surprising. He started solar work at Utrecht and founded the solar physics group there, but his own ideas about refraction in the solar atmosphere did not survive measurement of the pressure in the solar atmosphere.

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I am grateful to Dr. Paul Lambers of the University Museum, Utrecht, for information about material pertaining to Julius held by the University of Utrecht and to Professor V. Trimble for comments on an earlier version of the manuscript. This investigation has made extensive use of the NASA ADS on-line bibliographic database and, in practice, would have been impossible without it. It has also made substantial use of the *WORLDCAT* global on-line union catalogue of library holdings and the *JSTOR* on-line digital academic library. I was able to access *JSTOR* courtesy of the National Library of Scotland. Other on-line resources used are listed in the references. As ever, I remain grateful for the use of the Library at the Royal Observatory Edinburgh. Translations from Dutch and German were made using the on-line translation service Translate.com; I do not read either language. Any mistakes, of course, are my own.

Yours faithfully,
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2023 October 6

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All URLs accessed on 2023 October 6.

'Sprites' in 1893

Browsing recently in the pages of *Nature* for 1893, the undersigned chanced on the following letter containing the most striking description of 'sprites' he has yet seen. The letter[1] was written a good century before this intriguing phenomenon of atmospheric electricity was scientifically recognized, and is perhaps not widely known, so may be of interest to other readers of *The Observatory*.

"*Thunderstorms and Auroral Phenomena.*

I am residing in tropical Queensland, lat.21° S., and consequently am not likely to see any auroral phenomena, particularly in the middle of our hot and rainy season; but last night between 8 and 9 p.m. there occurred the following remarkable appearances, which were seen by me and several others.

There was a sharp thunderstorm with incessant lightning visible on the southern horizon, occupying a width of 10° and an altitude of from 5° to 10° above the horizon, probably from 80 to 100 miles off.

But for the distant thunderclouds the sky was clear and starlight, with a few light cirrus clouds drifting before the north wind.

I was sitting on the lawn watching the distant flashes, when suddenly a patch or cloud of rosy light — 5° to 6° in diameter — rose up from above the thunderstorm and mounted upwards, disappearing at an elevation of from 40° – 45°. There were about twenty to twenty-five of these patches in the course of half an hour, sometimes three or four in quick succession; they took from one to two seconds to mount, and were not associated with any particular flash; the rosy colour contrasted strangely with the silvery light of Nubecula Major just above. There were also occasional streamers, sometimes bifurcated, of 2° in breadth, which shot up in the same way as the auroral streamers, which I have seen both in the arctic and antarctic zones.

Auroral phenomena are known to be electrical manifestations, but here were the same phenomena exhibited in connection with a thunderstorm in the tropics. Thinking this phase of electrical action worthy of note, I send you this account and enclose my card.

J. Ewen Davidson.

Branscombe, Mackay, Queensland, February 5th.

P.S. — The thunderstorm, patches of light, and streamers were distinctly *connected*; it was not a case of an ordinary aurora, with a thunderstorm interposed."

A classic eyewitness report, indeed, of a beautiful phenomenon very rarely so well seen. The letter writer, J. E. Davidson (1841–1923) was a well-known English amateur astronomer, an early life-member of the Astronomical Society of the Pacific, elected in 1890, and most famous as discoverer of Comet Davidson 1889, as well as independently of Comet Holmes 1892. He returned from Australia in 1900 and lived at 98 Banbury Road, Oxford, until his death, where some of his scientific books and apparatus still remained until dispersed at a house-contents auction in the 1980s.

Yours faithfully,
CHRISTOPHER TAYLOR

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2023 November 27

Reference

(1) *Nature*, **47**, 582, 1893.

REVIEWS

Resolving the Rise and Fall of Star Formation in Galaxies, edited by Tony Wong & Woong-Tae Kim (Cambridge University Press), 2023. Pp. 333, 25 × 18 cm. Price £98/$130 (hardbound; ISBN 978 1 009 35295 6).

This volume is the proceedings of IAU Symposium 373, held in Busan in the Republic of Korea in 2022 August as part of the XXXI General Assembly. According to the preface there were 21 invited talks, 36 contributed talks, 78 e-posters, and 78 e-talks at the symposium. This has translated into 71 printed papers — many of them very interesting — split into five (somewhat overlapping) sections: 'Scales of Star Formation: From Molecular Cores to Galaxies' (19 contributions), 'Sustaining Star Formation: Gas Conditions & Environment' (also 19), 'The Decline of Star Formation: Feedback, Fuel Shortage or Inefficiency' (9), 'The Rise and Fall of Star Formation Across Cosmic Time' (14), and 'Regulation of Star Formation and the Evolution of Galaxies' (10). The organizers' intention was to draw together work on the full range of scales, and they certainly achieved that, though it would be interesting to know exactly how much those participants primarily involved with large-scale surveys or cosmological simulations were able to take away from papers on, say, ultra-compact H II regions or hot molecular cores (and *vice versa* of course). A conference overview or summary would have been useful. A plus point of the volume is the wide geographical spread of institutions and individuals among the contributors, but a negative is that many of the results had already been published (in more detail) in journals prior to the meeting and more will have appeared by now. The latter point raises the wider question of the on-going value of such volumes. With journals moving towards on-line only, why does a conference have to have a printed book (apart from them being pleasant souvenirs for attendees)? Does anyone seek them out and search them for new work anymore, or simply check astro-ph? — Steve Phillipps.

Inside the Stars, by Hugo Van Horn (IoP Publishing), 2023. Pp. 252, 26 × 18·5 cm. Price £30/$50 (hardbound; ISBN 978 0 7503 5792 0).

Our understanding of the Universe today, and in particular of the structure and evolution of stars, is vastly different from what it was when I started as a research student in 1963. The classic textbooks on stars, which I acquired early in my research career, were those by Eddington (1926), Chandrasekhar (1939), and Schwarzschild (1958), with the latter describing how to make numerical models of stellar structure by the laborious 'fitting method'. Van Horn's book starts with a masterly introduction to those early days, starting with the first attempts in the 19th Century to understand what a star is and how it works. As an American (as one can deduce from the spellings), he makes more of the pioneering work of J. Homer Lane than I have seen elsewhere. During Lane's time at the US Patent Office (shades of Einstein!) he began to wonder whether the Sun might be gaseous (a liquid or even solid interior was a more common view at the time) and thought about the balance between gas pressure and gravity that we take for granted today. He later (1870) produced what were probably the first polytropic models of a star, which may have inspired the later work of Ritter and Emden in Europe.

By the time of Schwarzschild's book, the modern view of a star had emerged, and our understanding of stars progressed rapidly. Van Horn's stated aim is to explain how we know about the interiors of stars and how we can deduce the internal properties from surface observations. At first sight, the structure of the book is similar to that of any other modern text on stellar structure, 19 separate sections, the longest of which are the early ones, but it is different in its approach and style. In Section 1, the first short chapter gives a broad overview of what a star is before discussing observations of the Sun as a star in the next chapter. Van Horn then turns to the physics, with short chapters on radiation, composition, and energy sources before describing the properties of the material inside stars — equation of state, opacity, and nuclear-reaction rates. In all the chapters, he introduces the principal players in the field, often with short anecdotes and a photograph, many of which were new to me. His writing style is informal but precise, making for easy reading, and he often quotes from an interview with Martin Schwarzschild by the oral historian William Aspray in 1986.

In Part 2, a closer look at the interior of the Sun covers three important topics — how we came to understand the present Sun, the detection of neutrinos, and the use of helioseismology. The first of these describes the improvement in computations once digital computers became available* and once Henyey had introduced his method using an approximate model and then using difference equations to find a converged model, Schwarzschild happily gave up his fitting method in favour of this more efficient procedure.

I remember the agonizing in the physics community over the 'solar neutrino problem', where all the predictions came out 2 or 3 times the observed flux. It was not finally resolved until 2004 when the *SNO* device in Canada measured the total neutrino flux and it was realized that the Sun emitted the predicted number of electron neutrinos but that neutrino oscillations between the Sun and the detector turned about two thirds of them into mu and tau neutrinos, which only *SNO* was set up to measure. My then-Sussex colleague David Wark (now in Oxford) was part of the *SNO* consortium, so we heard all the details at that time.

*I remember Roger Tayler telling me once of the months he spent in the 1950s calculating stellar evolution on a manual calculator for his PhD.

We are all familiar now with the concept of asteroseismology, but the 'five-minute oscillations' of the Sun were a surprise when they were first discovered by Robert Leighton in 1960. It took a decade before they began to be understood as the p-modes (sound waves) predicted by Tom Cowling in 1941. Like neutrinos, these sound waves gave us a way of discovering conditions inside the Sun, including the temperature, density, and rotation distributions and the existence of a transition layer (the tachocline) between the differential rotation in the convective envelope and nearly uniform rotation in the radiative core. UK contributions to helioseismology (*e.g.*, the BiSON group in Birmingham and Douglas Gough in Cambridge on the theory of interpreting the observations) are well described.

In Part 3, Van Horn turns to stars, using the Sun as a reference point and starting with the properties of main-sequence stars. That leads naturally on to discussions of star formation and of brown dwarfs, stars that are too cool to burn hydrogen at their centres. In Part 4 the action moves to stellar evolution and death. These seven chapters cover what happens to stars of low mass when they run out of hydrogen to burn (the 'He-flash'), how intermediate-mass stars become white dwarfs, the properties of white dwarfs, the evolution of high-mass stars, supernovae, neutron stars, and finally stellar-mass black holes, which are introduced with an account of the detection of gravitational waves from a pair of merging black holes. This part is the meat of the book, and proceeds in the same style, following the development of ideas from the 1950s to the present day and mentioning in passing such items as Hoyle's 1950s prediction of a resonant level in the ^{12}C nucleus to explain how the triple-alpha reaction to form carbon from helium works fast enough, and Faulkner's 1966 explanation of the horizontal branch in globular clusters.

Van Horn gives a lot of detail of how a star evolves, both for low-mass stars like the Sun and for intermediate-mass stars, including careful discussion in the latter case of the various stages of dredge-up as the convective envelope extends down into zones of mixed composition produced by previous convection in material processed by nuclear burning. He mentions thermal pulses on the asymptotic giant branch, mass loss, planetary nebulae, and neutrino emission. He then turns to stellar remnants, such as white dwarfs, introduced by the discovery of 40 Eri B and Sirius B; he discusses how Chandrasekhar was able to explain in the 1930s how those hot dense objects could exist, although he doesn't mention Chandrasekhar's struggles to get his model accepted in the face of Eddington's scornful disbelief, expressed trenchantly at a meeting of the RAS. However, he does give a full discussion of the physics of white dwarfs, including their observed atmospheric properties and the cooling mechanism explained by Leon Mestel in the 1950s.

The evolution of more-massive stars ($> 8\ M_\odot$) leads not only to supernovae but their remnants, both expanding shells and a remnant imploded core. Van Horn describes succinctly the successive nuclear fuels that are burned, leading to an 'onion skin' structure of the layers of burned material of successively higher atomic mass until an iron core has formed. He describes the explosion mechanism, in which neutrinos appear to play a vital role in ejecting the shell that becomes a gaseous nebula, and why the iron core collapses. The resultant super-dense remnant is either a neutron star or, if too massive for that, a black hole. He also discusses SN 1987A and the detection of its neutrinos, as well as reviewing other types of supernova and how Type I supernovae explode, laying out the uncertainties. Three further chapters cover the origin of the chemical elements (Big Bang and in stars) and the physics of neutron stars (with a nod to the discovery of pulsars by Jocelyn Bell). The binary pulsar is mentioned as a test of General Relativity, and X-ray bursters also get a mention. The third chapter discusses stellar-mass black holes and gravitational radiation. Van Horn was present at the historic event where the positive *LIGO* results were announced and gives a graphic account of the excitement. The final three chapters cover stars with special characteristics — pulsating stars, cataclysmic variables, and the first stars.

There are six appendices expanding on some topics, such as electron degeneracy and *LIGO*, plus an extensive bibliography as well as relevant references at the end of each chapter. I had a few gripes. Firstly, I dislike page numbering by chapter (1-1, 1-2 *etc.*), so that it is laborious to find out how many pages the book contains (I have not checked the number claimed by the *Magazine*'s Editor [who crudely adds the numbers given in the list of chapters — Ed.]). More seriously, there is no general index, so one has to rely on the List of Contents to see whether any particular topic is covered. If you wanted to find out whether a particular astronomer gets a mention, you would have to guess which chapter he or she might be in. A list of illustrations would help with that, but there isn't one. I hope that if there is a second edition the publisher might deal with those points.

In summary, then, a very comprehensive and attractively written account of stellar structure and evolution, let down slightly by editorial deficiencies. I would still recommend it warmly for those wanting to know the details of what goes on inside stars. It covers advanced material at a level that would be useful for final-year physics undergraduates and beginning graduate students in astronomy, but it is written in a style suitable for less-advanced students. Members of many astronomical societies would appreciate it. But beware: it weighs 872 g! — Robert Connon Smith.

Physics of Binary Star Evolution. From Stars to X-ray Binaries and Gravitational Wave Sources, by Thomas M. Tauris & Edward P. J. van den Heuvel (Princeton University Press), 2023. Pp. 852, 23·5 × 15·5 cm. Price £80/$95 (paperback; ISBN 978 0 691 17908 7).

The evolution of binary-star systems sounds like one of those dull but worthy fields worked arduously by the older and more-bearded members of a typical university astrophysics department. This is wrong to the point of mendacity. The evolution of binary systems depends on juicy physics and leads to some of the weirdest and most wonderful objects within astrophysics, including cataclysmic variables, X-ray binaries, multiple types of supernova, millisecond pulsars, gamma-ray bursts, and the progenitors of gravitational-wave events.

Due to the variety and complex interrelations between many of these objects, the research in this area can be a bit compartmentalized and difficult to develop an intuitive feel for. This is perfect territory for a hefty textbook where the many threads can be pulled together into a coherent overview of the subject. Such a textbook requires extensive knowledge and understanding from the authors, the space to cover all relevant points, clear writing that engages the reader, and careful organization to aid their understanding. Tauris & van den Heuvel have produced exactly this textbook; it is a masterpiece.

The book begins with a brief but informative review of history of the many types of binary star (astrometric, spectroscopic, eclipsing, cataclysmic variables, X-ray binaries, supernovae, and others). Celestial mechanics gets the same treatment, followed by the Roche model, mass transfer, tides, accretion discs, common envelopes, white-dwarf binaries (both wide and close), and more. The bulk of the book is dedicated to the ménage of X-ray binaries, as might be predicted by those familiar with the research interests of the authors. Topics covered include LMXBs, IMXBs, HMXBs, and ULXs, and the discussion begins with the observational viewpoint before moving on to the theoretical framework. A clear description of the evolution of single stars follows, and then is extended to cover the evolution of stars in binary systems. The final chapters concern interacting binaries in globular clusters, supernovae, binary and millisecond pulsars, gravitational-wave events, and binary-population synthesis. More detailed treatments of some of these concepts are available elsewhere, but Tauris & van den Heuvel cover a huge amount in one place. It goes well beyond what a typical 'binary stars' module would cover at the undergraduate level, and will be useful for anyone undertaking research in this area from PhD students onwards.

The writing style throughout is clear and easy to read, which is impressive given the material covered. There are many diagrams, illustrating both physical concepts and observational data, and a good number of pretty pictures. Colour is present in those pictures and in the majority of the diagrams. Careful attention is paid to tracing the evolutionary pathways of binary systems, which can otherwise be hard to tease from other sources. A fair number of exercises are given at the end of many of the chapters, with (extremely brief) answers in an appendix. The book is also produced to a high standard, and I did not find any grammatical or typographical errors. Tauris & van den Heuvel's book has immediately become the standard text in this science area and I recommend it unreservedly. — John Southworth.

Astronomy of Ancient Egypt: A Cultural Perspective, by Juan Antonio Belmonte & José Lull (Springer), 2023. Pp. 588, 21·5 × 15 cm. Price £129·99 (hardbound; ISBN 978 3 031 11828 9).

In 1969, the great historian of science, Otto Neugebauer, wrote: "Astronomy played a uniformly insignificant role in all periods of Egyptian history." And the present authors tell us: "However, there is not a single explicit or obvious reference to any lunar or solar eclipse in the entire history of Pharonic Egypt" (with the possible exception of a 610 BC* event). That remark occurs on page 516, leaving one to wonder what the previous 515 pages have been about.

The last, seventh, chapter deals with astronomy and chronology. It is followed by a generous glossary, a long list of works consulted, and a moderate index. But the chronological issues are real. When, for instance, did Khufu (Cheops) of the Fourth Dynasty build his pyramid (the biggest one)? Table 7.1 presents three chronologies from earlier authors in which Cheops' dates are 2554–2531 BC, 2589–2566 BC, and 2509–2482 BC, not even overlapping, and Belmonte and Lull tell us that all three are wrong.

By the time of the much-romanticized 18th Dynasty, the various numbers are at least overlapping, and the authors defend a chronology that puts Tutankamun's nine-year reign in 1322–1314 BC†. But numbers from all the authorities do not entirely converge until we reach the reign of 25th dynasty Pharaoh Taharqa, 690–664 BC, when Egyptian and chronologies from other civilizations can be synchronized.

*The Managing Editor and I have previously disagreed about the proper abbreviation for years long ago. I have a strong preference for CE (Common Era) and BCE (Before Common Era). The present authors, however, use AD and BC and are entitled to their insensitive choice.

†Zahi Hawass, in *Tutankhamen: Treasures of the Golden Pharaoh* (IMG Melchior, New York), 2018, chooses 1336–1327 BC in a volume that came with the higher-priced tickets to a presentation in San Diego in spring 2013, part of his national fund-raising tour. He also declared during the book-signing event that "Badawy was a genius", a point to which I shall return.

There are, of course, carbon-14 dates for materials from various periods. Most of these have error bars that extend across all reasonable choices. Years of spikes in C-14 contents of tree rings* happen not to come close in time to interesting events in Egyptian history. And a solar eclipse recorded only by nearby civilizations† is too late at 1209 BC to constrain anyone before Merneptah and Ramesses II (the Great), who were already pinned down to within plus/minus a couple of years anyway.

We turn with relief to things that can be observed and measured today. First, the book itself is gorgeous, printed on paper glossy enough for the colour photographs to look real and for names in hieroglyphs printed within lines of ordinary text to be readable (if you are at least a little bit used to reading such things). Yes, modern technology has made it possible for every major publisher, not just Oxford and Chicago University Presses to have full sets of hieroglyphic type fonts. These are based on carved versions dating from the Middle Kingdom, and I was greatly pleased to spot the stack of three wiggly lines (read mw or mu, which is close to the Coptic word for water), the one sign correctly interpreted by Athanasias Kircher (1598–1680), which form part of the name of a dean‡ called Stars of the Water.

As for what is illustrated and named in the book, two of the important topics are alignments of temples, pyramids, and other buildings and images of the sky, or at least its constellations. Alignments of faces, entrances, corridors, shafts, and such favour the cardinal compass points and the directions of sunrise and sunset on the solstices often enough for the authors to conclude that these must have been deliberate and determined from observations, and not just a tendency to make things parallel to the Nile (their Figures 6.6 and 6.7, for instance). The preface to the book discusses at some length how those alignments might have been achieved using various possible astronomical observations, plumb lines, and artificial horizons. One alignment not discussed is "the controversial issue of the air-shafts in the Great Pyramid as hypothetical stellar channels" because the senior author has already written on the topic in a 2012 book on "*Piramides, templos, y estrellas*" (that is, in Spanish, his native language). A harsh attack on the hypothesis¶ is, however, cited without comment. It is not often that an author receives the dubious honour of being attacked for something published 55 years before (60 by the time this appears), and I made no attempt to respond at the time. But here, for the record, is what I believe to be the first published suggestion on the controversial issue: "They are usually thought to be ventilation-channels, but would be better considered as open ways for the king's soul to reach the circumpolar stars to the North and the Orion constellation to the South."§

As for the images, some are cosmogonic, for instance, a very brightly coloured version of the sky goddess Nut being held up by the air god She, who is in turn supported by the Earth god Geb (Figure 1.4), though we have to skip to page 232 to

* See Miyake event on Wikipedia and keep your fingers crossed we don't have another one soon.

† C. J. Humphreys & W. G. Waddington, *A&G*, **58**, 5.39, 2017

‡ A group of a few stars used to tell time at night.

¶ R. Krauss in *Studien zur altaegyptichen Kultur*, **48**, 151, 2019. '*Die Kanaele in der Cheops-Pyramide: Luftschaechte, Modellkoridore oder Leitwege zu den Sternen?*' in German, his native language.

§ Page 138 of *A History of Egyptian Architecture*: Vol. I. *From the earliest times to the end of the old kingdom*, by Alexander Badawy, Architect, Cairo, 1954, the author being at that time an associate professor at Cairo University, a member of the Egyptian Exploration Society, and so forth (1913–1987).

find the epagomenal decan of the Senenmut list called sh-t-w-i, the Two Turtles. And as this is a family publication, I am probably not allowed to tell you what Nut and Geb are doing in Figure 1.13. There are also many illustrations of constellations and related patterns of stars in the sky, many clearly distorted from what was actually seen. The question most often asked is whether, and if so how, the Egyptian constellations are related to the ones we learned from the Babylonians, the Greeks, and the International Astronomical Union. The standard answer has been that Orion is recognizable as a striding man and the hippopotamus includes Sirius. The authors, however, have evolved a "working hypothesis" that identifies many more of the patterns shown in the Dendara astronomical ceiling (which you must now travel to Paris to see), including a Zodiac with Gemini, Taurus, Leo, Pisces, Cancer, and so forth, with the planets scattered among them. Their Sirius lives in the head of a recumbent cow, though the hippo is there (page 305) and seems to be carrying a folded umbrella.

Let us end with one item that lets us feel at home. The standard symbol for a celestial body (pronounced, roughly, seba) is a "five pointed star formed by an internal dot and five rays. The universal five-pointed star symbol presumably originated in Egypt in pre-Dynastic times" (page 540). — Virginia Trimble.

The ALMA Telescope. The Story of a Science Mega-Project, by Paul A. Vanden Bout, Robert L. Dickman & Adele L. Plunkett (Cambridge University Press), 2023. Pp. 264, 24·5 × 17 cm. Price £39·99/$49·99 (paperback; ISBN 978 1 009 27968 0).

ALMA took over 30 years to gestate, during which a great many committees, working groups, boards, and similar organizational bodies came and went. Each involved the dedicated services of numerous scientists, administrators, technicians, and financiers, and won the support and gratitude of innumerable (if understandably a little impatient) would-be users worldwide. This book is in many senses a corporate journal of the multitude of events, tasks, decisions, and recollections of how *ALMA* finally emerged in all its unique and transformational glory. An inevitable consequence is that the story moves painstakingly slowly, at times a little too much so, but the authors were present officially at, or not far removed from, the action during much of the period in question, thereby endowing the book with the status of a reference manual as well as a finely-interrelated collection of facts and figures.

This story of *ALMA* commences right at the start when a project of such magnitude could not be more than a pipe-dream, but that first distant whisper was sufficiently fertile to tickle the imagination of the more powerful activists among communities of millimetre and infrared astronomers, building on projects like the USA's *Millimeter Array* (*MMA*) already advanced in planning. And although it is freely admitted that this account of *ALMA* has been told from the perspective of the USA, in the end *ALMA* became a world project, not just an enhanced one owned and operated by that country alone. Indeed, as the concept slowly morphed into *ALMA* it became clear that one country alone simply could not manufacture, staff, or (most importantly) fund the entire project in all its complicated and detailed magnificence. A consequence of that somewhat myopic view is that no mention is made of the fact that it was British and Canadian radio astronomers who made breakthroughs in interstellar molecular physics, or that the all-important success with such a fundamental procedure as 'very long baseline interferometry' (VLBI) was initially a Canadian achievement.

The story is charmingly illustrated with cameos involving key players, some revealing things said *sotto voce*, even best left unsaid, that serve to brighten up the reams of details. Despite the eventually unchecked progress of the telescope from early idea to full completion, not everything was plain sailing, and the cliff-hanging description of the USA's very hesitant agreement at a late stage to accept the grossly enlarged budget for the telescope adds a welcome seasoning of excitement that brings its journalistic style alive. One aspect that could have been thought through differently was the wisdom to include specific costs in all their rather gory details. While indeed part of the journal, writing the exact figures with so many noughts might appear a bit vulgar to the general public (and to astronomers routinely strapped for cash), when descriptive words like 'several thousand million' would be more appropriate for a 'story'.

The book is generally well written, though the USA's habit of ignoring conventional grammar (including vital hyphens and commas) caused me some exasperation. Very few typos or other mistakes are apparent — until the final chapter, where the margins of several pages proved inadequate for me to pencil in all the corrections that I itched to make. The book includes a brief Appendix that explains the rudiments of radio astronomy and its attendant equipment, and (fortunately) it sports a 4-page 'Glossary' of the many acronyms that pepper the book freely, and (as with the costs) several could with advantage have been replaced by simple descriptive words. It will make interesting reading for the inquisitive public and for astronomers not directly involved, while primarily offering a fine set of reminiscences for the many who were so involved. It is a remarkable product of industrious archival research, and deserves a place on both science and departmental bookshelves. — Elizabeth Griffin.

Annual Review of Astronomy and Astrophysics, Volume 61, 2023, edited by E. van Dishoeck & Robert C. Kennicutt (Annual Reviews), 2023. Pp. 616, 24 × 19·5 cm. Price from $444 (print and on-line for institutions; about £365), $122 (print and on-line for individuals; about £100) (hardbound; ISBN 978 0 8243 0961 9).

The 2023 *Annual Review* begins with a remarkable story of a lady, raised in a Christian family in China, who rose to international prominence in the field of geodesy *via* long-baseline radio astronomy. Shuhua Ye overcame the turbulent history of her homeland in the latter half of the 20th Century to join the top ranks of the IAU and make a significant contribution to studies of Earth rotation and the establishment of accurate time services.

Starting at the beginning of time we find a tantalizing account by Klessen & Glover of the first stars to be formed — the so-called massive Population III stars (with masses up to $10^5 M_\odot$) — which will be hard to observe but particularly interesting because of their metal-free composition. Also at the 'Cosmic Dawn' we have a discussion of the earliest quasars by Fan *et al.*

A review I found particularly interesting was by Jewitt & Seligman on 'Interstellar Interlopers', a couple of which have been found wandering through the Solar System; it is thought that they may be planetesimals ejected from protoplanetary discs. The chemistry of volatile elements in such discs is examined by Öberg *et al.*

On the grand scale, we find a study of galaxy-cluster dynamics using hydrodynamical simulations by Crain & van de Voort, while swirling around those assemblies will be the circumgalactic medium whose processes are covered by Faucher-Giguère & Peng Oh.

On the smaller (but still vast) scale is the interstellar medium within the Milky Way, which is addressed by McClure-Griffiths *et al.* who consider the role of atomic hydrogen, and on an even smaller scale in accretion in the environment of binary stars by Lai & Muñoz. While we know quite a bit about the generation of magnetic fields in stars, it came as something of a surprise to me to find that galaxies themselves have dynamos, outlined in the work of Brandenburg & Ntormousi.

On the instrumental front we have a report on imaging spectroscopy of radio emission from the Sun by Gary, and on advances in interferometry, especially ESO's *GRAVITY* instrument on the *VLTI*, by Eisenhauer *et al.* And finally an elaboration of the benefits of Gaussian processes in the analysis of time-series data by Aigrain & Foreman-Mackey. — David Stickland.

America's First Eclipse Chasers. Stories of Science, Planet Vulcan, Quicksand, and the Railroad Boom, by Thomas Hockey (Springer, in association with Praxis Publishing), 2023. Pp. 444, 24 × 16·5 cm. Price £27·99/$37·99 (paperback; ISBN 978 3 031 24123 9).

Professor Thomas Hockey is well known for his authoritative and well-written historical studies. One recalls, for instance, his excellent *Biographical Encyclopaedia of Astronomers* and his *Jupiter before Voyager*. The present book looks back at the total solar eclipse of 1869, with the imminent prospect of yet another such event being visible from America in 2024.

In 1869, it had been four years since the Civil War of 1861–65, an apocalyptic national event. In those times, as the country was returning to normality, the recent growth of the railroad, racing ever westward to link the east and west coasts of America, was to play a key role in the eclipse expeditions of 1869 and later. It was now possible for astronomers and their bulky luggage to travel *en masse* to witness a total solar eclipse upon American soil.

Observations of total solar eclipses don't always go smoothly. When choosing a spot from which to watch one from India in 1995 I was threatened by an armed guard when innocently straying onto the pitch claimed by another group. Here, as Hockey follows the many and varied groups that travelled to position themselves beneath the long track of the Moon's shadow in 1869, the battle for legroom was hardly an issue: it was more a question of what facilities an isolated frontier town could offer to a scientific party. It is likely that Simon Newcomb carried a pistol in his luggage when he travelled to Des Moines, Iowa. Although there aren't any Tombstone-style shootouts in this book, some expeditions literally shot themselves in the foot through basic error and incompetence, while others succeeded admirably.

There is the story of the retired Naval Commander who bumped into his telescope, shaking his precious long-exposure photographs; how E. C. Pickering avoided the crowds and stayed safely in his hotel room to observe, simply propping up his telescope and spectroscope on a chair in an amateurish manner; and so on and so forth. Others were still wasting their time to look for the non-existent planet Vulcan. It is interesting that Asaph Hall, the leader of one party, once had to host President Lincoln when he had called unexpectedly one evening at the US Naval Observatory to do some practical observing, while Edward Curtis, who carried out spectroscopic work with Professor Harkness (also part of the USNO expedition), was a former pathologist turned photographer, and one who had performed the autopsy upon the assassinated Lincoln. The 1869 spectroscopic work was perhaps the most interesting from a scientific point of view, leading as it did to the discovery of the coronal green line.

The pioneering spirit pervades this enjoyable romp through the American mid-west. I highly recommend it. It is richly illustrated, and I have honestly only ever seen one or two of the illustrations previously. (Figure 5.1, by the way, is printed upside down. There are few obvious typographical errors.) There is a very good collection of portraits of individuals, observing locations, charts, and drawings and photos of the eclipse. Hockey's book offers sound background details, and nicely sets the 1869 events and discoveries in context. It can either be read from cover to cover or just dipped into at random, as the chapters are self-contained. It is an engaging work, always informative and comprehensive, and — in quite a few places — highly amusing. And what about that quicksand mentioned in the title? Well, I leave that to Hockey's readers to discover, but I might just add that the unfortunate Naval Commander was involved. — Richard McKim.

Nobel Prizes in Astronomy, by Pushpa Khare (Springer), 2023. Pp. 173, 23·5 × 15·5 cm. Price £22·99 (paperback; ISBN 978 3 031 29638 3).

Strictly speaking, there are no Nobel Prizes in Astronomy, but we all know of cases where a Nobel Prize in Physics has been awarded for work very strongly related to astronomy. Research significant enough to merit a Nobel Prize is often not easily explicable to high-school students and we owe this book to Dr. Khare's daughter, who suggested that she wrote an account suitable for students. Recently retired from Utkal University, near Pune, and with plenty of experience in giving popular talks and writing for science magazines, she took up the challenge.

She covers 13 Prizes, starting in 1967 with the award to Hans Bethe for his work on what we now call nuclear astrophysics: the nuclear reactions that happen inside stars and provide the energy source for stars. She recognizes seven categories: 'Stellar Structure', 'Stellar Evolution', 'Radio and X-ray Astronomy', 'Extra-solar Planets', 'Black Holes', 'Gravitational Waves', and 'Cosmology', and devotes one chapter to each category. For each Prize (sometimes several in each chapter) she starts with the citation, followed by some biographical information about the recipient (complete with a photograph in most cases; she did not in time receive permissions for two). She then gives appropriate background information, which for Bethe runs to 12 pages (an overview of the whole of stellar structure), followed by an account of the specific work for which the Prize was awarded.

As well as Bethe, the first chapter includes the 2002 award jointly to Ray Davis Jr. and Masatoshi Koshiba, mainly for their independent 'detection of cosmic neutrinos', using, respectively, the Homestake mine and *Kamiokande* (originally set up to look for proton decay; the full name is *Kamioka nuclear decay experiment*). Davis recorded solar neutrinos, but for a long time there was a puzzle: he detected only about a third of the expected number. It wasn't until the much later *SNO* experiment that it was realized that neutrino oscillations had reduced the number of electron neutrinos during the journey from the Sun to the detector. Koshiba's first detection was of neutrinos from SN 1987A, but later his group confirmed Davis's results for the solar neutrinos. *Super-Kamiokande* was able to detect muon neutrinos and confirmed the *SNO* result.

The 'Stellar Evolution' chapter records the 1983 Prize, shared between Chandrasekhar (essentially for the 'Chandrasekhar limiting mass' of a white dwarf, although the citation is much wider) and Fowler for his seminal work on nucleosynthesis in stars (the famous B^2FH paper is duly mentioned). The next chapter covers two separate Prizes, the 1974 Prize to Ryle and Hewish for radio astronomy and the 2002 Prize to Giacconi for X-ray astronomy. The 1974 citations pick out the invention of aperture synthesis for Ryle*, and "his decisive role in the discovery of pulsars" for Hewish. Jocelyn Bell is of course mentioned, but with no comment on the subsequent controversy. The 2002 citation for Giacconi mentions particularly "the discovery of cosmic X-ray sources", the first of these being Scorpius X-1. He shared the Prize with Davis and Koshiba (see previous paragraph). The differences between optical, radio, and X-ray telescopes are carefully explained.

The idea that there might be planets around other stars has existed for many years, probably for millennia in the more general sense of whether there might be life elsewhere in the Universe, but it was only in 1995 that the first discovery was announced by Michel Mayor and Didier Queloz. They received the 2019 Prize "for discovery of an exoplanet orbiting a solar-type star." Together they had developed a technique that enabled them to measure radial velocities to an accuracy of 10 to 15 m s^{-1}, sufficient to detect very small variations in a star's velocity caused by the orbital motion of a planet around the star, and in 1994 they detected a periodic variation in the motion of the star 51 Pegasi.

The 2020 Prize was awarded to three people: the mathematician Roger Penrose and two observers, Reinhard Genzel and Andrea Mia Ghez, for work on black holes. In 1965, Penrose had shown rigorously that Einstein's general theory predicted the formation of black holes, while Genzel and Ghez in the late 1990s discovered that our Galaxy has a massive black hole at its centre, as had been speculated nearly 30 years earlier.

General Relativity (GR), of course, also features in gravitational waves. Russell Hulse and Joseph Taylor received the 1993 Prize for their work in the 1970s on the binary pulsar, which they observed initially to find the mass of the pulsar. However, they also observed a slow decrease in the orbital period, which they attributed to the emission of gravitational waves. Careful measurements showed a very close agreement between the observed decrease and that predicted by GR, providing indirect evidence for the existence of gravitational waves. Much later, after many attempts to detect gravitational waves directly, starting with Weber's seminal experiments in the early 1960s, three other physicists, Rainer Weiss, Barry Barish, and Kip Thorne developed the idea of laser interferometry (first suggested by two Russian physicists, Gertsenshtein and Pustovoit in 1962) into the *Laser Interferometric Gravitational wave Observatory* (*LIGO*). *LIGO* successfully detected a signal on 2015 September 15 and the award of a Nobel Prize for this work came remarkably quickly, in 2017.

Cosmology has received no fewer than four Nobel Prizes, from the 1978 Prize to Arno Penzias and Robert Wilson for their accidental detection of the cosmic microwave background radiation (CMBR) in 1965 to three this century. The related work by George Smoot and John Mather showing that the CMBR has a pure black-body spectrum and that it has anisotropies at the 10^{-5} level received a Prize in 2006. The discovery by Saul Perlmutter and separately by Brian Schmidt and Adam Riess of the acceleration of the expansion of the Universe was published in 1997 and they received the Prize jointly in 2011. Finally, Jim Peebles was rewarded for a lifetime's theoretical work in physical cosmology by a share in the 2019 Prize (shared with Mayor and Queloz — see above).

*The author gives a percipient quotation from a letter, published posthumously, where Ryle says, "Our cleverness has grown prodigiously — but not our wisdom."

This is an interesting and informative book, written for high-school students but with plenty of stories of interest to other general readers and to professional astronomers. There are a few infelicities in the (American) English, but I only found three typos: on p. 52, four lines from the foot, Royal Society should be Royal Astronomical Society (the famous Chandrasekhar–Eddington disagreement occurred at a meeting of the RAS), on p. 101, line 2, 'Causal' should be 'Casual', and on p. 103, section 6.31 line 1, Martin should be Maarten. A Glossary will help the general reader and there is a useful index (although it doesn't include people's names). There are no references to any of the original work. — Robert Connon Smith.

Introduction to General Relativity and Cosmology, by Ian R. Kenyon (IoP Publishing), 2023. Pp. 307, 26 × 18·5 cm. Price £75/$120 (hardbound; ISBN 978 0 7503 3761 8).

General Relativity is more than 100 years old, and the number of GR textbooks about it probably exceeds 100, beginning with Einstein himself (1920, *Relativity, the Special and General Theory*, translated by Robert W. Lawson from *Uber die spezielle und die allgemeine Relativitätstheorie*) and Arthur S. Eddington (1920, *Space, Time, Gravitation*). The midpoint from then to now is marked by the massive *Gravitation* by Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler (otherwise known as *MTW*). Steven Weinberg entered the fray in 1972 with *Gravitation and Cosmology*, a portent of things to come.

The present volume is a second edition of a 1990 (Oxford University Press) original, very much updated to include gravitational waves, the *Event Horizon Telescope*, and especially cosmology, including the use of Type Ia supernovae to demonstrate the acceleration of cosmic expansion. It is one of five recent texts increasingly weighing down my desk, as part of a quest for a text for an undergraduate major course on General Relativity and black holes for winter quarter 2024. All share a much larger fraction of pages devoted to cosmology, including inflation, details of the CMB, Big Bang nucleosynthesis, and structure formation than is present in the earlier volumes.

Kenyon devoted eight of his 17 chapters to these issues, *versus* four of 44 in *MTW*, one-seventh of one chapter out of nine in Joseph Weber's 1961 *General Relativity and Gravitational Waves*, three of 24 chapters in James B. Hartle's 2003 *Gravity: An Introduction to Einstein's General Relativity*, and, for that matter, three brief sections out of 32 (called 'Considerations on the Universe as a Whole') in Einstein's 1920 monograph. The explosion of cosmology has made most of these volumes too long for a 10-week quarter, or even a 15-week semester, despite sometimes leaving out the classic tests of gravitational redshift, light bending by the Sun, and advance of the perihelion of Mercury (all considered by Einstein). These have the advantage of being reasonably easy to understand. Kenyon includes Mercury and light bending in a chapter with the Shapiro time delay, geodetic precession and frame dragging, and gravitational lensing.

He attempts some history, crediting John Michell in 1787 with the first suggestion that large GM/R can mean an escape speed larger than the speed of light. A similar conclusion by Pierre-Simon de Laplace in 1795 does not appear. The binary pulsar 1913+16 appears as a graph of period change from the time of its discovery up to approximately 2013. The data are perfectly fit by a general-relativistic prediction of energy lost in gravitational radiation. Each chapter has half a dozen or so exercises, including distortion of a human too close to a black hole and calculation of the flux of gravitational-wave energy from the binary pulsar to be expected here in Irvine

That flux would be very similar in Birmingham, where the author was a member of the particle-physics group for more than 50 years. The present head of that group, Paul Newman, is thanked in the author's acknowledgements, but is, in turn, the writer of a short tribute to author Kenyon, who sadly died while the book was in the final stages of production. Kenyon was also the author of undergraduate textbooks on particle physics, classical and quantum optics, and quantum physics under the title of *Quantum 20/20*. Kenyon's view of dark energy is that it is a scalar field that behaves, in most respects, like Einstein's cosmological constant. He sounded less sure about inflation being the manifestation of another scalar field.

Oh. Am I supposed to tell you which tome I have adopted for Physics 116 here at UC Irvine? Naturally, the one that Kip Thorne told me is the best General Relativity text ever written. No, not *MTW*. Hartle's *Gravity*. —Virginia Trimble.

To the Stars: Women Spacefarer's Legacy, by Umberto Cavallaro (Springer) 2023. Pp. 594, 23·5 × 14·5 cm. Price £34·99 (paperback; ISBN 978 3 031 19859 5).

Here are 75 women cosmonauts, astronauts, taikonauts, and possibly other designations for those who have flown well above the Earth's atmosphere between 1963 and 2022. At least a few are, or have been, national heroines — Valentina Vladimirovna Tereshkova (born 1937) in Russia and the Soviet Union; Sally Kristen Ride (1951–2013) in the United States; and (I hope) Helen Patricia 'Lenochka' Sharman (born in Sheffield in 1963) in Britain, though she flew on a Soyuz mission (TM-12). The volume is chock full of firsts, some by nation (Liu Yang the first female taikonaut, Chiaki Mokui of Japan, Yi So-Yeon of Korea, on to Anousheh Ansari, the first Iranian spacewoman, again on a Soyuz (TNA-0)).

Others are first mother in space, first teacher, first actress, first EVA (Extra-Vehicular Activity) by a woman, the first astronaut's daughter in space (Laura Shepherd Churchley), not to mention other extremes like Wally Funk at age 82 on *Blue Origin NS-16*, the oldest person to fly, 60 years after she had been the youngest of the *Mercury 13* women who were briefly tested and trained by NASA but never flew.

The author gives his affiliation as the Italian Astrophilately Society in Torino and here demonstrates his passion for stamps showing astronauts by illustrating his short biographies with images of 'first day cancellations' of most of the women featured. Sally Ride, who appears on stamps of 13 different countries, was herself a collector, whose personal stamp collection was donated by her surviving partner, Tam O'Shaughnessy, to the National Postal Museum in Washington, DC.

Every one of the capsule stories has a 'gee whiz' item. One woman played her flute on the *International Space Station*; another later headed NASA's Astronaut Office. Elena Kardakova was born the year of the *Sputnik* launch. The youngest American astronaut to date (Hayley Arceneaux) is a cancer survivor who flew with a prosthetic limb. Kathryn Thornton (and Story Musgrove) were the first civilians assigned to a military Shuttle flight (they launched an ELINT). MD Bonnie Bondar has received 24 honorary doctorates from Canadian and American universities. Ellen Ochoa, born in Los Angeles the year NASA was established, is living proof that it is better to be a professional electrical engineer and an amateur classical flautist than the other way around, and has served as Director (the 11th) of the Johnson Space Flight Center in Houston, Texas.

Nearly every page has a purple mark — not for errors (I have done no fact-checking) but for "ah ha!" moments — one of the women was a Girl Scout (no luck checking which one: the index is very sparse); another attended a high school that shared its name, Sidney Lanier (also not indexed), with the local public library of my childhood (both have probably been renamed). There really were icicles on the launch tower the day Judy Resnik (the first Jewish woman to fly) took off for the second, devastatingly brief, time. Karen Nyberg was the first astronaut to operate all three robotic arms on the Shuttle, and she also enjoys quilting, and made a dinosaur toy for her son out of Russian velcro-like fabric that lined their food containers. Megan McArthur celebrated her 50th birthday in space, the zeroth having been celebrated in Honolulu, because her father was a career naval officer.

Appendices list all the women, in chronological order by first flight (Tereshkova, Savitskaya, Ride, Resnik, McAuliffe…on to Mae Jamison (the first female African–American astronaut) and Elena Kondakova (third Russian woman, who appears in Appendix IV because of being married to another cosmonaut)), and on to the last eight, nearly all on commercial flights, beginning with Beth Moses. The other appendices list female EVAs (the longest 60 hours in ten separate activities by Peggy Wilson); astronauts with military affiliations; astronaut marriages and a good many divorces.

All in all a fascinating book, which is probably best read a few stories at a time, like consuming a large box of candy of many different flavours.

Of the women, I knew only Sally Ride, having met her when she was still a graduate student at Stanford, and then having served on her advisory board when she was running the California Space Institute (CalSpace) from UC San Diego. — VIRGINIA TRIMBLE.

Quantum Processes & Measurement. Theory & Experiment, by Claude Fabre (Cambridge University Press), 2023. Pp. 303, 26 × 18·5 cm. Price £49·99/$64·99 (hardbound; ISBN 978 1 108 47777 2).

We are rapidly approaching the centenary of the first papers on what is now called quantum mechanics, and the number of published textbooks on the subject must certainly also be close to 100. Early ones often emphasized puzzling aspects of the subject — that a careful calculation never gave an exact result for the product of a well-defined particle collision, for instance, but only the distribution of probabilities over the range of possible final states. Most of the later texts (at least in English) have been of the 'shut up and calculate' variety. Author Fabre takes a third approach, beginning with recent experiments that involve the detection of single quantum entities, photons, particles, and energy levels of an atom. Subsequent chapters alternate between theory (especially as required to understand recent experiments — entanglement and all) and those experiments. The experiments end with SQUIDs and the theory with quantum non-demolition.

The last 100 pages include 11 appendices, from qubits to quantum mechanics of electrical circuits, 187 references (from Aaronson to Zurek), and the usual inadequate 2¼-page index characteristic of physics texts. Each chapter and each appendix ends with exercises, some requiring serious derivations; others inviting the reader to attempt an order-of-magnitude estimate of some quantity she had probably never thought of before. She will, however, find lots of old friends in the list of references: Aharonov and Bohm, Bell, Bohr, and Born, Hanbury Brown and Twiss, Dirac, Podolsky, and Rosen, Landau (looking lonely without his Lifshitz), Planck, Robertson, and Schrödinger, von Neumann and Wigner.

Alice and Bob appear scattered through the text, though neither seems to be an author or an index entry.

Astronomers are obviously not the primary readership for this volume as we hardly ever encounter single atoms, let alone rubidium in $n = 49$ to 54 levels. It is, however, surely good for the soul to be reminded from time to time that there is a distinction between things nobody understands (the ratio of electromagnetic to gravitational forces) and things that other people understand and I do not! — Virginia Trimble.

From The Library

Suns and Worlds, by W. H. (William Herbert) Steavenson (A & C Black Ltd.), 1933. Pp. 104, 18 × 12 cm. Price about $25 for used copy from an on-line bookseller. (hardbound; no ISBN).

W. H. Stevenson (1894–1975) was a medical doctor, variously called Dr. Steave, Steave, and Old Steave (that last by Raymond Arthur Lyttleton) with a life-long love of visual astronomical observing with small-to-moderate-sized telescopes, some of his own design. Rather remarkably, he did this with only his left eye, the right one having been lost in a boyhood accident, and he abandoned observing at the age of 60 (1956), though he lived nearly another 20 years and participated in both RAS and the British Astronomical Association in his later years.

Dr. Steavenson's ADS publications come mostly from the *Journal of the BAA* and include many annual reports from his observatory in Norwood, but also this book. *Suns and Worlds: An Introduction to Astronomy* is a wonder of glorious English prose of a style I fear no one still knows how to write. Some sentences are quite long, but every word counts, is in the right place, and sometimes clarifies in a way that might easily have taken another whole sentence.

My copy once belonged to the Reverend R. Lacey Webb, who did not turn up in a very casual web search. The copy came with two bonus loose pieces of paper: a 28/11/71 clipping from the *Sunday Express* headlined "So maybe there is life on Mars", reporting water vapour seen in the Martian atmosphere from *Mariner 9*; and a handwritten page of notes on Earth, Pluto, Mercury, and the Sun taken from the *Readers Digest World Almanac*. Written with a fountain pen in a rather old-fashioned spikey hand, the extract claims that the Sun has a central temperature of 36 million degrees C and an estimated survival of 16 000 million years. These are, to our minds, too large by factors of about 2 and 3, respectively. But we must not blame Dr. Steave for the mistakes.

What then did Dr. Steave have to say? He is very sound on day and night, eclipses, motions of planets, and the like, giving the objects concerned personal pronouns (*She* for the Moon and Venus; *He* for the Sun and the other planets). We are told that use of Eros to get the length of the AU has replaced transits of Venus, which no one will again attempt to observe. Well, we did for the most recent pair, but not to determine the length of the AU!

Skipping to 'A Boundless Universe' at the end, he accepts that the Universe is expanding, and that indeed some mathematicians had expected this. He worries that the expansion time-scale is much shorter than the time needed for stars to form and achieve their various current appearances. Nowhere, however, does he attempt to estimate ages or life expectancies for the Sun or any other stars. There is an evolutionary scenario laid out in 'Other Suns' and 'Change and Motion in the Universe', but no time-scale at all.

The evolutionary scenario is essentially H. N. Russell's 'Giant and Dwarf Theory' (stars condense, heat up, move across the H–R diagram from right to left as giants, then descend diagonally down the main sequence to end as red dwarfs and, eventually, dark stars, though a few are allowed to reheat and become white dwarfs. All the stars and indeed all cosmic objects are averred to be made of the same substances, though the only entity mentioned as being dominated by hydrogen is the solar corona.

No credits are given for the rather nice photographs and drawings, which are therefore probably the author's own. His Milky Way is roughly that of Shapley, a disc with the Solar System far from the centre, but the disc is made of star clusters (we live in the local one), and our Galactic core has been largely denuded in forming stars that now occupy the spiral arms. That is, his picture of galaxy evolution endorses the vocabulary of 'early' (elliptical) and 'late' (spiral) types, just as his picture of stellar evolution endorses 'early' and 'late' spectral types. The Milky Way indeed has a flock of globular clusters above and below its plane (so does the Andromeda nebula), though they are not concentrated toward the centre and do not extend as far out as the edge of the disc.

In a bit of healthy scepticism, Steavenson suggests that it may not be true that other galaxies are much smaller than the Milky Way (indeed, modernized distance scales have taken care of that, as well as of the time-scale problem). His Milky Way rotates, at about 200 miles per second where we are (yes, miles, also inches, light years, and so forth), yielding a mass of about 100 000 million suns.

According to the received wisdom of 2023, Dr. Steave is very sound on the nearby (indeed he mentions two asteroids that come closer than Eros, though they were found in 1932 and did not yet have orbits as he wrote) and remarkably both accepting and sceptical of 1933 views of "the boundless universe." The parts we want to rewrite come in the middle!

Perhaps also odd by our standards are the author's choices of which astronomers to mention by name — Copernicus, Kepler, Tycho, Newton, William Herschel, and Galileo (in that order) — and none of his immediate predecessors or contemporaries, or looming successors. This probably saved him from making enemies — as indeed reflected in his election to the presidency of both the BAA and the RAS.

In summary, a lovely 90-minute read with two bonus pieces of paper (you would be surprised at the prices for nightgowns in 1971!) and a mysterious former owner. — VIRGINIA TRIMBLE.

Here and There

ALSO THE INVENTOR OF A TIME MACHINE

October 7: Death of Thomas Frederick Furber. Born in England in 1955 he was an Australian government surveyor of New South Wales; observed the Transit of Venus in 1882 from Lord Howe Island; FRAS 1896. — *The Observatory*, **143**, 283, 2023. [For which the Editors are guilty.]