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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2021 April 9 at $16^{h}\ 00^{m}$

P. Daniels, *Vice-President*
in the Chair

The Chair. The President is on leave at present and as a Vice-President of the RAS I've been asked to take her place today. Our first speaker this afternoon is Dr. Tom Collett from Portsmouth University. Tom is the winner of the RAS Winton 'A' Prize. Please send your questions to Pamela Rowden at the end of Tom's talk and we will have five minutes of questions after Tom's talk. That will be followed by early-careers poster-competition winners, their talks, and questions at the end of all of their talks.

Dr. T. Collett. The orbits of planets around our Sun are well described by ellipses. This fact falls naturally from Newton's universal law of gravitation which says that the force between two objects is proportional to the inverse of their separation squared. The orbit of Mercury, however, is not perfectly described by an ellipse. The perihelion of Mercury precesses at a rate of two degrees per century: force proportional to the inverse of their separation squared is not so universal after all. In 1915 Einstein formulated his theory of General Relativity (GR), explaining gravity as a result of massive objects deforming space–time. GR adds extra terms to the force that are only relevant at short distances or very high energies. These terms are relevant for Mercury, explaining the observed precession of its perihelion.

GR also makes predictions about the deflection of light near massive objects. In General Relativity the deflection is twice as large as in Newtonian gravity (assuming a constant-mass deflector). This is because in GR light 'feels' both the mass of the deflector and the curvature of space–time that the mass produces. Today we see many examples of the deflection of light through a phenomenon called strong gravitational lensing. This occurs when a massive galaxy is in front of a background source, such that multiple images of the background source are observed as an Einstein ring around the lensing galaxy. Unfortunately these spectacular systems were not discovered until 1979, so could not be used to demonstrate the validity of GR. Instead Sir Arthur Eddington set out on an expedition — funded by the RAS — to observe the positions of stars close to the solar limb during the eclipse of 1919. By comparing the positions observed with those seen six months earlier the team was able to demonstrate that the deflections were consistent with GR and inconsistent with Newtonian gravity.

Today, GR has been validated within the Solar System to exquisite precision: the curvature of space–time per unit mass has now been measured to 2 parts in 10^5. For all practical purposes GR is the correct theory of gravity in our solar neighbourhood. However, GR has not been well tested on cosmological scales. It is on these scales that our understanding of the Universe breaks down. Distant supernovae appear too faint compared to their local cousins, suggesting that the expansion of the Universe is speeding up. If GR is correct, this expansion requires the addition of a new component, dark energy, which makes up some 70% of the present Universe's energy budget. This mysterious fluid lacks a theoretical underpinning, yet there is a panoply of evidence that either it must exist, or our understanding of gravity is wrong over cosmological scales.

It was with the above context in mind that my collaborators and I set out to measure the curvature of space–time per unit mass around an entire galaxy, ESO325−G004 (hereafter E325). Analogously to Eddington, we would look to compare E325 as a strong gravitational lens 140 Mpc away, with the Einstein ring coming from a source 1·7 Gpc distant. The Einstein radius of this system is about 3 arc seconds, which is easily measured from existing *Hubble Space Telescope* data. However, the measurement of the mass of E325 is more challenging and we needed both measurements to constrain the curvature per unit mass. We acquired new data using an integral field unit (called *MUSE*) on the *Very Large Telescope* in Chile. These data told us how fast the stars are moving in E325 as a function of their distance from the centre of the galaxy. Somewhat like the Earth orbiting the Sun, the stars in E325 go round the galaxy's centre of mass, with gravity holding them in their trajectories. More mass in the galaxy means a stronger gravitational force and so the stars orbit faster.

By combining the lensing information from *Hubble* and the stellar dynamic data from *VLT*, we were able to fit a single model that reproduced both datasets. The model was a mass-traces-light approach for the baryons in E325 (with a mass-to-light gradient allowing for age and metallicity gradients within the lens galaxy), a dark matter halo, and a point mass for the supermassive black hole at the centre of E325. The key parameter of the model was the spatial curvature per unit mass which we fit for simultaneously with all the others.

Within the Einstein ring, we found a mass of $1{\cdot}4 \times 10^{11}$ of the Sun and that the black hole has a mass of $3{\cdot}8 \pm 0{\cdot}2 \times 10^9\ M_\odot$, which is typical for the central black hole of a galaxy as massive as E325. Interestingly, the model was only able to reconstruct both data sets if either there is a strong central mass-to-light gradient (potentially indicating deviations from a universal stellar initial mass function) or a very steep central dark-matter cusp (potentially indicating non-standard dark matter). In either scenario the spatial curvature per unit mass parameter was consistent with GR. By averaging over both scenarios plus cosmological-parameter uncertainties and systematic uncertainties in our ability to measure stellar kinematics, we found that the spatial curvature per unit mass parameter was $0{\cdot}97 \pm 0{\cdot}09$. The GR predicted value of 1 is well within this error bar. This result doesn't preclude deviations from GR over longer length scales or at levels smaller than our 0·09 precision, but it does show that, over 2 kiloparsec length scales, space–time curves more or less as expected.

The Chair. Thank you very much Tom, nicely on time; I will now hand over to Pamela who should have collected any questions.

Dr. Pamela Rowden. Please send me your questions in the chat. The first is, "Tom, how long had you been working with this particular galaxy?"

Dr. Collett. This galaxy was discovered about 15 or 20 years ago, and I first got interested in it, to do this measurement, back in 2016. We wrote the proposal for the *VLT* once we had the *Hubble Space Telescope* data to hand, so we then asked *VLT* for it. It actually takes an hour of observing time on the *Very Large Telescope* to get the data we needed to do this, and so the observations were taken, I think, in late 2016 and then the analysis took a couple of years. We actually have data for another ten such lenses that we're working on at the moment. These are slightly more distant so that we can test different scales but also try and improve the precision of this measurement. It's still on-going.

The Chair. Any more questions?

Dr. Rowden. "Were you surprised that the *Cassini* data was matching so exactly the predictions?"

Dr. Collett. I think not surprised particularly. My expectation is that GR is probably the right theory of gravity on cosmological scales as well. I think there is a lot of weirdness from the need to introduce dark energy to explain cosmic acceleration, but I think it's becoming very clear now that these modified theories of gravity are really getting pushed into ever smaller parts of parameter space to be able to explain away dark energy. *Cassini* was one of the early, very precise measurements but I think my personal prejudice was that I was expecting this to be right.

Dr. Rowden. And this leads on to the next question which is, "Does your analysis mean that the various attempts that used modified Newtonian gravity are null and void?"

Dr. Collett. It's complicated in that the typical kind of modified Newtonian gravity is really trying to explain differences in the motions of stars around galaxies. Most of them are introduced to explain away dark matter rather than the dark energy. At the moment there aren't really good relativistic formalisms for a lot of these modified Newtonian dynamics and so it's hard to know what they actually predict for the amount of lensing. What is clear is that to explain the lensing we see, not so much from this galaxy but from more distant ones, we really do need dark matter. There are plenty of cases where, if you just use the baryonic matter, you put the mass where you see light, but that does not precisely reconstruct the lensing data that we see, so I think there's pretty strong evidence that unless there's some perverse conspiracy in the observations there really must be dark matter in the Universe as well.

The Chair. Thank you very much, Tom, and thank you Pamela. Now we come to the section where we have five short talks by the winners of the early-careers poster competition, so please submit your questions in the same way that you've just done but at the very end of all five of the talks. Four of them will be talks and the fifth one will be a short video.

The next speaker is Soheb Mandhai from the University of Leicester and he is going to talk about 'The migration of compact binaries from their host galaxies'.

Mr. S. Mandhai. The Universe is home to extragalactic wanderers such as compact binaries. They are responsible for some of the most cataclysmic events observed to date. In our study, these binaries consist of a neutron star paired with another neutron star or black hole. These objects are the dense remnants following the deaths of stars that are at least eight times more massive than the Sun. Over a few million to a few billion years, the orbital separation between the two compact objects decreases due to the emission of gravitational radiation in the form of ripples in the fabric of space–time known as gravitational waves. The amplitude of these ripples intensifies until the binary coalesces and leaves behind a single compact object. Upon merging, these systems can also produce electromagnetic events in the form of kilonovae, and short-duration gamma-ray bursts (henceforth referred to as SGRBs). The former is a transient that spans many wavelengths of the electromagnetic spectrum and is about a tenth to a hundredth the brightness of a regular supernova. The latter consists of a short-lived jetted beam of gamma-ray radiation.

The first landmark detection of gravitational waves was made in 2015, around a hundred years following their prediction by Albert Einstein, following the merger of two black holes. On 2017 August 17 detectors unveiled another landmark event: the first gravitational-wave detection of a neutron-star merger. However, this detection was made more significant by subsequent detection of an SGRB and kilonova counterpart, marking the first-ever joint gravitational-wave and electromagnetic-counterpart detection — the start of the multi-messenger era of astrophysics. At present, this event is the only convincing compact-binary candidate to demonstrate a multi-messenger observation.

To understand these binaries, we would first need to know the frequency at which these binaries merge in the Universe and the demographics of galaxies in which they are formed. To achieve this, we must understand how far away merging compact binaries are from us. Gravitational waves grant us a constraint on these distances. However, the current generation of gravitational-wave instruments can only peer into the nearby Universe and provide sky positions with large uncertainties. On the other hand, assuming the majority of SGRBs arise from these merger events, we have detections with sky localizations down to a few arcsecs but with a lack of confident distances. Identification of the host galaxy (origin galaxy of the compact binary) enables estimations of the binary distance.

There are several layers of complexity to consider when associating a short-duration gamma-ray burst to a host galaxy. In situations where there is no overlapping galaxy with the location of the SGRB, a deep-sky search must be conducted to determine if there is a faint or distant galaxy present. However, the SGRB compact-binary progenitor could have also been ejected from the galaxy. In these scenarios, which we explore in our study, the binary responsible for the SGRB can merge well away from its host galaxy, resulting in an on-sky offset between the position of the burst and the host galaxy.

In our study, we attempt to gauge how many compact binaries would demonstrate large offsets. We do this by using simulated binaries and placing them in simulated galaxies. The binaries and their orbits are evolved until the binary coalescence. We can then extract the positional information of the binaries and the properties of the host galaxy. Additional velocities, known as kicks, are imparted onto the binary when the stars required to form the compact objects undergo a supernova. These velocities can lead to the ejection of a binary from its host galaxy.

Our predictions show that most compact binaries tend to merge with host galaxies like the Milky Way. For galaxies that are less massive than the Milky Way, such as dwarf galaxies, the binaries can migrate to distances greater than a hundred-thousand light-years from the centre of their host galaxy. Conversely, for heavier galaxies, such as elliptical galaxies, these distances are much shorter. Typically most of the compact binaries are retained by their host. Overall, we predict that 60–70% of binaries migrate within 33 000 light-years, around two-thirds of the Milky Way galaxy's radius. Approximately 20–40% of the mergers occur outside of their host galaxy.

We expect to see more compact-binary mergers with improved detections of gravitational waves and their electromagnetic counterparts in the future. With these observations, we hope to test and refine our predictions.

The Chair. Now we move on to the talk by Isobel Romero-Shaw which is entitled 'Eccentricity in gravitational-wave transients'.

Ms. Isobel Romero-Shaw. Gravitational-waves are ripples in the very fabric of space–time. The first gravitational-wave detection was made in 2015, using kilometre-scale interferometers to sense the minuscule length changes caused by its passage through the Earth. The signal conveyed information about the source of the wave: two black holes, each about 30 times the mass of the Sun, smashing into each other on the other side of the Universe. The wave caused by these enormous stellar corpses is surprisingly tiny: it only changed the lengths of the interferometer arms by about 1 part in 10^{21}. In my talk, I played the signal we detected, converted from raw strain data into an almost birdlike 'chirp' sound. Since 2015, we've detected collisions between many more black-hole and neutron-star pairs; about 50 signal detections have been published so far in the *LIGO–Virgo* collaboration's first and second transient catalogues.

This rapid increase in detections is very exciting, but also mysterious, since we aren't yet sure how these compact binaries are forming. It is thought that binaries that merge within the age of the Universe are formed *via* two primary formation channels: isolated and dynamical. When a binary co-evolves without being gravitationally influenced by any other bodies, it can have different properties than one that became bound within a crowded environment like a star cluster. One of the ways that these channels can be distinguished is through the shape of the orbits of their binaries. Binaries that are detectably eccentric are more likely to have been formed dynamically. It turns out that, while isolated binaries should be essentially circular at detection, there is about a 1 in 20 chance that any binary formed in a dense star cluster will be detectably eccentric. This is what my colleagues and I work on: trying to measure the shapes of the orbits of compact binaries from their gravitational-wave signals, so that we can work out how they formed.

When we considered the results of our analysis of the first ten gravitational-wave signals from binary black holes, we found that none of the first ten binary black holes had a detectably eccentric orbit — which is consistent with both formation channels, since we expect only 1 in 20 eccentric mergers from the dynamical channel. I then showed our eccentricity measurements for two additional events: GW190425, a heavy binary neutron star, and GW190521, the most massive binary black hole yet detected with gravitational waves. GW190425 has no detectable eccentricity, but according to our method, GW190521 does appear to have high eccentricity at detection.

There are caveats to the apparent eccentricity of GW190521: our method cannot account for spin-induced precession, and other studies (including the *LIGO–Virgo* collaboration's papers on this event) have shown that the orbit of GW190521 was likely to be precessing. Nonetheless, precession is also a signature of dynamical formation, so our measurement supports the hypothesis that GW190521 was dynamically formed. Furthermore, this detection implies that if all of our observed mergers are dynamically formed, then we may expect to detect up to two more eccentric mergers within the second transient catalogue of *LIGO* and *Virgo*.

The Chair. Thank you very much, Isobel. So questions again at the very end. We move on now to Heidi Thiemann and her talk is entitled 'Red novae candidates? An investigation of near-contact red-giant eclipsing binaries'.

Ms. Heidi Thiemann. We have identified a set of candidate stars that appear to be long-period examples of near-contact eclipsing binary stars, with orbital periods of up to a month or more. To be in contact, or near contact, at such long periods requires the stellar components to be giants. Such objects have been proposed as the progenitors of red novae, but none have been conclusively identified pre-nova. The outbursts are believed to be due to stellar mergers, but only one progenitor of such an event has ever been studied, V1309 Sco, and that was only recognized retrospectively, after the merger occurred.

We have identified our candidates from a search of the *SuperWASP* periodicity catalogue and *ASAS-SN* Catalogue of Variable Stars. Each target has a *SuperWASP* light-curve showing the same period and shape, characteristic of a contact, or near-contact eclipsing system.

We are coming to the end of a two-year-long programme of multi-colour photometry of these targets using the LCO robotic telescopes and The Open University's own *PIRATE* (*Physics Innovations Robotic Astronomical Telescope Explorer*) observatory. We have taken spectroscopy of northern candidates with the *Liverpool Telescope*, and southern candidates using the SAAO 74-inch telescope and *SALT*. By combining the multi-colour photometry with radial-velocity spectroscopy we have been able to model the parameters (masses, radii, temperatures, *etc.*) of the stellar components using the Wilson–Devinney code, implemented in the PHOEBE modelling package. We are also currently working on modelling the evolution of the binaries using MESA and BINARY_C.

We have now confirmed that at least ten of the 27 candidates are long-period near-contact giant eclipsing binaries. By studying these objects, we have an unrivalled opportunity to identify and characterize binary mergers before the merger event itself, and advance our understanding of the formation of red novae.

Contact-binary-star mergers are thought to be the progenitors of red novae, but none have been identified pre-nova. Red novae are smaller, redder, dustier, and more mysterious cousins of supernovae. There are only approximately 16 known red novae.

The Chair. Thank you very much, Heidi. Our next speaker is Núria Jordana-Mitjans. 'What is the role of the magnetic fields in GRB outflows? The case of GRB 190114C.'

Ms. Núria Jordana-Mitjans. Gamma-ray bursts (GRBs) are briefly the most powerful explosions in the Universe. Their catastrophic origin — the merger of compact objects (*e.g.*, neutron-star binaries) or the collapse of massive stars — drives the formation of a new-born black hole (or magnetar), which powers two highly relativistic jets. Candidate mechanisms for the production of the gamma-ray flash, the so-called gamma-ray prompt emission, are internal shocks or reconnection of the large-scale ordered magnetic fields ejected by the central engine. After this characteristic emission that we generally detect with space-borne telescopes, usually follows the 'afterglow', which can be detected seconds to years after the burst at wavelengths across the electromagnetic spectrum. The afterglow is usually well described by an external shock — that is, the deceleration of the relativistic ejecta by the circumburst medium. At the shocked region, a reverse shock propagates backwards into the jet — powering bright and short-lived emission sensitive to the central-engine properties — whilst a forward shock travels into the interstellar ambient medium.

But how can such material be accelerated and focused into narrow beams? The internal-shock model proposes that repeated violent collisions between material blasted out during the explosion can produce the gamma-ray flash and the subsequent fading afterglow. In contrast, the competing magnetic model credits primordial large-scale magnetic fields ejected from the central black hole that collimate and accelerate these relativistic outflows. To distinguish between these models and ultimately determine the power source of these energetic explosions, our team studies the polarization of the light during the first minutes after the explosion (using novel instruments on fully autonomous telescopes around the globe) to probe directly the magnetic-field properties in these distant jets. Using this technology, our team made the first detection of highly polarized optical light and confirmed the presence of mildly magnetized jets with large-scale primordial magnetic fields (*e.g.*, GRB 120308A was $P = 28\%$ polarized). In a mildly magnetized jet, the prompt can still be understood in terms of internal shocks and both the prompt- and reverse-shock emission should be highly polarized.

Our most recent observations of the most energetic and first GRB detected at very high TeV energies (GRB 190114C) provide new insights into the jet physics of GRBs. We report remarkably low polarization for GRB 190114C just after the end of the gamma-ray flash ($P = 7{\cdot}7\%$), a sharp drop of polarization one minute later ($P = 2\%$), and constant levels during the following half an hour. However, the modelling of the emission suggests a clear interplay between the reverse and forward shock and more magnetization in the reverse shock, which denotes the existence of these primordial large-scale magnetic fields. Therefore, why is the polarization from the reverse shock so low in GRB 190114C? We propose that the large-scale magnetic field catastrophically collapsed during the first tens of seconds of the gamma-ray flash *via* magnetic-reconnection mechanisms and that the $P = 7{\cdot}7\%$ measurement is a relic from this emission. These findings suggest that some GRBs can be launched highly magnetized; it pins down time-scales (and distances) for which large-scale magnetic fields survive in astrophysical jets and challenges the current models for the production of GRBs.

The Chair. Thank you very much, Núria. Now we have the final talk from Shannon Jones of the University of Reading. Her talk is called 'The visual complexity of coronal mass ejections'. I've got a video to show of Shannon's presentation.

Ms. Shannon Jones. Coronal mass ejections (CMEs), or solar storms, are huge eruptions of particles and magnetic field from the Sun. If a huge CME were to hit Earth, there could be serious consequences such as long-term power cuts. Many of these impacts could be reduced if we had adequate warning that a storm was going to hit. Therefore we created a citizen-science project to investigate CMEs, to help improve our space-weather forecasts.

We had 4028 citizen scientists participating in our Zooniverse project 'Protect our planet from solar storms'. We showed pairs of images from the wide-angle white-light cameras on board the twin *STEREO* spacecraft and asked the participants to decide which CME in each pair looked most complicated, or complex. The images shown were running-differenced, *i.e.*, the previous image was subtracted from each image, to highlight the movement of the storm.

We fitted a Bradley–Terry model to this data (a statistical model widely used by psychologists to rank items by human preference) and ranked 1110 CMEs by their relative visual complexity, *i.e.*, we gave each CME a complexity value which describes how complex that CME appeared compared to the other 1109 CMEs in the dataset.

The Sun has an approximately 11-year cycle, over which the number of sunspots (darker spots on the surface of the Sun) rise and fall. We call the period when the Sun has a higher number of sunspots 'solar maximum', and the period when the Sun has fewer sunspots 'solar minimum'. Many studies have found that the number of CMEs rises and falls with the number of sunspots, and that CMEs appear wider and travel faster at solar maximum.

From our ranking of the relative visual complexity of 1110 CMEs, we found that the average complexity of CMEs also changes with the solar cycle. At solar maximum, CMEs appear more complex, and towards solar minimum, CMEs appear less complex. Complex CMEs appear wider and brighter, whilst simpler CMEs appear narrower and less bright. The figure on this slide shows the relative complexity of all 1110 CMEs, with CMEs observed by the *STEREO-A* spacecraft shown by pink dots, and CMEs observed by the *STEREO-B* spacecraft shown by blue dots. This shows that the average complexity of CMEs observed by *STEREO-B* is consistently lower than the complexity of CMEs observed by *STEREO-A*.

When we asked the citizen scientists how they chose the most complex CME, they described complex CMEs as 'big', 'messy', and 'bright' with complicated 'waves', 'patterns', and 'shading'. We plan to determine quantitatively which of these characteristics are associated with visual complexity. We will also investigate what is causing the CMEs to appear differently. Possible causes include: the complexity of the magnetic field at the CME source region on the Sun; the structure of the solar wind the CME passes through; or multiple CMEs merging, causing a CME to look more complex. Our results suggest that there is some predictability in the structure of CMEs, which may help to improve future space-weather forecasts.

The Chair. Thank you to all our speakers. We have questions now for our first four 'poster' speakers, and Shannon has said that she's happy to answer questions by email. I'll pass you over now to Pamela for the questions.

Dr. Rowden. I have a question for Heidi, which is "So cool to see such citizen science. How many people got involved in the classification so far?"

Ms. Thiemann. Thanks for the question. I did an initial analysis back in 2018 September; we had around four and a half thousand registered volunteers. I checked it this morning actually, just to update my thesis, and we've had almost 9 000 registered volunteers involved, and that doesn't include people who maybe haven't registered with this XENOVERSE platform. So we've had quite a wide reach from around the world which has been really satisfying.

Dr. Rowden. Thank you. Our next question is for Soheb, which is "What a lovely talk. Did you animate Neutrals yourself?"

Mr. Mandhai. Yes I did. I used a 3-D modelling program, BLENDER, to create a 3-D model and I rigged the system which enables the mouth to move following any given dialogue or script.

Dr. Rowden. Thank you. Don't forget to post your questions in the chat or the Q&A. We seem to have an interesting focus on GRBs here and gravitational waves. Here is a question for any of the speakers "What did you find most interesting in the other people's talks?"

Mr. Mandhai. Well for me, I think learning about the actual mechanism behind the GRBs was really fascinating, and then also combining that with the formation of gravitational waves from Isabel and Núria's talks. I think it's really cool to see them unified and come together, from one single event you can get all this different information.

Ms. Thiemann. I was just going to say that I really enjoyed the fact that there was a huge contingent of both citizen science and binary stars, so I'm just impressed by hearing about all of them.

Ms. Romero-Shaw. I agree, I think it's really exciting that this field is fairly new and we're all working on similar things and driving the progress, I think it's really good.

Dr. Rowden. Núria?

Ms. Jordana-Mitjans. In my case it was really interesting to see the connection, like the three cases and how from the single event, just many phases of it and different science in this case.

Dr. Rowden. Brilliant. I was very interested in your very rare red-giant binaries, Heidi. So you found 26 of them so far, yes?

Ms. Thiemann. Well, we found 27 candidates which we thought could be red-giant binaries. We managed to exclude about half of them, as they are Cepheids just masquerading as binaries. The radial velocity sorted that out. There are a few quite interesting shell stars as well, hidden in there, but we've got a nice selection of 12 near-contact red-giant eclipsing binaries which might merge and become red novae. We'll see, though it might take a few million years to do that.

Dr. Rowden. Thank you, Heidi. And there's a question here which is, "Is anyone here working with the *MAGIC* telescopes on La Palma in their projects?"

Ms. Jordana-Mitjans. Not really. In my case that GRB was detected by *MAGIC*. It was the first one that was detected at TeV energies, but I just use the polarimetric data in the optical. Therefore the high-energy data is complementary to our results but I didn't use it in this case.

Dr. Rowden. Here's another question: "The short GRBs that have been sent out of their galaxies: do you find that to be dominant for the short GRB mechanism or do you find other mechanisms for short GRBs?"

Mr. Mandhai. This is an interesting question. When we detect short GRBs what we're really detecting is a burst of gamma-ray radiation, and what we found is that at least from nearby sources — 10 megaparsecs — you can get magnetars which give off giant flares which contain short bursts of GRBs as well. So whilst these aren't SGRBs as we know them, they do get registered as GRB detections. So in the samples of GRB detections that we have, it is possible for these magnetars' giant flares to reside and hide within these samples. It's a tricky one, it's hard to tell them apart but these giant flares last less than a second so that's one way we can home in on these other GRB sources that could fall into this category.

Dr. Rowden. The next question is for anyone working with *LIGO*, which is "What is the current estimate for the number of black-hole–black-hole, black-hole–neutron-star observations per annum by *LIGO etc.*?"

Ms. Romero-Shaw. For BH–BH it's on the order of hundreds at the moment. I can't reveal too much about what the current detections have been, but on the order of hundreds. For the black hole–neutron stars, it is less: we expect to detect fewer of those. I guess on the order of one per annum at the moment, but the sensitivity is improving all the time and when the fourth observing run starts, that number will again increase for both of them because we'll be able to see further out into the Universe and detect more things.

Dr. Rowden. Thank you very much, and someone has sent a message saying "That's significant, wow."

The Chair. Thank you very much, Pamela. Thank you again to all our speakers on the panel here and to Tom earlier for his talk. Just a reminder again that the AGM of the Society will take place at 4 pm on Friday the 14th of May and because the next meeting is an AGM the next Ordinary Meeting of the Society will be on Friday the 8th of October this year. I hope to see you all at the AGM.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 7: DELTA SCUTI, GAMMA DORADUS, AND TIDALLY-PERTURBED PULSATIONS IN RR LYNCIS

By John Southworth

Astrophysics Group, Keele University

RR Lyn is a detached eclipsing binary with a 9·95-d orbit containing two A-stars, one metallic-lined and one possibly metal-poor. We use the light-curve from the *TESS* satellite and two sets of published radial-velocity measurements to determine the properties of the system to high precision. We find masses of 1·939 ± 0·007 and 1·510 ± 0·003 $M_{\odot}$, and radii of 2·564 ± 0·019 and 1·613 ± 0·013 $R_{\odot}$.

After adjusting published effective temperatures upwards by 200 K we find a good agreement with theoretical models for a solar chemical composition and an age of 1 Gyr, and a distance slightly shorter than expected from the *Gaia* EDR3 parallax. The light-curve of RR Lyn shows clear evidence for pulsations. We measure 35 pulsation frequencies and attribute the higher frequencies to δ Scuti-type pulsations, and the intermediate frequencies to γ Doradus-type pulsations (some of which may be tidally perturbed). The lower frequencies may be tidally-excited pulsations in RR Lyn or alternatively of instrumental origin. Most or all of these pulsations are likely to arise in the secondary star. RR Lyn is one of the few eclipsing binaries known to have well-established properties and to exhibit several types of pulsations.

Introduction

Eclipsing binary stars are our primary source of direct measurements of the masses and radii of normal stars[1,2]. Detached eclipsing binaries (dEBs) are of value as their properties can be compared to the predictions of theoretical models of stellar evolution in order to guide the refinement of those models[3,4].

Another type of object well suited to probing the physical properties of stars, in particular their interior structure, is the pulsating star[5]. Detected oscillation frequencies in these objects may be compared to theoretical models to constrain properties such as their densities, ages, and rotational profiles[6–9].

An obvious goal is to combine these two types of analysis by studying dEBs containing pulsating stars, in order to wield as many constraints on stellar theory as possible. This has now been achieved for many types of pulsator including δ Scuti stars[10–13], γ Doradus stars[14–15], slowly-pulsating B-stars[16], β Cephei pulsators[17–19], and red giants with solar-like oscillations[20–22]. The binarity of these systems may also lead to tidal perturbation or excitation of their oscillations[23–26].

The pulsation type most commonly detected in stars in dEBs is δ Scuti[27–29]. These are main-sequence or subgiant stars with masses of 1·5 to 2·5 $M_{\odot}$ and effective temperature ($T_{\rm eff}$) values of 7100 to 9000 K[30]. They show low-amplitude radial and non-radial pressure-mode oscillations with periods of 0·015 to 0·33 days[29,31] that can be used to determine their density[8,9,32].

Another class of oscillation that can occur in late-A and early-F stars is γ Doradus pulsations[33]. These are gravity-mode pulsations that are sensitive to the interior properties of the stars[5]. The pulsation periods range from 0·3 d to 4 d and the amplitudes are up to 0·1 mag[31,34]. δ Scuti and γ Dor oscillations can co-exist[31] and such stars are called hybrid pulsators. Balona *et al.*[35] found that all δ Scuti stars show low-frequency oscillations in high-quality data, so hybrid pulsation may be the standard situation.

In this work we present the detection of δ Scuti and γ Dor pulsations in the dEB RR Lyn. This is part of our work to reanalyse systematically dEBs in the *DEBCat*★ catalogue[36] (see Paper I of the series[37]).

RR Lyncis

RR Lyn is a bright dEB containing two stars of significantly different mass and radius in an orbit with a period of 9·95 d and a small eccentricity. Other basic data are given in Table I. It was discovered to be a spectroscopic binary from observations in early 1911 collected by Adams[46]. A first period determination and single-lined spectroscopic orbit was given by Harper[47], under the moniker Groombridge 1149, based on 30 photographic spectra. Another single-lined orbit was obtained by Douglas & Popper[48] and double-lined orbits have since been published by Popper[49], Kondo[50], Tomkin & Fekel[51], and Bensch *et al.*[52]. The last two papers are of particular interest as they present high-quality radial velocities (RVs), obtained with échelle spectrographs, that can be included in our analysis.

The discovery of eclipses in RR Lyn was announced by Huffer[53], where it was named Boss 1607. Photoelectric light-curves have subsequently been obtained by Magalashvili & Kumsishvili[54], Botsula[55], Linnell[56], Lavrov *et al.*[57], and Khaliullin *et al.*[45]. Those of Linnell[56] were in the *UBV* system and are tabulated in that work, so may be used in future to determine the individual *UBV* magnitudes of the two stars.

Table I

Basic information on RR Lyn

Property	*Value*	*Reference*
Bright Star Catalogue	HR 2291	38
Henry Draper designation	HD 44691	39
Gaia EDR3 designation	997809280404484480	40
Gaia EDR3 parallax	12·416 ± 0·092 mas	40
TESS designation	TIC 11491822	41
B_T magnitude	5·790 ± 0·014	42
V_T magnitude	5·585 ± 0·009	42
J magnitude	5·471 ± 0·290	43
H magnitude	5·066 ± 0·020	43
K_s magnitude	4·993 ± 0·016	43
Spectral type	A3/A7V/F2 + F0 V	44,45

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

The presence of a third body in the system was suggested by Khaliullin & Khaliullina[58] based on deviations of the eclipse times from a linear ephemeris. These authors suggested a period of 39·7 ± 4·2 yr, an extreme orbital eccentricity of $e = 0{\cdot}96 \pm 0{\cdot}02$, and a minimum mass of 0·10 ± 0·02 $M_{\odot}$. The putative tertiary component should imprint deviations of 0·002 d on eclipse times[58] and 2·5 km s^{-1} on the systemic velocity[51], but the evidence for either is weak. The referee has instead found evidence for a light-time effect due to a third body on an orbit of roughly 65-yr period; a detailed eclipse-timing analysis of the system is warranted.

Another method for detecting third components is to search for third light (ℓ_3) when analysing light-curves of eclipses[59]. In the case of RR Lyn third light has been found by Linnell[56] and Budding[60] but was not needed in the analyses by Botsula[61] and Khaliullin *et al.*[45].

RR Lyn has been known for a long time[62–64] also to exhibit clear chemical peculiarities of the Am type[65,66] in its spectrum. Popper[49] classified it as A3 based on the calcium *K* line and F0 based on the hydrogen Balmer lines. Levato & Abt[44] noted its metallic-line nature and gave its spectral type as A3 based on the Ca II *K* line, A7 V based on the Balmer lines, and F2 based on the metal lines. Abt & Morrell[67] classified the system as A3/A8/A6. Khaliullin *et al.*[45] obtained spectral types photometrically using the *UBVR* filter system, finding A6 IV for the primary (hereafter star A) and F0 V for the secondary (hereafter star B). They furthermore obtained [Fe/H] values of +0·31 ± 0·08 for star A and 0·24 ± 0·06 for star B based on the manifestation of line-blanketing effects in the *WBVR* passbands.

Observational material

RR Lyn was observed using camera 2 of the NASA *TESS* satellite[68] in Sector 20, and no further observations are planned from this satellite. The light-curve comprises 18 954 data points obtained in short-cadence mode[69], which were downloaded from the MAST archive* and converted to relative magnitudes. All datapoints whose QUALITY flag was not zero were rejected, leaving 17 552 observations.

As with previous papers of this series, we used the simple aperture photometry (SAP) version of the *TESS* data. This light-curve contains two primary and two secondary eclipses observed in their entirety. One further secondary eclipse was only partially observed as it fell near the mid-sector pause for download of the data to Earth (Fig. 1).

Analysis of the TESS light-curve

The great majority of the data in the *TESS* light-curve of RR Lyn are far from an eclipse and contribute negligible constraints on the radii of the stars. We therefore cut from the light-curve all data points more than 1·25 d (approximately three times the eclipse duration) from the midpoint of the four eclipses that were fully observed. This left a total of 3553 data points for detailed analysis. We rescaled their error bars to force a reduced χ^2 of $\chi^2_\nu = 1$.

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

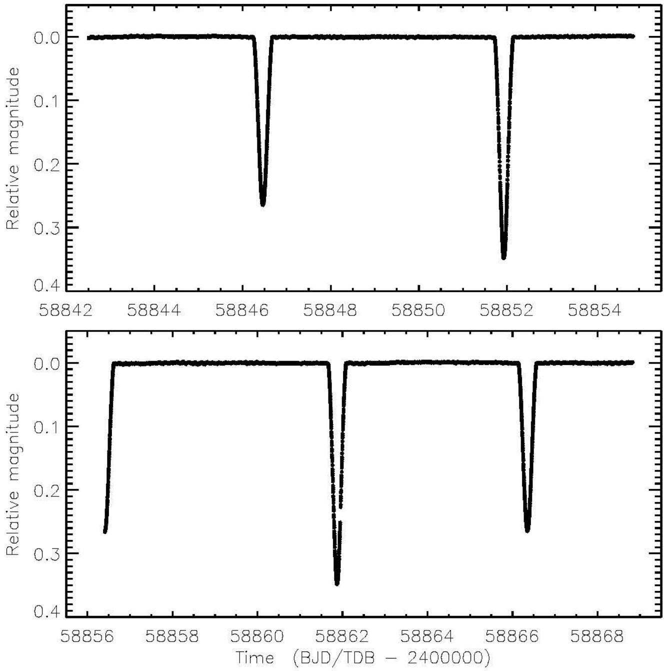

FIG. 1

TESS Sector 20 short-cadence SAP photometry of RR Lyn. The two panels show data from before and after the mid-sector pause.

We then modelled the 3553 data points using version 41 of the JKTEBOP* code[70,71], which is appropriate for systems with well-separated stars[72]. By definition the primary eclipse is the deeper of the two, star A is eclipsed during primary minimum, and star B is eclipsed during secondary minimum. JKTEBOP is parameterized using the fractional radii of the stars ($r_A = R_A/a$ and $r_B = R_B/a$) where R_A and R_B are the true radii and a is the semi-major axis of the relative orbit. We included their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$) as fitted parameters, along with the orbital inclination (i), period (P), time of mid-primary-eclipse (T_0), and the central-surface-brightness ratio of the two stars (J). RR Lyn shows a small but highly significant orbital eccentricity (e) which we accounted for by fitting for $e \cos \omega$ and $e \sin \omega$ where ω is the argument of periastron. Limb darkening (LD) was accounted for using the quadratic law[73] with the linear coefficients of the two stars fitted and the quadratic coefficients fixed at theoretical values obtained from Claret[74]. We included third light (ℓ_3) as a fitted parameter due to the possible presence of a tertiary star. The final fitted parameters were the coefficients of a straight line fit to the out-of-eclipse brightness of the system for each eclipse.

The best fit is shown in Fig. 2 and the measured parameters are given in Table II. We include solutions calculated with ℓ_3 fitted and with $\ell_3 = 0$ for

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

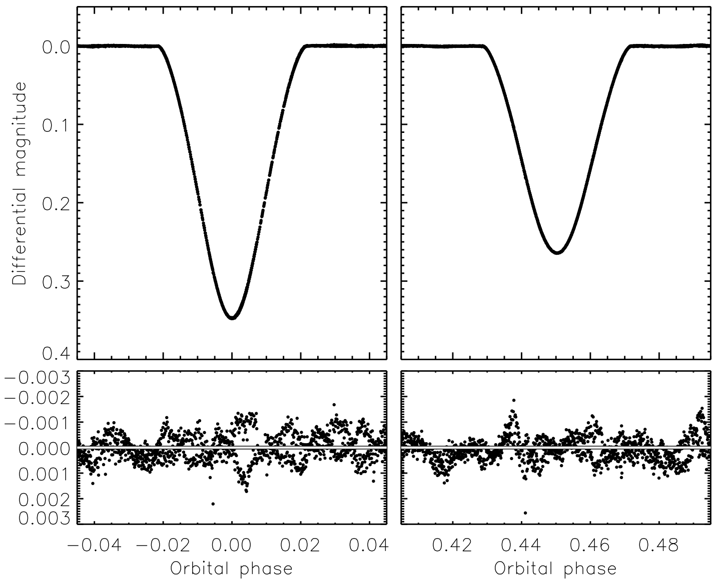

FIG. 2

The *TESS* light-curve of RR Lyn (filled circles) around the primary (left) and secondary (right) eclipses. The best fit is not plotted as it is indistinguishable from the data. The lower panels show the residuals of the fit with the line of zero residual overplotted in white for clarity.

TABLE II

Parameters of the best JKTEBOP fit to the TESS light-curve of RR Lyn, with and without third light. The adopted solution is that including third light. The uncertainties are 1σ. The primary eclipse time is given as BJD/TDB – 2400000.

Parameter	*Third light*	*No third light*
Fitted parameters:		
Time of primary eclipse	58851·92622 ± 0·00010	58851·92622 ± 0·00007
Orbital period (d)	9·945120 ± 0·000073	9·945120 ± 0·00066
Orbital inclination (°)	87·46 ± 0·13	87·18 ± 0·07
Sum of the fractional radii	0·14206 ± 0·00082	0·14393 ± 0·00071
Ratio of the radii	0·6292 ± 0·0069	0·637 ± 0·011
Central-surface-brightness ratio	0·816 ± 0·032	0·817 ± 0·030
Third light	0·036 ± 0·023	0·0 (fixed)
Linear LD coefficient star A	0·177 ± 0·062	0·240 ± 0·029
Quadratic LD coefficient star A	0·25 (fixed)	0·25 (fixed)
Linear LD coefficient star B	0·230 ± 0·077	0·312 ± 0·096
Quadratic LD coefficient star B	0·22 (fixed)	0·22 (fixed)
$e \cos \omega$	−0·078061 ± 0·000018	−0·078043 ± 0·000017
$e \sin \omega$	−0·0016 ± 0·0032	0·0019 ± 0·0034
Derived parameters:		
Fractional radius of star A	0·08720 ± 0·00063	0·08790 ± 0·00019
Fractional radius of star B	0·05486 ± 0·00045	0·05603 ± 0·00083
Orbital eccentricity	0·078078 ± 0·000076	0·078067 ± 0·000094
Argument of periastron (°)	178·8 ± 2·3	178·6 ± 2·5
Light ratio	0·3183 ± 0·0060	0·3247 ± 0·0091
rms residual of the fit (mmag)	0·5137	0·5158

reference. We adopt the solution with third light as it is a slightly better fit and is less affected by any imperfections in the sky-background calculation during the reduction of the *TESS* data. The two solutions are consistent to within 1·4σ for r_B, which is the most discrepant parameter. Our adopted solution has a positive but insignificant ℓ_3, so neither proves nor disproves the possible presence of a third body.

The uncertainties in the measured parameters were determined using Monte Carlo and residual-permutation algorithms[75,76], and the larger of the two uncertainties for each parameter was retained. The pulsations were not explicitly accounted for in the JKTEBOP analysis so have the effect of contributing red noise to our results. In all cases the residual-permutation error bars were significantly larger than the Monte Carlo error bars, by factors of typically 4 to 6. This is likely due to the effects of the pulsations combined with having only a small number of eclipses observed by *TESS*. The net result is measurement of r_A to 0·7% and r_B to 0·8% precision. The measured fractional radii and their uncertainties are of similar size to previous values[45] but likely more reliable as they rest on data of greater number and much higher precision. The orbital phase of mid-secondary-eclipse is 0·4504. The residuals in Fig. 2 are slightly larger during primary eclipse, which suggests that star B is the source of pulsational brightness changes discussed below.

Analysis of published radial velocities

Two works have previously obtained and analysed RVs from high-dispersion spectra, and we have obtained these and fitted them with JKTEBOP to confirm and combine the results. Tomkin & Fekel[51] presented 21 measurements for each component, neglecting a single zero-weight observation, with a scatter of 0·22 km s^{-1} for star A and 0·51 km s^{-1} for star B. Bensch *et al.*[52] obtained 37 spectra of which 23 had resolved lines for both components. Our own fit of these 23 pairs of RVs returned scatters of 0·70 and 0·78 km s^{-1} for the two stars, respectively.

Under the presumption that it is best to combine datasets to obtain the most precise results, and bearing in mind that Bensch *et al.*[52] did not quote the velocity amplitudes from their fit to the RVs, we fitted the two datasets simultaneously with JKTEBOP (Fig. 3). We fitted for the velocity amplitudes (K_A and K_B), $e \cos \omega$, $e \sin \omega$, and T_0. The uncertainties in the RVs were set to give $\chi^2_\nu = 1$ for each star in each dataset and the systemic velocities of the two stars in each dataset were fitted separately. We find $K_A = 65{\cdot}620 \pm 0{\cdot}045$ km s^{-1} and $K_B = 84{\cdot}28 \pm 0{\cdot}13$ km s^{-1}, plus values of $e \cos \omega$, $e \sin \omega$, and T_0 consistent with those from the previous section. The uncertainties were obtained using Monte Carlo simulations, although the formal errors of the fit are very similar (see Paper 6 of this series[77]). The values of K_A and K_B are consistent with those from Tomkin & Fekel[51] but have smaller error bars.

Physical properties of RR Lyn

We have determined the physical properties of the system from the values of the quantities r_A, r_B, i, e, P, K_A, and K_B measured above. This was done using standard formulae[79] and the JKTABSDIM code[80], and resulted in the quantities shown in Table III. The masses of the stars are measured to precisions of 0·3%, and their radii to 0·8%.

A determination of the distance to the system and the luminosities of the stars needs their $T_{\rm eff}$ values. These were found to be $T_{\rm eff(A)} = 7570 \pm 120$ K and $T_{\rm eff(B)} = 6980 \pm 100$ K by Khaliullin *et al.*[45] using *WBVR* photometry and a

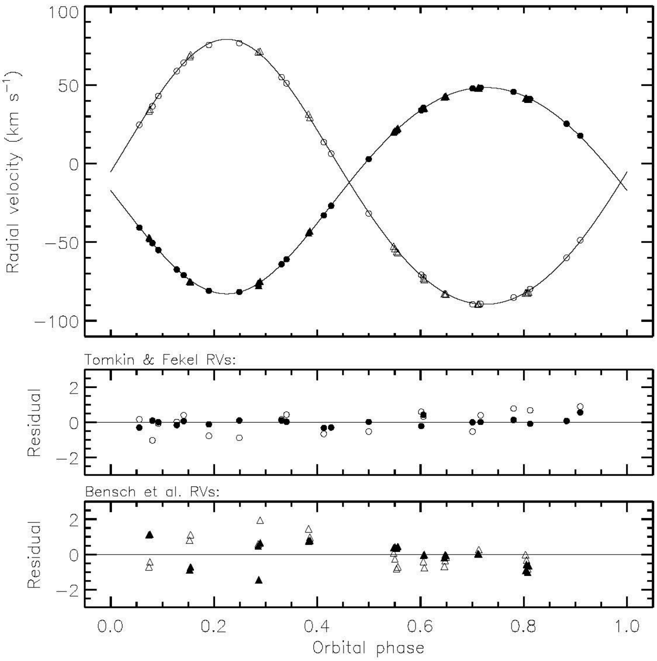

FIG. 3

The spectroscopic orbit of RR Lyn compared to the RVs from the two different sources. Circles show RVs from Tomkin & Fekel[51] and triangles show RVs from Bensch *et al.*[52]. The value 2 km s^{-1} has been subtracted from the RVs from Bensch *et al.*[52] for display purposes, to place them on the same systemic velocity as the RVs from Tomkin & Fekel[51]. Filled symbols are for star A and open symbols for star B. The solid lines show the fitted spectroscopic orbits for the stars. The residuals are shown on an expanded scale, and separately for the two sources of RVs, in the lower panels (labelled). Orbital phase zero is the time of primary eclipse.

TABLE III

Physical properties of RR Lyn defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 78).

Parameter	*Star A*	*Star B*
Mass ratio	0·7790 ± 0·0013	
Semi-major axis of relative orbit ($R^{N}_{\odot}$)	29·405 ± 0·027	
Mass ($M^{N}_{\odot}$)	1·9394 ± 0·0065	1·5100 ± 0·0033
Radius ($R^{N}_{\odot}$)	2·564 ± 0·019	1·613 ± 0·013
Surface gravity (log[cgs])	3·9078 ± 0·0063	4·2017 ± 0·0071
Density ($\rho_{\odot}$)	0·1150 ± 0·0025	0·3597 ± 0·0089
Synchronous rotational velocity (km s^{-1})	13·044 ± 0·095	8·106 ± 0·068
Effective temperature (K)	7770 ± 200	7180 ± 200
Luminosity log($L/L^{N}_{\odot}$)	1·334 ± 0·045	0·795 ± 0·049
$M_{\rm bol}$ (mag)	1·40 ± 0·11	2·75 ± 0·12
Distance (pc)	76·7 ± 1·0	

calibration of the T_{eff} scale[81]. To these we added the apparent magnitudes of the system given in Table I, and an interstellar extinction estimate of $E(B–V) = 0{\cdot}002 \pm 0{\cdot}002$ mag obtained using the STILISM* on-line tool (Lallement *et al.*[82,83]). The resulting distance measurement is significantly shorter than that from the *Gaia* EDR3 parallax of the system (80·54 ± 0·59 pc; Table I), and the T_{eff} values are low compared to theoretical predictions (see below). To (partially) alleviate these discrepancies we took the simple step of adding 200 K to the T_{eff} of both stars, and also increased the error bars to ±200 K. The adjusted T_{eff} of star A is consistent with its spectral type of A7 V[84] and with a recent determination by Graczyk *et al.*[85]. The surface-brightness ratio found in the JKTEBOP analysis implies that the T_{eff} values of the stars differ by a smaller amount than this, 370 ± 70 K, suggesting that further work on this point is needed, preferably in the form of a detailed analysis using high-resolution spectroscopy.

In order to gain a theoretical perspective of RR Lyn, the masses, radii, and T_{eff} values of the stars were compared to the predictions of the PARSEC models[86] assuming a solar chemical composition. The models match the observed masses and radii for this composition and an age of 950 ± 20 Myr, where the error bar is a fitting uncertainty which does not take into account any imperfections in

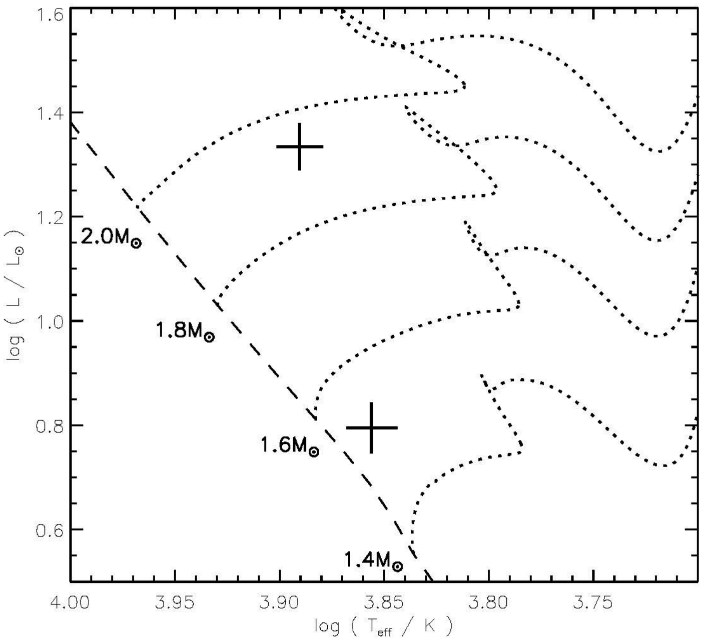

FIG. 4

Hertzsprung–Russell diagram showing the components of RR Lyn (solid crosses) and selected predictions from the PARSEC models[86] (dotted lines) beginning at the zero-age main sequence. Models for 1·4, 1·6, 1·8, and 2·0 $M_{\odot}$ are shown (labelled), all for a solar chemical composition.

*https://stilism.obspm.fr

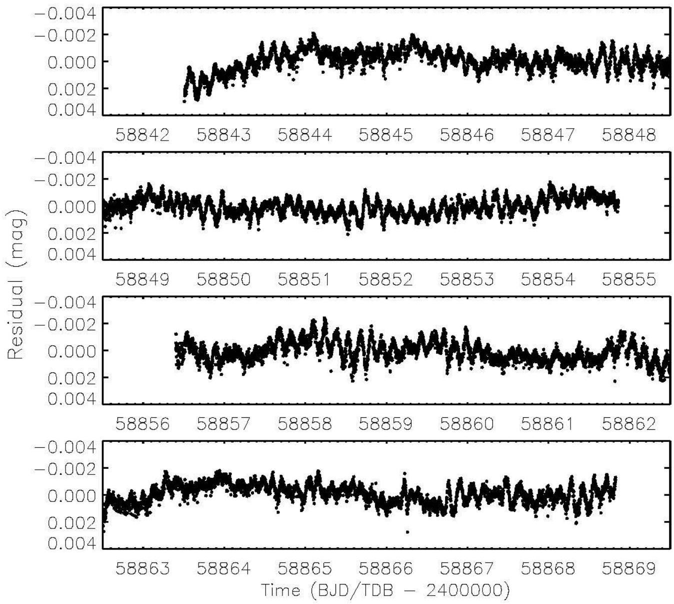

FIG. 5

Residuals of the best fit to the full *TESS* light-curve of RR Lyn, plotted so as to make the pulsations clear.

the models. The higher T_{eff} values given in Table III agree very well with the theoretical predictions for this age. We also performed a comparison on the Hertzsprung–Russell diagram (Fig. 4), finding that star B is close to the zero-age main sequence but that star A has evolved roughly half-way to the terminal-age main sequence.

Pulsation analysis

The light-curve in Fig. 1 shows evidence for short-period variability, which can be investigated using the residuals from the JKTEBOP fit. We therefore performed a fit to the full *TESS* data using JKTEBOP in order to remove the effects of binarity from the light-curve. The residuals of this fit are shown in Fig. 5, where the details have been brought out by stretching the time axis over several panels. A short-period variation is obvious, and several longer-period variations are also present in these data.

To measure pulsation frequencies from the residuals we used version 1.2.0 of the PERIOD04 code[87] to calculate a frequency spectrum from 0 to the Nyquist frequency of 360 d^{-1}. No significant periodicities above 19 d^{-1} were detected. We then selected significant frequencies in the spectrum and fitted sinusoids simultaneously to all of them. We included only those frequencies for which the signal-to-noise (S/N) is more than 10. This is much higher than the widely-used criterion of S/N > 4 (refs. 88,89) but is sufficient to illustrate the general nature of the star. For reference the orbital frequency is 0·1006 d^{-1} and the Loumos &

TABLE IV

Significant pulsation frequencies found in the TESS light-curve of RR Lyn after subtraction of the effects of binarity. Frequencies that are close to a multiple of the orbital frequency f_{orb} are labelled with the multiple in the Notes column.

Label	*Frequency* (d^{-1})	*Amplitude* (*mmag*)	*Phase*	*Notes*
f_1	0·1064 ± 0·0005	0·250 ± 0·004	0·912 ± 0·003	$\approx f_{\rm orb}$
f_2	0·1558 ± 0·0009	0·164 ± 0·004	0·249 ± 0·004	
f_3	0·2071 ± 0·0003	0·383 ± 0·004	0·882 ± 0·002	$\approx 2f_{\rm orb}$
f_4	0·2983 ± 0·0007	0·139 ± 0·004	0·681 ± 0·005	$\approx 3f_{\rm orb}$
f_5	0·3990 ± 0·0008	0·096 ± 0·004	0·565 ± 0·006	$\approx 4f_{\rm orb}$
f_6	0·5016 ± 0·0007	0·114 ± 0·004	0·733 ± 0·006	$\approx 5f_{\rm orb}$
f_7	0·5548 ± 0·0003	0·272 ± 0·004	0·559 ± 0·002	
f_8	0·7106 ± 0·0009	0·095 ± 0·004	0·348 ± 0·007	$\approx 7f_{\rm orb}$
f_9	0·7884 ± 0·0007	0·111 ± 0·004	0·320 ± 0·005	
f_{10}	0·9062 ± 0·0009	0·089 ± 0·004	0·829 ± 0·007	$\approx 9f_{\rm orb}$
f_{11}	1·6206 ± 0·0005	0·156 ± 0·004	0·711 ± 0·004	
f_{12}	1·7137 ± 0·0009	0·093 ± 0·004	0·552 ± 0·006	$\approx 17f_{\rm orb}$
f_{13}	3·5072 ± 0·0011	0·071 ± 0·004	0·467 ± 0·009	
f_{14}	5·0973 ± 0·0015	0·050 ± 0·004	0·674 ± 0·012	
f_{15}	5·2227 ± 0·0013	0·061 ± 0·004	0·327 ± 0·010	
f_{16}	5·7965 ± 0·0016	0·050 ± 0·004	0·807 ± 0·012	
f_{17}	5·4925 ± 0·0017	0·045 ± 0·004	0·788 ± 0·013	
f_{18}	5·6198 ± 0·0012	0·069 ± 0·004	0·754 ± 0·009	
f_{19}	6·1746 ± 0·0013	0·056 ± 0·004	0·362 ± 0·010	
f_{20}	6·2468 ± 0·0008	0·092 ± 0·004	0·277 ± 0·006	
f_{21}	6·3988 ± 0·0007	0·106 ± 0·004	0·861 ± 0·005	
f_{22}	6·5374 ± 0·0012	0·067 ± 0·004	0·189 ± 0·009	
f_{23}	6·5811 ± 0·0011	0·072 ± 0·004	0·063 ± 0·009	
f_{24}	6·7768 ± 0·0008	0·088 ± 0·004	0·221 ± 0·006	
f_{25}	6·9022 ± 0·0004	0·186 ± 0·004	0·906 ± 0·003	
f_{26}	6·9630 ± 0·0008	0·103 ± 0·004	0·536 ± 0·006	
f_{27}	7·0827 ± 0·0007	0·114 ± 0·004	0·669 ± 0·005	
f_{28}	7·1872 ± 0·0008	0·102 ± 0·004	0·273 ± 0·006	
f_{29}	7·3696 ± 0·0003	0·244 ± 0·004	0·435 ± 0·002	
f_{30}	7·5615 ± 0·0014	0·050 ± 0·004	0·461 ± 0·011	
f_{31}	7·6983 ± 0·0009	0·086 ± 0·004	0·704 ± 0·007	
f_{32}	7·8237 ± 0·0014	0·055 ± 0·004	0·267 ± 0·011	
f_{33}	10·8958 ± 0·0010	0·078 ± 0·004	0·019 ± 0·008	
f_{34}	11·1864 ± 0·0009	0·091 ± 0·004	0·892 ± 0·007	
f_{35}	18·8836 ± 0·0007	0·108 ± 0·004	0·641 ± 0·006	

Deeming[90] frequency resolution is $2{\cdot}5 / \Delta T = 0{\cdot}095$ d^{-1} where ΔT is the time interval covered by the data.

We measured a total of 35 frequencies from the data and calculated the amplitude and phase of each one (Table IV). Some of these are close to multiples of the orbital frequency ($f_{\rm orb}$) and are labelled in Table IV. The detected frequencies fall into three categories. Frequency spectra of the data before and after subtraction of the 35 frequencies are shown in Fig. 6.

The lowest three frequencies (f_1, f_2, f_3) are close to $f_{\rm orb}$, $1{\cdot}5f_{\rm orb}$, and $2f_{\rm orb}$. These either arise from imperfections in the light-curve model or the normalization of the *TESS* data, or are pulsations induced by the orbital motion of the system[23,24]. Because these frequencies are similar to the length of the time intervals over which RR Lyn was continuously monitored by *TESS*, we cannot be sure they arise from the target. More detailed analysis is necessary before claiming the reality of these signals.

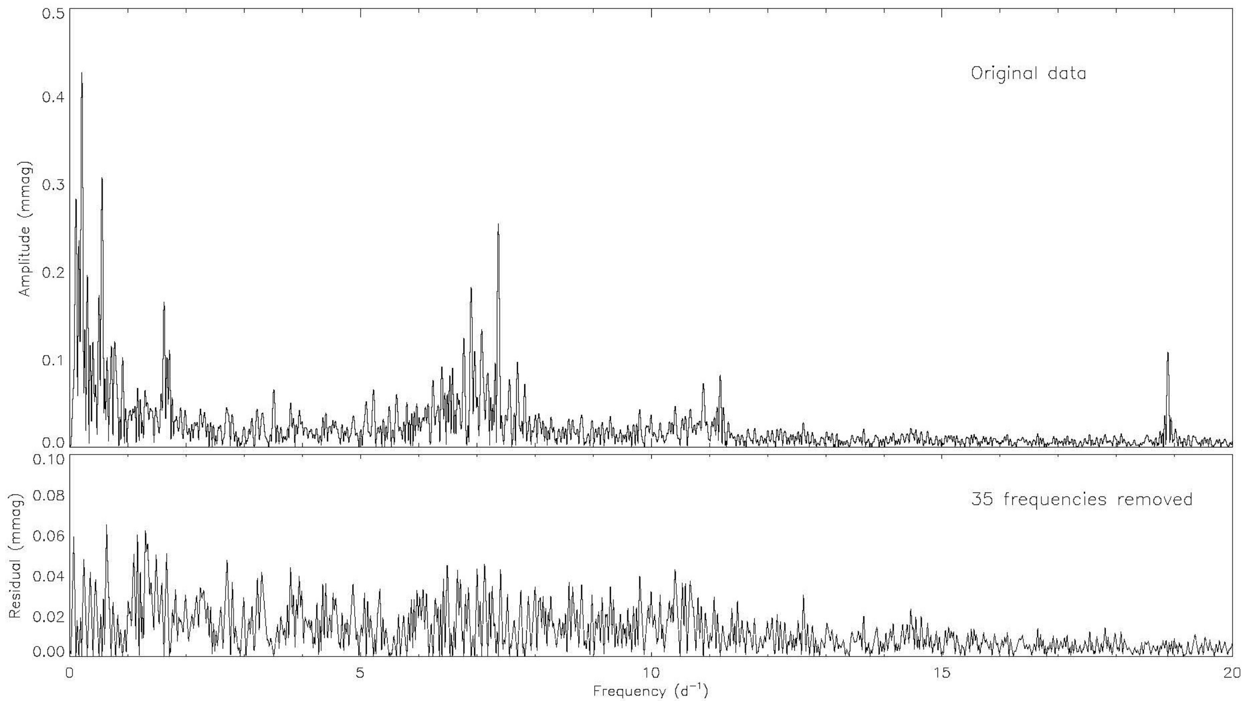

FIG. 6

Amplitude spectrum of the *TESS* light-curve of RR Lyn. Top: spectrum of the data after subtraction of the binary model. Bottom: spectrum after subtraction of the binary model and the 35 frequencies measured in this work.

Frequencies f_4 to f_{12} are within the realm of γ Doradus pulsations[31,91], which are found between approximately 0·3 and 3 d^{-1}. Several of the detected frequencies are multiples of f_{orb}, which suggests that they are tidally perturbed or excited pulsation modes[92]. The last set of oscillations detected (f_{13} to f_{35}) have frequencies consistent with δ Scuti pulsations[29,31].

We have therefore detected pulsations in RR Lyn arising from tidal effects, and from the γ Dor and δ Sct mechanisms. Some of them are integer multiples of f_{orb} and some adjacent frequencies in the list are separated by f_{orb}. Both stars have physical properties (T_{eff} and log g) consistent with the γ Dor and δ Sct instability strips[31,34,93,94] so we are not able to assign specific pulsation frequencies to individual stars. Fig. 2 shows a slight increase in pulsation amplitude during primary eclipse, and the opposite during secondary eclipse, implying that the secondary star is the source of most of the pulsations, but our data are not sufficient to allow definitive conclusions.

Summary

RR Lyn is a dEB with several interesting features. The primary component is a slightly-evolved 1·9 $M_\odot$ star and shows chemical peculiarities of the Am type. The secondary component is an unevolved 1·5 $M_\odot$ star and may be metal-poor. There may be a third body in the system causing changes in the eclipse times due to the light-time effect. We have used the *TESS* light-curve and published RVs to determine the masses and radii of the stars to high precision (0·3% in mass and 0·8% in radius). These properties, plus their T_{eff} values, match the predictions of theoretical models for a solar chemical composition and an age in the region of 1 Gyr.

The *TESS* light-curve of RR Lyn shows clear evidence for pulsations. We have measured 35 pulsation frequencies from these data, and find that they are consistent with being tidally perturbed γ Dor and δ Sct pulsations. We tentatively assign the pulsations (or at least the majority of them) to star B, in agreement with past observations that the incidence of pulsations in Am stars is lower than for normal A-stars[95–97]. The photospheric abundances of the stars should be carefully measured to investigate the metallic-line nature of star A and to determine the chemical composition of the system from star B. When combined with the precisely-known masses, radii, and oscillation frequencies, it may be possible to place stringent constraints on the stellar physics incorporated into the current generation of theoretical evolutionary models.

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NOTES FROM OBSERVATORIES

R. F. Griffin's Unpublished Radial-Velocity Observations

Readers of this *Magazine* will be well aware that for many years each issue included an instalment of R. F. Griffin's series of papers on *Spectroscopic Binary Orbits from Photoelectric Radial Velocities*. That series is now concluded owing to the lamented demise of its author. He had, however, accumulated a substantial number of radial-velocity observations of other stars, many of which might have featured in his series of papers if only he had lived to write them. Recognizing that he would not personally be in a position to continue the series indefinitely, he arranged that his unpublished observations would become accessible to interested parties. His family is in the process of carrying out his wishes, and additionally arranging to make all his unpublished data available on the Web; accordingly please consult www.squarewheels.org.uk/rfg/ which explains the current situation and gives links to data as they become available. The unpublished observations all exist in manuscript form in card indexes that are destined to reside in the Library of St. John's College, Cambridge, CB2 1TP, and may be consulted there through the kindness of the Librarian. Those that pertain to spectroscopic binaries that were being actively investigated are also held in computer files that are easy to understand and can form the inputs to one or another of several orbit-solving programmes that deal with single-lined and double-lined systems, and also with triple systems which have one, two, or three measureable components in their spectra. A listing of those files may be obtained from Dr. R. E. M. Griffin at the Dominion Astrophysical Observatory, Victoria, B.C. (Elizabeth.Griffin@nrc-cnrc.gc.ca), who may be willing to instruct interested parties in the application of the orbit-solving programmes to the data files if those parties do not possess their own software for the purpose.

REVIEWS

Kelvin–Helmholtz Instability in Solar Atmospheric Jets, by Ivan Zhelyazkov & Ramesh Chandra (World Scientific), 2021. Pp. 244, 25 × 16 cm. Price £85 (hardbound; ISBN 978 981 122 374 7).

The Kelvin–Helmholtz instability, which appears in sheared fluid flows, was discovered in the 19th Century, but its importance in many space and astrophysical flows has become increasingly clear in recent years. The presence of magnetic fields, important in the solar corona and elsewhere, significantly modifies the instability. This book presents a thorough overview of mainly theoretical developments in predicting the onset of the instability in various jet-like phenomena in the solar atmosphere. After brief introductions to the Sun, solar jets, and the theory of magnetohydrodynamic waves and instabilities, a series of models of solar jets are described.

The focus is on setting up one-dimensional cylindrical models of jets with appropriate magnetic fields, density differences, and flows, and then deriving the dispersion relation for linear disturbances. Spicules and photospheric jets are discussed first, moving on to jets in the chromosphere and corona, including EUV and X-ray jets, and finally coronal mass ejections. The models are clearly set in the context of observed phenomena, and although the models seem quite idealized, they agree well with observations. However, I would have appreciated more discussion of nonlinear effects and the consequences of the Kelvin–Helmholtz instability (such as onset of turbulence); the figures consist almost entirely of dispersion relations, which becomes somewhat repetitive.

Disappointingly, there are quite a large number of grammatical errors, and the book could have benefitted from better editing; nevertheless, things are clearly explained and this is a readable overview.

The book would be very useful for postgraduates and new researchers setting out in this field, as well as advanced undergraduates. The mathematical models are very clearly set out, so it would be easy to build on the work presented.

The techniques could be applied in many situations where magnetized jets are found, and the book could thus be of interest beyond solar physics. — Philippa Browning.

Neptune: From Grand Discovery to a World Revealed. Essays on the 200th Anniversary of the Birth of John Couch Adams, edited by William Sheehan, Trudy E. Bell, Carolyn Kennett & Robert W. Smith (Springer), 2021. Pp. 403, 24 × 16 cm. Price £99·99/$139·99 (hardbound; ISBN 978 3 030 54217 7).

Any mention of the planet Neptune takes me back to my days as a PhD student in Cambridge, when I spent so much time cycling up and down Madingley Road to use the telescopes at the University Observatories. Memories come back to me of nights spent at the eyepiece of the *Northumberland* refractor, the very same telescope with which Neptune had *not* been discovered by James Challis, even if in my days the original objective had already been replaced by an apochromat of similar aperture. I had the pleasure of locating the still more distant Pluto with it, decades before the IAU so unfortunately demoted its status as a proper planet.

In the text, it is explained how the as-yet-undiscovered planet was thought to be far more distant than it actually turned out to be, and that the *Northumberland* with its 30-cm objective was considered by Airy to have been the only telescope in England capable of finding it. By implication it would not easily have shown a disc, requiring instead a laborious comparison of star fields with charts. And as anyone who has worked with it knows only too well, the *Northumberland* had never been designed as an easy-to-use search instrument.

There is one account, due to H. Sadler and not repeated in this volume, of how Galle had described Neptune as a 'big fellow', supposedly on account of its telescopic disc (*Journal of the BAA*, **18**, 35, 1907). A pity, then, that Challis did not examine his chart interlopers with higher magnification. And by way of compensation, when he finally did see Neptune, he was only too ready to believe that he could confirm Lassell's phantom ring (a product of the flexure of the latter's heavy speculum metal mirror). But whatever his failings were as a planet discoverer, we should finally point out, in a mainstream journal like the present one, that Challis is still remembered today by the University Astronomical Society *via* its 'Challis Group'. In his honour, its die-hard Committee members mount an annual naval expedition upon the River Cam on a fine summer evening, when punts are procured from colleges or hired from among the rows moored at Scudamore's, and picnics eaten on board. And I recall Minute Books of the Challis Group, in which every toast in his honour was properly recorded, and past expeditions remembered: and unsurprisingly at least one volume (and always at least one punter during every trip) was lost overboard. With luck, though never in my personal experience, the pub at Grantchester would be reached before last orders.

Having begun with Newtonian gravitational theory and the work of the 'Celestial Police', this Neptune volume looks at the controversies surrounding the discovery of the world from every possible angle, and includes an account of the 'German side' of the story in Chapter 6. The latter account reminds us that Germany in 1846 was not yet a unified national state. The night of the discovery is nicely re-enacted, including how Galle and D'Arrest must have been 'party crashers' at Encke's 55th birthday celebrations. One still has the chance to visit New King Street in Bath from where Herschel discovered Uranus, but no comparable pilgrimage to the discovery site for Neptune is possible, for of the original Berlin observatory, we are told that not a stone remains. The volume is rich in biographical details and the life of Adams is nicely described in Chapter 4. The awkward position Airy found himself in is dealt with by Robert Smith in Chapter 7.

The text is not limited to details of biography and to the discovery of the eighth planet from the Sun, for an essay by editor-in-chief Bill Sheehan gives a nice sketch of Neptune as a 'world revealed' in the closing part of the book, and also discusses the outer limits of the known Solar System. Indeed, Sheehan has written or contributed to half of the ten chapters. In all, it is an engaging, well-balanced, competently edited, and well-illustrated volume. I will unkindly remark that, of the many formal portraits, surely Jacques Babinet was having a bad day when he sat for his.

Errors of any sort seem to be exceedingly rare: there is an omission of a star chart from Figure 9.2, while the late Richard Baum (who had contributed to one essay) hailed from Chester, not London. The authors, editors, and publisher are to be congratulated upon adding a fine Neptune volume to the literature, and one which gives a balanced, detailed, and satisfying picture of the discovery. — Richard McKim.

The Next 500 Years: Engineering Life to Reach New Worlds, by Christopher E. Mason (MIT Press), 2021. Pp. 280, 23·5 × 16 cm. Price $29·95 (about £22) (hardbound; ISBN 978 0 262 04440 0).

In this book, Christopher Mason, a geneticist and computational biologist who has been a co-investigator on several NASA life-science experiments, aims to provide an overview of the contributions that genetic engineering may make to the future of space exploration. These might range from relatively modest genetic enhancements to make crops grown in future Mars colonies more radiation resistant, to the much more extreme possibilities of making the human colonists themselves better adapted to Martian and other planetary environments. Parts of the book would certainly have been deemed science fiction until a few years ago, but rapid advances in genetic engineering and synthetic biology now mean that future space applications of these techniques need to be taken seriously.

I think the book does a useful service in raising awareness of the possible long-term implications of genetic technologies for the future of humanity. Indeed, Mason's insistence (p. 215) that the human future, both on and off Earth, may come to involve "ubiquitous and continual biological engineering" seems very plausible and is, I think, underappreciated. That said, I wasn't entirely convinced by the proposed timeline, where advances in both space technology and biotechnology are considered in seemingly arbitrary 'phases' over the next five-hundred years. Not only does it seem hopeless to try to predict technological developments so far into the future, but the estimated dates for the introduction of some anticipated future capabilities appear arbitrary and, in some cases, mutually inconsistent. Based on very rapid developments to-date, I could easily believe that some of the capabilities Mason describes will be realized well ahead of his proposed timeline, although there are others (*e.g.*, photosynthetically powered humans) that I suspect will not be possible at all.

There are also some annoying factual errors that could easily have been spotted by careful checking. For example, NASA's *Perseverance* rover is repeatedly called 'Resilience', the first heavier-than-air flight is said to have occurred in 1906 (p. 17; it was actually in 1903), and humans are said to have "emerged in their current form about 6 million years ago" (p. 159); possibly the latter statement was intended to refer to *Homo sapiens*' last common ancestor with chimpanzees, but this cannot refer to the appearance of modern humans (*c.* 200 000 years ago) and seems an odd error for a biologist to make. I should perhaps also say that the author's occasional attempts at humour may not be to the taste of all readers, but I will refrain from giving examples here.

Readers of this *Magazine* are likely to be especially frustrated by some of the astronomy, especially as it relates to exoplanets. Exoplanets feature quite heavily in the book because the author identifies a synergy between (exo-)planetary science and genetics, which he sees as "paired engines of scientific discovery [that] are both essential to human survival" (pp. 193–4). However, it has to be said that Mason's understanding of exoplanet science is in places rather naïve. For example, the statement (p. 135) that "eventually the Voyager probes will send back data on nearby solar systems" shows a serious lack of understanding of both the *Voyager* missions and the scale of the Universe. Similarly, the claim (p. 170) that "hundreds of these candidate [exo-]planets are within the habitable zone, indicating people may be able to live on them" reveals a misunderstanding of both the 'habitable zone' concept and our actual state of knowledge regarding these systems.

Still, should it ever be possible to reach exoplanets (Mason advocates multi-generational 'worldships' transporting appropriately genetically engineered colonists), his wider point about possible synergies between planetary and genetic engineering remains plausible. There is actually a long history of speculation in this field, and it is slightly disappointing that Mason doesn't refer to any of it. For example, in 1948 the philosopher Olaf Stapledon (*JBIS*, **7**, 213, 1948) reasoned that "if the planets are unadaptable to man in his present form … given sufficient biological knowledge and eugenical technique, it might be possible to breed new human types … to people the planets." These days we may baulk at the term "eugenical", but if we replace it with "genetic engineering" we have a clear precursor to Mason's argument in this book.

Moreover, there are other, less extreme, possibilities that Mason rightly identifies. Even if humans (or engineered post-humans) can never make the journey, it seems likely that it will become technically possible to send genetically engineered microorganisms to nearby exoplanets well within the next 500 years (see, *e.g.*, C. Gros, *Astrophys. Space Sci.*, **361**, 324, 2016). Whether we *should* do so or not will likely become an increasingly important ethical and political question within the next hundred years. Mason is convinced that spreading Earth life (albeit genetically engineered Earth life) through the Galaxy will be ethically desirable because life has so much more potential than non-life (consistent with what he terms 'deontogenic ethics'). However, there are other sides to this question, not least how we could avoid Earth-derived life interfering with indigenous lifeforms (if any), and these issues could have been discussed in greater depth.

Finally, I was a bit frustrated by the references. There is a collection of references at the end of the book, but it isn't very comprehensive, and it wasn't always easy to find statements made in the text explicitly supported by the references. The book's value for scientific readers would have been enhanced by a more comprehensive reference list and a more transparent style of citation. On the other hand, the index is very comprehensive (Mason acknowledges his parents for putting the index together, and they are to be congratulated for it!).

Overall, and despite my various criticisms, I am glad that I read this book. It does quite a good job in explaining the state of the art of genetic engineering and synthetic biology for non-specialists, and the possible application of these rapidly developing fields to future space activities. And I absolutely agree with the author (p. 204) that "the only way to find out what is truly possible is to leave our first home and explore." — Ian Crawford.

Master of Galactic Astronomy: A Biography of Jan Hendrick Oort, by Pieter C. van der Kruit (Springer), 2021. Pp. 356, 23·5 × 15 cm. Price £27·99/$39·99 (hardbound; ISBN 978 3 030 55547 4).

Piet van der Kruit, Professor Emeritus at Groningen, produced magnificent, extended biographies of Jacobus Kapteyn and Jan Oort (reviewed here in **135**, 299, 2015 and **140**, 104, 2020, respectively). Then, feeling that these were perhaps too technical and two expensive for a readership of interested students, amateurs, and ordinary folks, a feeling apparently shared by his publisher, he has gone on to produce shorter, less technical, less expensive versions of both biographies. 'Short Kapteyn' appeared here recently (**141**, 207, 2021); and here is 'Short Oort'. The first thing to be said is that, while 726 pages have been shrunk to 356, a large fraction of the wonderful images from the original are still here, including Fig. 12.7 of Oort accompanied by Lodewijk Woltjer, Adriaan Blaauw, and Harry van der Laan (all former Directors General of the European Southern Observatory) making clear that Oort really was short, at least by Dutch standards. Another delightful image (Fig 9.4) shows Maarten Schmidt and Gart Westerhout on the platform of the Kootwijk radio telescope. Both are wearing bow ties, and that was the telescope that had to be cranked forward every 15 minutes during an observation. Boring by day, rather grim by night, as Schmidt later recalled.

Has the author achieved his aim? Mostly, I think, but perhaps not entirely. Many of the astronomical details have been removed or placed in an appendix. Ones remaining in the main text make good sense (p, 246. "the third integral of the motion of a star in a spiral galaxy is the total energy (kinetic plus potential) in the vertical direction") but p. 105 puts red giants in the upper left of a Hertzsprung diagram. Perhaps more seriously, the reduced astronomy leaves a heavier dose of details of Dutch politics, history, and education, undoubtedly perfectly clear to the first intended readership, but less so to monoglot American and British astronomers.

Yes, 'Short' Kapteyn and Oort were originally written in Dutch, and the translation process (by the incredibly polyglot author and an automated system) left traces, for example, "Te Oorts" (Fig. 8.14 caption); "the unit is … 25 magnitudes per square arc second" (p. 128); "Oort's oldest son Coenraad (Coen) en daughter Marike …" (caption to Fig. 8.15). That is, 'Te' is 'The', 'en' is 'and', and the unit is one 25th magnitude star per square arc second. That I do not understand the explanation given of Kapteyn's star streams is no fault of the author.

Many are the gems to be found here: Oort indeed could "walk with queens nor lose the common touch" (for there he is with Queen Juliana in Fig. 9.19). Van der Kruit suggests that if Oort had not recognized Galactic rotation, either Jan Schilt (1894–1982) just then at Mt. Wilson and Yale, or John Stanley Plaskett (1865–1941) then director at Dominion Astrophysical Observatory, would have.

Oort's extraordinary service to the International Astronomical Union (yes, there he is, hiding in the conference photo from Rome 1919, before he was a member) and the very real suffering during the 'hunger winter' (of 1944–45) appear, but are less striking than in the longer volume.

Perhaps the first paragraph should have mentioned that author van der Kruit was Oort's student (PhD Leiden 1971) and that Oort had begun his studies at Groningen under Kapteyn (1851–1922) but completed his 1925 PhD with P. J. van Rhijn. Indeed the scientific genealogy can be traced back to Philipp Müller (1585–1659) who corresponded extensively with Kepler! Missing, however, from the 'Long Oort' is the complete list of his PhD students, their thesis topics, and dates of defences.

Oort's prowess as ice-skater and cyclist appear, and what is more (Figs. 10.8 and 8.12) he could ride both horses and donkeys. His papers on Galactic rotation and the density of matter in the Galactic plane are probably his most cited, but there is also the Oort cloud of future comets, and probably his greatest contribution to astronomy in the country he and his wife loved was the early recognition that radio astronomy was going to be important and that it could be done from the Netherlands.

So, if someone offers you a copy of 'Short Oort' for love or money, take it eagerly, but upgrade to 'Long Oort' if you can possibly manage it and you are fond of both history and astronomy. — VIRGINIA TRIMBLE.

Flashes of Creation: George Gamow, Fred Hoyle, and the Great Big Bang Debate, by Paul Halpern (Basic Books), 2021. Pp. 274, 23·5 × 25 cm. Price $30 (about £22) (hardbound; ISBN 978 1 5416 7359 5).

The leading men of this volume, George Gamow (1904 Odessa–1968 Boulder, Colorado) and Fred Hoyle (1915 Bingley, West Yorkshire–2001 Bournemouth, Dorset), devoted large fractions, though not 100%, of their scientific lives to the Universe, the former attempting to understand what had happened during a hot, dense, early phase, the latter to denying that such a phase had happened. They came to the Universe by rather similar paths, from the 'gee-whiz' physics of their youth, *via* the stars. Gamow's PhD dissertation work (essentially with Lev Landau) appeared in 1928 as *Zur Quantentheorie des Atomkernes*, in *Zeitschrift für Phyik*, **51**, 204, and remains to this day his most-cited paper, primarily because of its treatment of quantum mechanical tunnelling in alpha-decay. (R. W. Gurney & E. U. Condon in *Nature*, **122**, 4391, 1928, published the same idea essentially simultaneously.) Alpha, Beta, Gamow is only his second-most-cited paper (310 ADS citations to more than 1200 at the end of 2011 June).

Hoyle's first publications (he never completed a PhD) in 1937–38 dealt with a generalized Fermi interaction, capture of orbital electrons, and beta transitions in a Coulomb field. His most-cited paper is, of course, B^2FH (2527 citations from its 1957 publication to 2021 June), which, like Gamow's is part of the territory carefully surveyed by Halpern. But before that, each had tackled aspects of the structure and evolution of stars. Gamow in 1932, with Landau, considered the internal temperatures of stars and with Mario Schoenberg in

1941 the effects of neutrino production leading to stellar collapse, as well as a number of papers on his own. Hoyle, collaborating with Hermann Bondi (from 1941, Hoyle's second-most-cited paper, onward), looked at accretion onto low-mass stars to make high-mass ones (thereby avoiding the need for on-going star formation, an unfashionable idea at the time).

Curious and a bit surprising (I knew both at least slightly) are the joint efforts of Hoyle with the slightly older Raymond Arthur Lyttleton (1911–1995) concerning the effects of interstellar matter on climate variation (1939 and highly cited), theory of Cepheid variability (1943), and evolution of stars (1939); this last has at least an approximation to our modern understanding of an interior discontinuity as the cause of red-giant structure.

Jump forward a bit to 1958 and the General Assembly of the International Astronomical Union (Moscow) and, there in the proceedings are Gamow and Hoyle in their only joint commission membership, 35, stellar constitution. Hoyle spoke at the C35 session on computer models of stellar evolution; Gamow, by then Professor at the University of Colorado and increasingly interested in biological phenomena, was not at the GA. Hoyle's later interests, of course, also had biological flavours.

Indeed, as author Halpern and others have remarked, General Relativity and cosmology were not particularly popular during the 1940s and 50s. At the 1952 Rome IAU GA, Evry Schatzman proposed a resolution to establish a commission on cosmology, but was persuaded to withdraw it before it came to a vote. He mentioned several people who were doing important work on the topic, not including either Gamow or Hoyle. Perhaps even Evry was of two or three minds on the topic; Helge Kragh, in *Cosmology and Controversy* (1996 Princeton University Press, p. 14) quotes him as saying (at a Liège symposium the very next year) that one should not invoke a state of the Universe very different from the current one completely different from its actual state. But Kragh also wrote that the very French Schatzman was Belgian. There was eventually an IAU Commission on Cosmology, C47 from 1970 to 2015, which Hoyle duly joined. But it was, of course, too late for Gamow.

Author Halpern brings us many lovely sugar-plums. For instance, while Hoyle was (as is widely known) a pioneer of cosmological radio broadcasting in the UK, Gamow was a pioneer in 1950 of educational television broadcasting in the US on the DuMont Television Network.

Not everything is what you might have supposed either. Stephen Hawking in coming to Cambridge at age 22 wanted Hoyle as his thesis advisor, but was turned down (and so turned to Dennis Sciama). And Robert Herman (the 'deltas' after alpha-beta-gamma) was examined by a thesis committee chaired by Howard Percy Robertson, author of *Relativity, Thermodynamics and Cosmology*. But the thesis was molecular spectroscopy. We get two versions of "Einstein's biggest mistake": the cosmological constant, as transmitted by Gamow, but also his letter to US President Franklin Delano Roosevelt (which played some role in aiming the US toward the creation of atomic bombs), that story as retold by Linus Pauling.

Halpern also introduces us to a number of additional heroes of the Universe, including Robert Dicke and P. James. E. Peebles, as well as providing a number of interesting photographs (many his own, especially of buildings). Was my purple pen also busy marking items I feel could have been better or more accurately expressed? Yes, of course. But read it for yourself when the final version is published (I have an advance uncorrected proof copy). — VIRGINIA TRIMBLE.

Gravity: An Introduction to Einstein's General Relativity, by James B. Hartle (Cambridge University Press), 2021. Pp. 604, 24 × 19·5 cm. Price £44·99/$59·99 (hardbound; ISBN 978 1 316 51754 3).

Like another book with a similar subtitle[1] recently reviewed in these pages[2], this is an appropriately heavy tome which was originally published by another publisher but has now found a new home at Cambridge University Press. The titles perhaps reflect differences between the approaches; that of the former involves "introducing differential geometry and tensor calculus before moving on to physics", while the latter aims to "teach the basic physics first, stress real-world applications, and leave the mathematical framework for later". Hartle has been teaching General Relativity (GR) since 1966 and the book evolved from his lecture notes. Tastes of course may differ; mine is for the latter approach. Although perhaps best known for topics such as quantum cosmology, Hartle's book is very down to earth (to the extent that that is possible for a book on GR); more advanced topics are mentioned, but nothing more except for a note saying that it is beyond the scope of the book. There is no shortage of books on GR, and none of *good* books on GR, but levels and approaches differ. (See ref. 3 for an overview; note that it dates from 1998 and thus includes no books published after that year, presumably the reason why the original version of Hartle's book, from 2003, is not included.)

The five chapters of Part I provide an overview of Newtonian physics and Special Relativity. There are some mathematical details here, but no more than are needed for Parts I and II. Part II, with 14 chapters and more than 300 pages, introduces curved space–times and General Relativity in three chapters before discussing various applications: the Schwarzschild solution for non-rotating spherically symmetric cases, Solar System tests of GR, gravitational lensing, AGN, binary pulsars, gravitational collapse and black holes, rotating black holes (the Kerr solution), and three chapters on cosmology (essentially cosmography, theoretical cosmology, and observational cosmology). Hartle stresses the fact that while such examples are important, this is a book on GR and by no means an exhaustive or even thorough discussion of the corresponding topics. Part III is concerned with the Einstein equation, finally making its appearance in non-vacuum form on p. 483, less than 60 pages before the end of the main part of the book. Two topics touched on earlier, gravitational waves and relativistic stars, are discussed in more detail in the final two chapters. Four appendices discuss units, curvature quantities (essentially a collection of formulae), curvature and the Einstein equation (referring to the *Mathematica* notebook which, along with other resources, is available at https://www.cambridge.org/hartle/), and a rather detailed discussion of the pedagogical strategy. Not only here is it apparent that the book has benefitted from decades of teaching and, as he notes in the preface, the approach works. As a textbook, there are only occasional references in the text; those are listed in the six-page bibliography, along with eleven books. There are comments on the five of those which are classic texts; here Hartle mentions the influence of the legendary 'telephone book'[4] on his own book; not only the boxes scattered throughout the main text remind the reader of that classic. The end papers provide useful formulae and constants.

The book is well written and essentially free of typos. There are many diagrams and a few photos throughout the text. In addition to the boxes, there are also examples in the text and problems (usually several pages) at the end of each chapter (solutions are available at the book website mentioned above). The book ends with a thorough 14-page small-print index. My only real complaint is that none of the example applications has been updated for this reissue;

that is particularly apparent with regard to the CMB and gravitational waves. Even though the examples are just that — examples — one could argue that, in contrast to many others, in those cases recent advances have made significant qualitative advances, rather than just reducing uncertainties of older, classic experiments. But that is a minor gripe, especially since such newer information is readily available elsewhere and, especially in the case of gravitational waves, would have to be updated again very soon anyway.

This is probably my favourite book on GR at this level. It should appeal to those who also like the physics-first approach, and be accessible to those with an undergraduate-level understanding of mechanics. Practically no other knowledge of physics is assumed, and more advanced mathematics is presented in enough detail as needed. As such, it is probably a good choice for those with a background in astronomy, astrophysics, and/or cosmology who want to learn GR at more than a qualitative level. — Phillip Helbig.

References

(1) S. M. Carroll, *Spacetime and Geometry: An Introduction to General Relativity* (Cambridge University Press), 2019.
(2) P. Helbig, *The Observatory*, **140**, 33, 2020.
(3) https://www.desy.de/user/projects/Physics/Administrivia/rel_booklist.html
(4) C. W. Misner, K. S. Thorne & J. A. Wheeler, *Gravitation* (Freeman), 1973.

Reviews in Frontiers of Modern Astrophysics, From Space Debris to Cosmology, edited by P. Kabath, D. Jones & M. Skarka (Springer), 2020. Pp. 411, 23 × 15·5 cm. Price £109·99/$149·99 (hardbound; ISBN 978 3 030 38508 8).

ERASMUS+ is a European-Union-funded collaboration of five institutions, two in the Czech Republic (Astronomical Institute in Ondrejov and Masaryk University in Brno), two in Slovakia (Comenius University in Bratislava and Astronomical Institute in Tratanska Lomnica), and the Instituto de Astrofisica de Canarias in La Laguna, Canary Islands. I don't know what the + means, but then I don't know what ERASMUS means either, for the (obvious) acronym is not decoded in the foreword or anyplace else that I could find. It is, however, a likely bet that the E is European, the R might be research, A for Astronomy, and S for Space (and Strategy and Science), U might be University, and the M remains a Mystery. In any case, what is here are 13 chapters from 19 authors (all connected with the member organizations, apart from two with Hungarian affiliations). The chapters indeed range from space debris to cosmology, with solar activity and starburst galaxies tacked on the end (perhaps because the chapters arrived late?). Chapters are 20–40 pages, and each has anything from 80 to more than 250 references, in something like 13 different formats, a few of which leave briefly the impression that someone named "Recently (19)11 has carried out some important research." I think the most notable and valuable aspect of this volume is that the chapters are all written by members of the community who don't generally provide high-profile reviews in *ARA&A*, IAU Symposia, and so forth. Each set of references includes at least a few papers by the chapter author(s), meaning that they are active members of the groups represented.

One can carp at details — the cosmology author knows about Hubble, Friedmann, and Lemaître, but not Slipher; the author of nebular abundances from optical spectra has invented a few acronyms, like CELs and ORLs (collisionally excited lines and optical recombination lines) that send one backward through the text to decode.

Every chapter has at least a few important items: there are a lot more close binary stars in globular clusters than there were when I worked on the subject (and it might have been zero); just how core-collapse supernovae eject their envelopes remains uncertain (neutrinos and turbulence are favoured by the author, who, however, also mentions that rotation and magnetic field of the residual core might be important, without citing 1969 papers called "do pulsars make supernovae?"). Those globular clusters present two different age–metallicity relations — those in the Galactic bulge suggesting formation there with the other bulge stars, and the ones in the more extended halo suggesting they came from captured dwarf galaxies. There has been (at least) one "failed supernova", meaning a massive star that disappeared between images without a supernova happening in between. Meteroroid, meteor, and meteorite are correctly and graphically defined.

Every chapter has interesting graphics. As a 'star person', I particularly like the clear depiction of Roche geometry and of maximum sizes of stars at various phases in the discussion of common-envelope binaries. While the largest masses have the largest radii at the tip of the asymptotic giant branch, some smaller masses achieve the largest red-giant radii, affecting whether they will become case A, case B, or case C common-envelope systems (but let me enter a complaint that Ed van den Heuvel who coined the A,B,C, distinction does not seem to be cited). The chapter on massive OB stars shows a spectroscopic H–R diagram with lots of evolutionary tracks for stars of 9 to 120 solar masses, taking them through the territories of the Cepheid variables, red supergiants, luminous blue variables, and Wolf–Rayet stars, but also yellow hypergiants and A and B supergiants (which might just be supergiants or subgiants).

To return to generalities, the chapters have all been refereed, sometimes by more than one person. The copious references are less prejudiced toward *ApJ* and American authors than one might find in a similar volume from some Anglophone collaborations. The treatment of the history of each topic is, at best, spotty. And every author is eager for the next, larger telescope, detector, satellite, or computer. Most are young, at least by my standards, and so their hopes may yet be fulfilled. — VIRGINIA TRIMBLE.

Foundations of Modern Physics, by Steven Weinberg (Cambridge University Press), 2021. Pp. 310, 25 × 17·5 cm. Price £34·99/$44·99 (hardbound; ISBN 978 1 108 84176 4).

Once upon a time, many technical majors in American universities began with two years of *Physics for Students of Science and Engineering*, otherwise known as Resnick & Halliday, and someone (well, actually it was me) remarked that "if you know all the physics in Resnick and Halliday, you know a h--- of a lot of physics", indeed enough to score at the 75th percentile on the physics exam of the Graduate Record Exam (of blessed memory) and get into Caltech. Steven Weinberg (physics Nobel 1979 for unification of the electromagnetic and weak interactions) has now brought us the book containing what he hopes "an ambitious physics student would already know when he or she enters graduate school. At least it is what I wish I had known when I entered graduate school." This would not quite have been possible, since some content refers to discoveries made later than his PhD, for instance, the resolution of the solar-neutrino problem. Is there specific astronomical content? Yes, some, for instance, solar neutrinos (p. 249), maser emission by molecules in galaxy discs like NGC 4258

(p. 86) though not by molecules in our own interstellar medium, cooling of that ISM by CO molecules (and why they work better than OH, p. 175), and a bit of stellar convection (p. 31) as part of a discussion of entropy.

The main sections are 'early atomic theory', 'thermodynamics and kinetic theory', 'early quantum theory', 'relativity', 'quantum mechanics', 'nuclear physics', and 'quantum field theory'. That is, he moves from ideas from around 1800 inexorably toward the present, with gradually increasing mathematical sophistication. He feels that it is important (*i*) for physicists (even ones focussed on *LIGO* or density-fluctuation theory) to know about entropy, equipartition, viscosity, and diffusion, and (*ii*) to grasp how we got to what we currently (think we) know, or at least how physicists tell each other how we got here.

Weinberg says firmly in his preface that he is not writing "history of physics" as understood by historians of science. Some of his earlier writing along these lines has been accused of being "whiggish" or "presentist" or some other version of "think like us, not like yourself". A couple of examples will suffice: the periodic table is attributed entirely to Dmitry Ivanovich Mendeleev and its clarification through X-ray crystal spectroscopy to Henry Moseley (whose 1915 death goes unexplained — he volunteered for war service and was shot at Gallipoli in August 1915).

The smoothed history plus mathematical present can make for a somewhat bumpy ride. There you are, reading peacefully about the discovery of alpha decay (sections 3.3 and 6.4), accidentally turn over more than one page, and bump your head, hard, on equations 6.4.17–6.4.54, some of which take several lines.

Not everything is claimed as fully understood. Weinberg would prefer that neutrinos be their own antiparticles (Majorons; what happened to Majorana (1906–38) is another of the end points not addressed).

I never mastered second quantization (applying quantization to wave functions as well as to particles) and so was very pleased to learn (p. 251) that it is "an obsolete, historic relic". And there are things known that Weinberg will not address, at least here, saying of "a spontaneous breakdown of local gauge symmetry" to account for the masses of the W and Z bosons that "these matters are beyond the scope of this book". Thus, even if you master all of *Foundations of Modern Physics* and so are ready to go on to graduate school, there is still much to learn.

A few items count as fun. For instance, Ernst Mach (1838–1916, eponym of speed and principles) was still saying in the year of his death (not in English I suppose) that he "can accept the theory of relativity as little as I can accept the existence of atoms and such dogmas".

A few claims are too vague: (*i*) only helium, not "some elements" was discovered in the Sun before they were found on Earth (p. 77), and (*ii*) "… Balmer (1825–1898) had noticed that the wavelengths of many of the lines in the visible spectrum of hydrogen are well fit by the formula …" (the Balmer lines of hydrogen are the only ones at visible wave lengths).

The last chapter is followed by "assorted problems", some computationally difficult (invoking particles and forces different from the ones we know about), others suitable for contemplation. And, when you have dealt with No.7, "In the electrolysis of water, how long does it take a 1 ampere current to produce one gram of oxygen gas?", you may think about "If 10 men can dig 10 holes in 10 days, how long does it take 1 man to dig one hole?"

No, at my age, I do not now expect to know "all the physics in Weinberg", but if I were something like 57 years younger and just about to start graduate school, I would try. And so should you. The price per equation is remarkably small, and you will get Noether's theorem and the spin-statistics connection practically for free. — VIRGINIA TRIMBLE.

Note added in proof. Your reviewer and Editors share community-enveloping sorrow at the loss of Steven Weinberg on 2021 July 23, after this review was written, with all the verbs in present tense. He was a brilliant young man, born in 1933, and graduating in 1950 from the Bronx High School of Science, in the same class as his later fellow-Nobel-Prize-winner, Sheldon Glashow. Weinberg's achievements in science, education, national policy, and much else defy summarizing. A first generation American, he was firm in both atheism and support for Israel. Short obituaries have appeared in *Nature* and *Science* and a longer one in the *New York Times* for 2021 July 25. Please read it and his Wiki and, to feel the sheer energy he projected, at least one of his books or papers before the end of the year. — VT.

Star-Formation Rates of Galaxies, edited by Andreas Zazas & Véronique Buat (Cambridge University Press), 2021. Pp. 281, 25 × 18 cm. Price £120/$155 (hardbound; ISBN 978 1 107 18416 9).

The purpose of this graduate-level text — Volume 55 of the *Cambridge Astrophysics Series* — is perhaps best summarized in the editors' own words in the preface, *viz.* "to provide an up-to-date and comprehensive review of methods used to measure the intensity of star-forming activity in galaxies … their astrophysical foundation, and the different factors that affect their precision and accuracy."

To a large extent the book achieves this aim, including the 'up-to-date' part (the most recent references in most chapters coming from 2019 with a few from 2020). It is divided into eleven chapters by different (sets of) authors, four on 'Background', seven on 'SFR Measurements'. It certainly matches its aim of 'comprehensive', covering processes related to star formation which generate emission all the way from X-rays to radio and even gamma-rays and gravitational waves. Inevitably the chapters vary in style, from informative and easy to read to places where erudition exceeds illumination. There is also more overlap and repetition than would be the case for a single *Annual Reviews*-type report. However, that is no bad thing in the current context, as it makes it possible to concentrate on individual fairly-self-contained chapters if required. Each chapter is followed by its own long list of cited literature, totalling nearly 60 pages in all. What you won't find is much discussion of the results obtained by measuring star-formation rates. The 'main sequence' of star formation and the cosmic star-formation history, for instance, are only briefly discussed. Nevertheless, if you want to know how to measure star formation (and why it is difficult), then this book can be recommended, both in itself and as an entry to the literature. — STEVE PHILLIPPS.

The History of Modern Astronomy in Japan, by Tomokazu Kogure (Springer), 2021. Pp. 295, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 57060 6).

The title of this book is somewhat misleading. It is essentially biographical, concentrating on academic Japanese astronomers and their specific astronomical activities. The book abounds with portraits of nearly forty Japanese gentlemen, with detail of their education and careers, together with clear, well-illustrated, well-referenced, concise summaries of their astronomical achievements.

The approach is chronological. Japanese astronomy started slowly. In the Tokugawa period (pre-1868) the country was isolationist, the aim being to protect the traditional values and guard against the influence of Christianity. The only astronomy was calendrical. Interestingly Professor Tomokazu (Kyoto University) mentions a few names, but says nothing about any specific calendar, or about what a calendar was used for in Japanese society.

We read about how the pre-World War Two militaristic society tried to catch up with western scientific advances by sending personnel to foreign universities. That war saw Japan being expelled from the IAU. But after the war the country became democratic and entered a period of impressive economic growth. Astronomy flourished. The professional membership of the Astronomical Society of Japan went from 126 in 1950 to 1370 in 2000. University astronomical departments were equipped with a host of telescopes, astronomy was introduced into the school curriculum, and many towns and cities were equipped with planetaria and public viewing facilities. Japan embraced all forms of the subject and we read of impressive telescopes, solar towers, radio-antenna arrays, and space satellites. What I missed was a discussion of the motivation. I also missed any discussion of the distribution of the facilities. I was left with no indication as to why the telescopes were chosen and why they were placed where they were, or why some universities specialized in astronomy and others did not. I learnt much about what the Japanese did, but too little about why they did it. I also learnt too little about the instrumentation. The book gave the strong impression that Japanese women were allowed nowhere near the eyepieces of research telescopes.

But I was generally impressed. After a slow start in the 19th Century, we read an intriguing story of just what an industrious and hard-working nation can achieve. — David W. Hughes.

Rosetta: The Remarkable Story of Europe's Comet Explorer, by Peter Bond (Springer), 2021. Pp. 403, 24 × 17 cm. Price £24·99/$34·99 (paperback; ISBN 978 3 030 60719 7).

Going to a comet is a perilous business for a spacecraft. Comets are far from being dormant. *Rosetta*'s target, 67P Churyumov–Gerasimenko, weighs in at $9{\cdot}98 \times 10^{12}$ kg and is shaped like a duck with a 4·1 × 3·3 × 1·8 km body and a 2·6 × 2·3 × 1·8 km head. In the future these two bits will probably split apart. It is in the Jupiter family and orbits the Sun every 6·44 years between an aphelion of 5·68 AU and a perihelion of 1·24 AU. On its last orbit it lost $10{\cdot}5 \times 10^{9}$ kg, equivalent to an average layer loss of 70 cm. Near the Sun, it surrounds itself with a gaseous dusty coma which is not a safe place for a spacecraft to be.

The European Space Agency decided to follow its successful *Giotto* 1986 fly-by mission to Halley's Comet with a comet orbiter. *Rosetta* did not start well. The intended launch vehicle blew up causing a delay, and the intended target 46P/Wirtanen had to be replaced by the more massive 67P. Launch eventually took place on 2004 March 2, and the spacecraft arrived at the comet over ten years later on 2014 August 6. Comet 67P passed perihelion on 2015 August 13 and the *Rosetta* mission ended on 2016 September 30 when the spacecraft impacted the nucleus.

Peter Bond, a space journalist, treats us to a blow-by-blow account of the mission, and its predecessors. Every instrument is described in detail and the results of each investigation are expertly summarized. The illustrations in the book are superb and I found the detailed referencing especially useful. Bond clearly enjoyed interviewing all the investigators and his biographical section was fascinating. I enjoyed the engineering but I missed the scientific controversies. We are told in detail what was done but are given less information as to why it was done. When it comes to the results, we are left to make up our own minds as to which were game-changing, and which revealed further mysteries.

The *Rosetta* mission included a landing probe called *Philae*. This 'soft' landing on the nucleus was to be followed by surface sampling. But what was it going to land on? Was the surface of the nucleus a solid icy crust, where drills and harpoons would be needed, or was it an expanse of soft snow where a spoon would satisfy? Unfortunately the scientists did not know and Bond did not underline the problem. The engineers had to guess. *Philae* 'landed', but bounced, landed again 100 minutes later and bounced again and finally, after another seven minutes ended up wedged in a dark crevasse.

The main *Rosetta* instrumentation was a huge success. Bond stresses how the surface revealed cliffs and cracks and also surprisingly flat regions. Most of the mass loss was through spasmodic jets, these beings switched on and off during the comet's daily and seasonal temperature variations. Regional chemistry of the gas emission showed that different parts of the comet were probably formed in different regions of the early Solar System. The density of the comet was about half that of water. The interior is porous, but is probably just fluffy without great voids.

I enjoyed this book greatly. Bond is clearly a comet fan and indicates clearly that not only were the one billion euros spent on *Rosetta* a bargain, but there is still a great deal to learn about these ephemeral bodies, and other comets need to be visited. — David W. Hughes.

Nobel Life: Conversations with 24 Nobel Laureates on their Life Stories, Advice for Future Generations, and what Remains to be Discovered, by Stefano Sandrone (Cambridge University Press), 2021. Pp. 220, 25 × 18 cm. Price $19·99/$24·99 (hardbound; ISBN 978 1 108 83828 3).

Some, but not all, of our honoured colleagues and friends are here: Arno Penzias yes, Robert Wilson no (1978, for discovery of the cosmic microwave background); John Mather yes, George Smoot no (2006, for CMB discoveries with the *COBE* mission); Brian Schmidt yes, Saul Perlmutter and Adam Riess no (2011, for acceleration of cosmic expansion from studies of supernovae). And none of the trios from 2017, 2019, and 2020, these last because the interviews on which the book is based took place at the 2015 Lindau Nobel Laureate Meeting. These gatherings, pioneered in 1951, bring together Nobel Laureates (I think just from the sciences and economics) and students of exceptional promise in scientific subjects. Besides those just mentioned, there is one more physicist (David Gross (in 2004): Asymptotic freedom in the theory of the strong interactions), nine chemists, eight winners from medicine or physiology, and three economists.

The interviewer and author is an Italian neuroscientist working in London. Not surprisingly, his questions elicited more science from the medicine and physiology winners and from the chemists than from our astronomical colleagues. One sample from each is probably enough. Penzias: "I hope there is a God. I deeply hope there is a God."

Mather: (when asked where he was at the time of the Apollo Moon landing) "I was a summer camp counselor, putting nine year old boys to bed."

Schmidt: (in response to who are your heroes and heroines in fiction and real life, and who are your favourite painters and composers?) "Hermione Grainger, Indiana Jones, Marie Curie, and Nelson Mandela; Renoir, Dali, J. S. Bach, Brahms, and Saint-Saens."

And a longer quote from Roger B. Myerson (2007 economics), because it embeds a number I have often wondered about: "But in the end, I felt it wasn't the Weimar constitution that drove the rise of Nazism. Rather it was the reparations from the Versailles Treaty … (which implied) the threat to attack Germany if they didn't pay an amount in the order of three or four percent of the GDP annually for the next two generations." — VIRGINIA TRIMBLE.

The WSPC Handbook of Astronomical Instrumentation, edited by David N. Burrows (World Scientific), 2021. In five volumes, 23 × 17·5 cm. Price £1536/$1850 (hardbound; ISBN 978 981 4644 31 0).

"Our goal is to produce a comprehensive handbook of the current state of the art of astronomical instrumentation with a forward view encompassing the next decade." This has been achieved through a set of five volumes, each carrying a number of up-to-date reviews.

Volume 1 covers 'Radio Astronomical Instrumentation' and its topics range from 'Single-dish radio telescopes' through to 'Pulsar data acquisition systems' in 199 pages.

Volumes 2 and 3, in 378 and 404 pages, respectively, move us on to shorter wavelengths and cover, in the same format as the first volume, UV (one chapter), optical (mainly), and IR instrumentation, for both astronomical and solar applications.

Volume 4 moves yet further to short wavelengths with chapters on X-ray optics, detectors, gratings, and polarimetry in 304 pages.

Finally, Volume 5 covers γ-ray astronomy and other multi-messenger contributors (neutrinos and gravitational waves), in 216 pages.

I gather that these five, nicely produced books will only be sold as a set, so one might expect to find them only in well-resourced libraries. There is also an e-version at a marginally reduced price,

This 'review' is intended only as a notice, and it is hoped to acquire more substantial expert reviews that can be published in these pages in due course. — DAVID STICKLAND.

OTHER BOOKS RECEIVED

Studying Compact Star Equation of States with General Relativistic Initial Data Approach, by Enping Zhou (Springer), 2020. Pp. 78, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 981 15 4150 6).

Published in Springer's series 'recognizing outstanding PhD research', this book focusses on the equation of state in compact stars, including the possibility of a 'quark star model'.

ASTRONOMICAL CENTENARIES FOR 2022

Compiled by Kenelm England

The following is a list of astronomical events, whose centenaries fall in 2022. For events before 1600 the main source has been Barry Hetherington's *A Chronicle of Pre-Telescopic Astronomy* (Wiley, 1996). For the 17th to 20th Centuries lists of astronomical events came from Wikipedia and other on-line sources such as *Encyclopedia Astronautica*, supplemented by astronomical texts. Discoveries of comets, asteroids, novae and other objects for 1922 appeared in the February issue of *Monthly Notices of the Royal Astronomical Society* in the following year. There were also references from *Popular Astronomy*, *Journal of the British Astronomical Association*, and *Publications of the Astronomical Society of the Pacific*. Professional discoveries and observations were followed up in *Astronomische Nachrichten*, *Astronomical Journal*, and *Monthly Notices*. Details of individual astronomers were supplemented by articles published in *Biographical Encyclopedia of Astronomers* (Springer, 2007). Gary Kronk's *Cometography* Volumes 1–3 (Cambridge, 1999–2007) provided details on all the comets. Finally NASA's Five Millennium Canons of Eclipses and planetary tables were consulted for information on eclipses and planetary events.

1922

January 1–4: A bright display of the Quadrantid meteor shower.

January 8: Birth of Dale Dehaven Myers, an American aerodynamicist, managing the Apollo and Shuttle spacecraft designs; NASA Deputy Administrator (1986–9) after the *Challenger* disaster; died 2015.

January 18: Birth of Oleg Genrikhovich Ivanovskii, a Soviet rocket engineer, working on early Sputnik and Vostok craft; Deputy Chief Designer of OKB-301 Lavochkin Design Bureau (1971–83) responsible for lunar and planetary spacecraft; died 2014.

January 20: William Reid (Rondebosch, South Africa) discovered a small comet in Antlia, which was about magnitude 10 and remained a southern object. It gradually faded and was last seen on April 25. The comet had been at perihelion on 1921 October 28 ($q = 1{\cdot}629$ AU) [Comet C/1922 B1 (Reid)].

February 7: William Frederick Denning (Bristol, England) saw a very bright fireball in daylight at about 4 p.m. A loud detonation was heard 4½ minutes later. A number of people in the Bristol area reported seeing the meteor.

February: Edward Walter Maunder published a paper on the extended solar minimum from 1645 to 1715, based on Gustav Spörer's work [now known as the Maunder Minimum].

March 4: Birth of Benjamin Franklin Peery, an American astronomer at the University of Iowa, studying red giant stars; died 2010.

March 5: Metcalf's comet, discovered in 1906 but missed in 1915, returned to perihelion ($q = 1{\cdot}594$ AU). Searches for the comet were made at the beginning of the year, but it remained too faint to be seen until 1991 [Comet 97P/Metcalf–Brewington].

March 23: Robert Hutchings Goddard test fired his liquid-fuelled rocket engine for the first time.

March 28: An annular solar eclipse was visible from Brazil, North Africa, and Arabia. The partial phase could be seen from Central and South America, North and Central Africa, Europe, and the Middle East [Saros 128].

April 6: Birth of William Charles White, an American astronomer, who studied the upper atmosphere. On 1962 December 13 he flew with Joseph William Kittinger on the first mission of *Project Stargazer* (further flights were cancelled), reaching 25 km and observing stars with a 30-cm telescope; died 2011.

April 20: A meteorite landed near Hedeskoga, Skåne, in Sweden. This H5 chondrite weighed 3·5 kg [Hedeskoga Meteorite].

April 21 & 22: P. C. Daniels and P. C. Mead (Drake Observatory, Des Moines, Iowa) observed 30 meteors belonging to the Lyrid meteor shower. The Lyrids were also recorded by Alice Grace Cook (Stowmarket, England).

May 1: Birth of Roger Hildebrand, an American physicist on the Manhattan Project and teaching particle physics at the University of Chicago. He developed instrumentation for the study of the far infrared; died 2021.

May 2–10: Meeting of the International Astronomical Union in Rome. The current 88 constellations (plus Argo) were officially established with three-letter abbreviations.

May 16: James Francis Skjellerup (Rosebank, South Africa) discovered a very faint comet in Gemini one day after perihelion ($q = 0{\cdot}889$ AU). It slowly faded to magnitude 12 at the end of May but displayed a diffuse coma. The comet continued to fade, was closest to the Earth on June 12 (0·268 AU), and was last seen on August 19. The orbit indicated that it might be identical to a comet discovered by John Grigg in 1902, which was confirmed at its return in 1927 [Comet 26P/1922 K1 (Grigg–Skellerup)].

May 29: Alexander Alexandrovich Friedmann published his paper *O Kreveznye Prostranstva* (*About the Curvature of Space*), showing that Einstein's gravitational-field equation allowed for an expanding universe.

May 30: A Japanese farmer, Tokosuke Inone (Nagai, Yamagata Prefecture), saw a meteorite coming from the southwest amid loud detonations, and land in his field. This L6 chondrite, weighing 1·8 kg, remained unreported for more than fifty years [Nagai Meteorite].

June 5: Birth of John Gatenby Bolton, a British-born radio astronomer at Australia's CSIRO Division of Radiophysics in 1946, identifying the first 'radio stars' in 1948 and discovering quasars at the Parkes radio telescope; elected FRAS in 1973 and awarded the RAS Gold medal 1977; died 1993.

June 12: Birth of Margherita Hack, an Italian astrophysicist, Professor of Astronomy at the University of Trieste (1964–92); member of Accademia Nazionale dei Lincei; political activist; died 2013.

June 17: Taylor's comet, discovered in 1915 and split in two in 1916, returned to perihelion ($q = 1{\cdot}558$ AU). Searches were made, but the comet remained too faint and was feared to have broken up, until it was recovered in 1976 [Comet 69P/Taylor].

June 18: Death of Jacobus Cornelius Kapteyn. Born in 1851, this Dutch astronomer joined the Leiden Observatory in 1875 and became professor of theoretical mechanics at the University of Groningen. He worked with David

Gill on the Cape Photographic Durchmusterung of southern stars. He found star streams in the Milky Way and used statistical methods to determine the structure of the Galaxy.

June 22: Birth of Ewen Adair Whitaker, a British astronomer, who studied the lunar surface and was involved with NASA's *Ranger*, *Surveyor*, and *Lunar Orbiter* programmes. He reconstructed the Digges telescope; BAA Walter Goodacre Medal 1982; died 2016.

June 29: Alexander Friedmann's paper *About the Curvature of Space* appeared in German. Einstein rejected the idea of an expanding universe at first.

July 17: Annie Jump Cannon (Harvard College Observatory) discovered a nova (mag. 9·9) in Scorpius. Images of the nova appeared on photographs taken on July 11 and 12. The nova was confirmed spectroscopically and faded rapidly during August [V707 Scorpii].

July 28 & 29: Robert M. Dole observed 44 meteors belonging to the η Aquarid meteor shower.

August 3: Birth of Arthur Anthony Page, an Australian physiotherapist and amateur astronomer, involved in radio astronomy at CSIRO's Division of Radiophysics, publishing catalogues of flare stars; died 2011.

August 5: Birth of Howard George Miles, a British college lecturer in mathematics and amateur astronomer; elected FRAS 1953; BAA member 1960 and Director of the Artificial Satellites Section (1960–97); died 2016.

September 21: A total solar eclipse was visible from the Indian Ocean and Central Australia. The partial phase could be seen from the Middle East, East Africa, the Indian Ocean, the East Indies, and Australia. Maximum totality lasted 5 minutes 59 seconds [Saros 133]. Harold Spencer Jones led a team from the Royal Observatory at Greenwich to Christmas Island. In Western Australia William Wallace Campbell led a number of astronomers from the Lick Observatory. As well as studying the solar corona, the groups wanted to confirm Einstein's theory of relativity in the bending of starlight by the Sun's gravity, first observed by Andrew Crommelin and Arthur Eddington in 1919.

September 27: Death of Charles Michie Smith. Born in 1854, he was a British astronomer in India, Professor of Physics at the Christian College, Madras, in 1876 and Government Astronomer in Madras (1891–1911); elected FRAS in 1894. He also established the Kodaikanal Observatory in 1899. He specialized in solar studies and organized the viewing of the total solar eclipse in 1898.

September 28: Death of Thomas Hinsley Astbury. Born in 1858, he was a British schoolmaster and amateur astronomer, member of the BAA Variable Star Section Nova Patrol, who visually discovered the variables RT Aurigae, RS Vulpeculae, and TV Cassiopeiae.

September 29: Death of Sir Robert Pearce. Born in 1840, he was a British politician, elected FRAS in 1877, who introduced the Summer Time Act 1916; knighted in 1916.

October 19: Wilhelm Heinrich Walter Baade (Hamburg Observatory) discovered a comet (mag. 11·5) in Cygnus with a coma 2 arcminutes across. This comet was the first to be announced by IAU Circulars and so was soon observed widely by professional astronomers. It gradually brightened to 9th magnitude and reached perihelion on October 26 ($q = 2{\cdot}259$ AU). Being so distant, the comet changed little during the rest of the year and was observed until 1923 March 19. After solar conjunction it was recovered on August 17 (mag. 14) and continued to fade until the last observation on 1924 January 28. The orbit was distinctly hyperbolic; the comet will never return (Comet C/1922 U1 (Baade)].

October 22: First issue of the International Astronomical Union Circular by the Copenhagen Observatory.

November 10: Willem Jacob Luyten published a list of 40 M-class dwarf stars.

November 25: Birth of Aden Baker Meinel, an American scientist at the Jet Propulsion Laboratory, creating optical designs for several major US telescopes; died 2011.

November 26: James Francis Skjellerup (Rosebank, South Africa) discovered a 10th-magnitude comet, while searching for new comets in Crater. Reaching perigee on December 6 (0·881 AU), it brightened to magnitude 7 and moved south, until it could only be observed from the Southern Hemisphere. The comet reached perihelion on 1923 January 4 ($q = 0{\cdot}924$ AU) and slowly faded, until it was last seen on February 25 [Comet C/1922 W1 (Skjellerup)].

November 29: While searching for Perrine's Comet, Kaname Nakamura (Kyoto University Observatory) found a 13th-magnitude comet with a coma 2 arcminutes across near the head of Hydra. He observed it again on November 30 and December 1, before reporting it as the recovery of Perrine's comet. No other observations were made and further calculations indicated that this was not the same comet. Nakamura's object remains unconfirmed.

December *12*: Benjamin Jekhowsky (Algiers Observatory) discovered an 11th-magnitude asteroid, which proved to be (132) Aethra, lost since its discovery in 1873.

December 13: Birth of Arnold Noel Argue, an Assistant at the Cambridge University Observatory (1953–90); died 2001.

December 14: Death of Fritz Cohn. Born in 1866, he was a German mathematician and astronomer at the Königsberg Observatory (1891–1909) and Professor of Astronomy in Berlin. He calculated orbits of asteroids and comets; Associate of the RAS 1913.

December 19: Charles Edward St. John and Seth Barnes Nicholson (Mount Wilson) reported that they could detect no significant water vapour or oxygen in the spectrum of Venus' atmosphere.

December 23: Birth of Harold Masursky. He was an American astrogeologist at the US Geological Survey, studying images of lunar and planetary surfaces from NASA space missions; died 1990.

December 23: Perrine's comet, seen in 1896 and 1909, returned to perihelion ($q = 1{\cdot}199$ AU). Despite searches at the end of the year, the comet was not detected and was not observed again until 1955 [Comet 18D/Perrine-Mrkos].

December 27: Release of the science-fiction film *The Man from M.A.R.*S.

First issue of BAA observer's *Handbook*.

Elias Howard Sellards recognized a meteorite crater 168-m across, 16 km southwest of Odessa, Texas. An iron meteorite, weighing 1·6 tons, was also found [Odessa Iron Meteorite].

An iron meteorite weighing 41·7 kg was found by some gold prospectors at Tieraco Creek, Western Australia. They took it to Meeskatharra but, thinking it was worthless, threw it away. It was found on the town rubbish tip by J. F. Connelly [Tieraco Creek Meteorite].

Archaeologists at the Mesa Verde Park, Colorado, found a 3·5-kg iron meteorite, while excavating a Hopewell culture site [Mesa Verde Meteorite].

An American farmer Jefferson Long (4 km northwest of New Baltimore, Pennsylvania) ploughed up a 20-kg iron meteorite [New Baltimore Meteorite].

A 20·4-kg iron meteorite was ploughed up in a field 5 km southwest of Glasgow, Kentucky [Glasgow Meteorite].

1822

February 6: A partial lunar eclipse was visible from the Far East, the Americas, Europe, and Africa [Saros 111].

February 21: An annular solar eclipse was visible from the North Pacific and north-western North America. The partial phase could be seen from the North Pacific and North America [Saros 137].

April 3: Birth of Edward Everett Hale, an American writer, who wrote *The Brick Moon* (1869). This was the first description of a manned space station; he died in 1909.

April 16: Birth of Karl Theodor Robert Luther, a German professional astronomer at the Berlin Observatory and then at Bilk Observatory, near Düsseldorf, where he discovered 24 asteroids from (17) Thetis in 1852 to (288) Glauke in 1890, keeping many of them under constant observation; Associate of the RAS 1854; died 1900.

May 12: Jean Felix Adolphe Gambart (Marseilles, France) discovered a comet low in the northwest sky at sunset. The comet was just visible with the naked eye and was independently discovered by a number of astronomers over the next few nights. It brightened at the beginning of June but was last seen on June 22, as it moved into twilight. Perihelion had occurred on May 6 ($q = 0{\cdot}504$ AU) [Comet C/1822 J1 (Gambart)].

May 31: While searching for Encke's comet, Jean Louis Pons (La Marlia, Italy) discovered a nebulous object in Pisces. The comet remained faint, as it moved south, and was last seen from Europe on June 13. On June 18 William Robertson and Charles Drinkwater, on board HMS *Creole* in Rio de Janeiro harbour, observed the comet and made measurements of its position until June 25. It reached perihelion on July 16 ($q = 0{\cdot}847$ AU) [Comet C/1822 K1 (Pons)].

June 2: Johann Franz Encke had identified the comets of 1786, 1795, 1805, and 1818 as apparitions of the same comet. He predicted that it would return in May 1822 and searches were made from the beginning of the year. It was finally recovered by Christian Karl Ludwig Rümker (Parramatta, New South Wales) close to the predicted position. During June William Robertson and Charles Drinkwater, on board HMS *Creole* at Rio de Janeiro harbour, described it as a circular nebula without a tail. The comet had reached perihelion on May 24 ($q = 0{\cdot}346$ AU) and was last seen on June 29 [Comet 2P/1822 L1 (Encke)].

June 3: A very bright meteor was observed from Angers and nearby Poitiers, followed by a loud detonation. A large number of stones fell, but only two were retrieved, consisting of about 1 kg of L6 chondrite material [Angers Meteorite].

July 3: Charles Babbage published a proposal for a difference engine to calculate logarithms and trigonometrical functions, vital for creating astronomical ephemerides.

July 13: Jean Louis Pons (La Marlia, Italy) discovered a very faint comet in Cassiopeia. It was also discovered by Jean Felix Adolphe Gambart (Marseilles) on the 16th, and Alexis Bouvard (Paris) on the 20th. They followed the comet as it moved to Cepheus and Draco. Other astronomers began observations from August 19, as news finally spread. The comet could be seen with the naked eye showing a tail 2 degrees long in September. Detailed observations continued into October, as the comet reached perihelion on October 24 ($q = 1{\cdot}145$ AU); it was last seen on November 11 [Comet C/1822 N1 (Pons)].

August 3: A partial lunar eclipse was visible from the Americas, Europe, Africa, and most of Asia [Saros 116].

August 13: Birth of Heinrich Ludwig d'Arrest, a German astronomer, who was working with Johann Gottfried Galle, when he discovered Neptune in 1846. At the Leipzig and Copenhagen Observatories he discovered comets C/1844 Y2 (d'Arrest), 6P/1851 M1 (d'Arrest), and C/1857 D1(d'Arrest), and asteroid (76) Freia in 1862; awarded RAS Gold Medal 1875; died 1875.

August 16: A total solar eclipse was visible from Northern Australia and the South Pacific. The partial phase could be seen from the East Indies, Australia, and the South Pacific [Saros 142].

August 19: Death of Jean-Baptiste-Joseph Delambre. Born in 1749, he was a French mathematician and astronomer, who studied under Joseph Jérôme de Lalande (1732–1807). He calculated an early orbit for Uranus and was part of the survey team to measure the Prime Meridian through Paris. A senior member of the French scientific community, he published vast quantities of astronomical and geodetic data.

August 25: Death of Sir (Frederick) William Herschel. Born in Hanover in 1738, he moved to England as a musician in 1757. He began constructing telescopes for sale in Bath and in 1772 was joined by his sister Caroline Lucretia (1750–1848). In 1779 he began sweeping the sky, eventually finding 848 double stars. On 1781 March 13 he spotted what he thought was a comet but turned out to be the planet Uranus. He was elected to the Royal Society and awarded the Copley Medal. Given the title the King's Astronomer, he moved to Datchet in 1782, Windsor in 1785, and finally Slough in 1786. He built his 19-inch reflector in 1782 and then the 48-inch in 1788, which appears as the emblem of the RAS. In 1784 he drew a cross-section of the Milky Way with the Sun off-centre. He discovered Uranus' moons Oberon and Titania in 1787 and Saturn's moons Mimas (1787) and Enceladus (1789). In 1800 he detected infrared radiation in the solar spectrum He published a catalogue of 2400 nebulae and clusters in 1802 and 5000 objects in 1820; knighted 1816; President of the RAS 1821–2. As well as his sister Caroline, his son John (1792–1871), grandsons and great-grandsons became astronomers.

September 11: The Roman Catholic Church permitted Galileo's *Dialogue Concerning the Two Chief World Systems* (1632) to be taken off the *Index*. It could finally be published officially.

September 13: A bright meteor broke up over Épinal, France, and fragments of rock with a blackened crust landed. About ¼ kg of H5 chondrite was recovered [Épinal Meteorite].

October 23: Birth of Friedrich Wilhelm Gustav Spörer. He studied at the University of Berlin, working on the orbits of comets, but in 1846 began a career in teaching. His main interest was the study of sunspots, noting their rotation and the differential rotation of the Sun. He discovered a lack of sunspots from 1645 to 1715 (now known as the Maunder Minimum) and another from 1460 to 1550 named after him (the Spörer Minimum). He was awarded the Valz Prize in 1885; Associate of the RAS 1886; died 1895.

A meteorite landed near Imilac, Chile. Weighing 920 kg, it was a rare example of a Pallasite [Imilac Meteorite].

1722

January 2: A total lunar eclipse was visible from Europe, Africa, Asia, and North America [Saros 120].

January 17: A partial solar eclipse was visible from Antarctica [Saros 146].

June 13: A partial solar eclipse was visible from the South Pacific [Saros 113].

June 29: A total lunar eclipse was visible from the Americas, Europe, and Africa. Maximum totality lasted 62·7 minutes [Saros 125]. Captain Bartholomew Candler, commander of HMS *Launceston*, observed the entire eclipse from Port Royal, Jamaica. Edmond Halley (Greenwich) was clouded out, but Christfried Kirch (Berlin Observatory) was able to obtain timings for the beginning of the eclipse.

November 2: Death of Captain Benjamin Candler. He was a Royal Navy officer, who surveyed the coastline of Hispaniola (present day Haiti and the Dominican Republic) and observed the total lunar eclipse of 1722 June.

December 8: An annular solar eclipse was visible from the coast of North America and Northwest Africa. The partial phase could be seen from the eastern half of the Americas, Europe, and the northern half of Africa [Saros 118].

December 22: A partial lunar eclipse was visible from Europe, Africa, Asia, and North America [Saros 130].

Birth of Thomas Barker, grandson of William Whiston (1667–1752). He was a British meteorologist and astronomer, who wrote *An Account of the Discoveries concerning Comets* (1757); died 1809.

Edmond Halley, as Astronomer Royal and member of the Board of Longitude, began a 19-year study of the Moon's motion, which he completed in 1741. He was attempting to solve the problem of mariners finding their longitude accurately.

1622

January 28: Birth of Adrien Auzout, a French mathematician and astronomer, founder member of the Académie des sciences, who convinced Louis XIV to set up the Royal Observatory at Paris. He designed the filar micrometer to measure angular distances in a telescope; died 1691.

February 19: Death of Henry Savile. Born in 1549, he lectured on mathematics and astronomy at Oxford; endowed the Savilian Chairs of Geometry and Astronomy at the University of Oxford.

March 23: Birth of Lawrence Rooke, an English astronomer, who observed eclipses, the moons of Jupiter, and comets; Professor of Astronomy (1652–7) and Geometry (1657–62) at Gresham College, London; died 1662.

March 25: Birth of Thomas Streete. He created planetary ephemerides and in 1661 published *Astronomia Carolina* (*Charles' Astronomy*), which used Kepler's laws to model the Solar System; died 1689.

May 10: An annular solar eclipse was visible from Brazil and Central Africa. The partial phase could be seen from Central and South America, Africa, and Southern Europe [Saros 122].

May 15: Death of Petrus Plancius. Born in 1552, he was a Dutch mapmaker, who constructed terrestrial and celestial globes. In 1589 he included Crux Australis, Triangulum Australe, and Nubeculae Magellani (the Magellanic Clouds). He added eight constellations in 1612, including Camelopardalis, Monoceros, and Columba.

November 3: A total solar eclipse was visible from the Cape of Good Hope. The partial phase could be seen from East Africa, India, and Southeast Asia [Saros 127].

1522

March 12: A total lunar eclipse was visible from East Asia, the Pacific, the Americas, Western Europe, and West Africa [Saros 105].

March 27: A total solar eclipse was visible from Eastern Siberia. The partial phase could be seen from East Asia and the Arctic [Saros 131].

May Death of Johannes Werner. Born in 1468, he was a German mathematician, geographer, and astronomer, refining the Jacob's staff for measuring angular distances between objects and defining longitudes between two places by timing the beginning or end of a lunar eclipse.

September 5–6: Nicolaus Copernicus (Frombork, Poland) observed a lunar eclipse and recorded it in *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*). The total lunar eclipse was visible from the Americas, Europe, Africa, and Asia [Saros 110].

September 19: An annular solar eclipse was visible from Antarctica [Saros 136].

Birth of Hermann Witekind. He was professor of mathematics at Neustadt, wrote *De Sphaera Mundi et Temporis Ratione Apud Christianos* (*On the Sphere of the World and the Calculation of Time Among the Christians*), and mentioned the use of machines to represent the movements of the planets; died 1603.

Johannes Werner's work on conic sections was published.

1422

August 22: Portugal stopped using the Spanish era for their calendar in favour of the Anno Domini system.

(about) Birth of William Caxton. His invention of the printing press using movable type revolutionized Western arts and sciences, including astronomy; he died in about 1491.

1322

November 4: An aurora was seen.

1222

September 2: Korean astronomers discovered a bright comet in Ursa Major with a tail 3 degrees long. It was found by observers in Japan, China, Europe, Russia, and Baghdad in the next few nights. The comet brightened and its tail lengthened to 20 degrees. It was even seen during daylight. The comet moved quickly east through Boötes, Virgo, and Libra. It gradually faded and was last seen on October 8. Philip Cowell and Andrew Crommelin calculated the orbit of Halley's comet before the return in 1910. They confirmed that this was a previous apparition. It was closest to the Earth on September 5 (0·313 AU) and reached perihelion on September 28 ($q = 0{\cdot}574$ AU) [Comet 1P/1222 R1 (Halley)].

September 9: Korean astronomers observed Venus during the day, while following Halley's comet.

Abu al'Abbas ibn Ishaq al-Tamimi al-Tunisi [Ibn Ishaq], a Moroccan astronomer, published a table of solar positions.

Ibn al-Banna published *Minhaj*, a table of solar positions.

1122

January 10: The Chinese saw a very large sunspot, recording that "within the sun there was a black spot as large as a plum."

March 24: Cosmas Pragensis (Prague, Bohemia) recorded a lunar eclipse. This was a partial lunar eclipse seen across the Americas, Europe, Africa, and Asia [Saros 108].

April 4: A meteor shower was recorded in *Annales Seligenstadenses*.

December 7: An intense auroral display was observed. "There were many sailors on sea and on inland waters who said that they had seen a great and extensive fire near the ground to the northeast which continually increased in width as it mounted in the sky. And the heavens opened into four parts and fought against it as if determined to put it out, and the fire stopped rising upwards. They saw the fire at the first streak of dawn until full daylight."

1022

April 24: Chinese astronomers saw seven bright meteors crossing slowly across Crater. They appeared in the southern sky at midnight.

922

Death of Abul Abbas al-Fadi ibn Hatim al-Nairtzi [Anaritius]. Born in about 865, he was a Persian mathematician and astronomer who wrote on atmospheric phenomena and a treatise on the spherical astrolabe.

822

February 6: Ukit Took' became the last *ajaw* of Copan. As a Mayan priest-king, he was responsible for observing the sky for the calendar and religious ceremonies. His reign and the independence of Copan had ended by 830.

February 7: The Chinese observed a conjunction of Mars and Jupiter, which were less than one degree apart.

June–July: The Chinese saw a comet near the Pleiades, which was visible for ten nights.

722

August 19: Japanese astronomers discovered a nova near δ Cassiopeiae, which remained visible for five nights.

September 12: The Japanese observed a conjunction of Venus and Jupiter.

622

February 1–2: George of Pisidia (Constantinople) recorded that there was a lunar eclipse. The eclipse was total over the Americas, Europe, Africa, and Asia [Saros 82].

522

March 3: The Chinese observed a close conjunction of Jupiter and η Virginis.

June 10: The Chinese observed a total solar eclipse from Chien Kang. The eclipse was total over Southeast Asia, Southern China, Japan, and the Pacific. The partial phase could be seen from most of Asia, the East Indies, the Pacific, and western North America [Saros 84].

July 4: The Chinese observed Jupiter occulting η Virginis.

Autumn: Chinese astronomers reported that "in the south of the dwelling place of the emperor's father, there appeared on several occasions the strange scene of the red light and the purple clouds." This appears to be a sequence of very intense auroral displays or could be related to stratospheric clouds caused by a major volcanic eruption in the East Indies.

422

March 26: Chinese astronomers discovered a 'sparkling star' in the morning sky in Aquarius. At Constantinople "there appeared in the sky a star which emitted a ray exceedingly long and white". The comet was seen in the morning sky in March and remained visible for ten nights. The Chinese followed the comet, as it moved into Cygnus and passed Altair in Aquila. Despite the detailed observations, no orbit could be calculated [Comet X/422 F1].

August 8: Birth of 11 Rabbit, *ajaw* of Palenque (435–87). As a Mayan priest-king, he was responsible for making astronomical observations for the calendar and religious ceremonies; sacrificed 487.

December 18: The Chinese discovered a second 'sparkling star' in the Square of Pegasus. The comet appeared in the evening sky and moved across the northern sky to the Plough.

322

March 11: Ma Tuan Lin recorded that Chinese astronomers observed a large spot on the Sun.

November 6: The Chinese observed that "there was a black spot within the sun". Solar activity was near maximum.

222

November 4: Chinese astronomers discovered a 'guest star' near γ Virginis. This object appeared in the morning sky and may have been a tailless comet or, less likely, a nova.

Death of Bardaisan [Bardesanes]. Born in 154, he was a Syriac scientist, astrologer, scholar, and philosopher.

On the death of the Roman emperor Elagabalus, the new emperor Severus Alexander sent the Sacred Stone of Emesa, a large meteorite found in the desert in prehistoric times, back to Syria.

AD 22

November–December: The Chinese observed a comet in Hydra for five nights, as it moved into morning twilight.

79 BC

The Roman writer and politician Marcus Tullius Cicero travelled to Athens to study philosophy. At Rhodes he met the philosopher and astronomer Posidonius.

279 BC

(about) Birth of Chrysippus of Soli. He was a Greek philosopher and astronomer, studying in Athens and head of the Stoic school of philosophy (232–207 BC). His cosmology of nested spheres for the fixed stars and the seven planets dominated Greek cosmology; died 207 BC.

479 BC

The Greeks set up a monument at Delphi following the defeat of the Persians at the Battle of Plataea. This iron pillar was later taken to Constantinople (present day Istanbul). Its lack of corrosion would strongly suggest a meteoritic origin.

OBITUARY

Roger Francis Griffin (*1935–2021*)

When Roger Griffin passed away on 2021 February 12 the astronomical world lost an astute observer, a gifted instrument-user and adjuster, a deep intelligence of things astrophysical, an encyclopædic knowledge of bright stars, and a compulsive proof-reader.

The formative years

Roger was born near Banstead, in Surrey, just beyond the outskirts of the spreading metropolis that was London. His parents were rather elderly, and neither was in academia. His mother had been a school-teacher in Brighton until her marriage, when the conventions of the day expected (if not required) her to relinquish her position. His father was secretary to a small company a few miles away in Sutton, and commuted by bicycle in all weather, even when nearing retirement. The Edwardian characteristics that were thus foundational in parental attitudes and mannerisms naturally shaped those of the children (Roger had a brother two years his junior), and stood him in good stead for the formal document-writing which his later academic life would require.

Roger's early years were restricted by wartime privations, though the nation-wide blackout offered him a singular advantage as it permitted unusually dark skies on clear nights and encouraged his first interests in the night sky. When invited to a birthday party at age 7 he disdained the fun and games that attracted the others and spent the time behind the sofa, deep into a copy of *The Splendour of the Heavens* (Hutchinson, 1923). His gracious party hosts gave him the book to take home, whereupon he announced that when he was old enough he would become an astronomer.

Even as a child Roger was developing an urge to accumulate 'data'. When confined to his bedroom for some weeks with scarlet fever (aged 6), he observed the times at which buses passed the house and applied faultless logic to divine the schedules for the route. That urge sparked a fascination in the London Underground too. From Morden station — the nearest — he would purchase a ticket to the next one but actually travel all around the system without passing through an exit, one aim being to determine the depths of the stations by counting the number of stairs between street level and platform. He displayed the information on an extensive map.

Roger attended local infant and junior schools during those years of WW II, and at age 11 obtained a scholarship to Caterham School, about 12 miles away. There he flourished, maintaining excellent grades throughout, gaining the School's top academic award and winning (in 1954) a Major Open Scholarship to St. John's College, Cambridge. A school contemporary described him as "quick, bright and highly charged, always busy about something with intensity"; he also displayed the unusual talent of walking the length of the school gym on his hands. Gifted with a strong musical aptitude and a liking for playing hymn tunes on the piano, he would accompany the school's morning assembly, occasionally playing jokes by notching the hymn's key up a semitone until even the headmaster thought it was "over the top". He was also developing an ability to conjoin his visual acuity with a manual dexterity that was to stand him in good stead as his efforts gained a more scientific focus. He created stage amenities, including a professional-standard lighting system, for the school's dramatic productions, built a rain-gauge that displayed its results on a moving chart, and kept meticulous weather records. He also built a 6-inch reflecting telescope, grinding the mirror by hand from a thick glass disc and constructing the mechanical parts for its stand, complete with illuminated dials, by incorporating gears from war-surplus hardware that could then be purchased cheaply. He made observations of variable stars and communicated his results to the BAA. From age 13 he was permitted 'day release' from school in order to attend BAA monthly meetings in London.

One technical skill that was born at Caterham School was woodwork. He learned to apply his naturally good eye–hand coordination to advantage, and in later life created many highly acceptable pieces of furniture, from the large and practical (including a family-sized dining table and a stout, glazed front door) to small boxes to hold index cards for his astronomical observations. Being ambidextrous, he would use his right hand for pens and pencils since the conventional etiquette of the times expected it, but took up a chisel or saw with his left hand when close accuracy was needed.

Not very enamoured of formal sport (ball games were rendered difficult if not dangerous by his need to wear glasses, acute short sight being a legacy of scarlet fever), he did on occasion go running, and as a Cambridge student he accepted a challenge (made in jest) to run the University's annual Boundary Run, the equivalent of a marathon but much of it on soggy ploughed fields. In fact the challenge stuck, and two years later he 'won' the race (though it was never intended as competitive), and he continued to run marathons, or long-distance training, until he was 78, when he ran the last of his 11 London Marathons, always shining near the top of his age group.

Roger's undergraduate years at St. John's College (Cambridge) were a mixture of the required and the chosen. The Observatories provided a ready outlet for his astronomical energy; he gained permission to use one of the telescopes in order to continue his programmes of variable stars, and to that end he would literally climb out of College on fine nights (in those days the colleges were gated after 11 pm) and cycle to the Observatories for a night of scientific data-gathering, suffering winter cold gladly (down clothing was not then in vogue, nor would his wallet have stood it). His interest in geography, triggered by the teaching of an eminent geographer at Caterham School, found its roots in studies of geology, which he selected as an ancillary in the Natural Sciences tripos; he created a geological map of the Isle of Arran, and for many years it was on display in the Department of Earth Sciences. He found or made time to study diligently, receiving awards for tripos performances in the first and second years, and an upper-second-class degree at the end, qualifying for a research studentship at the Observatories.

Elected to a College Research Fellowship for 1962–65 and able to live in College, Roger provided a friendly sanctuary, with coffee and biscuits, for undergraduates who could be persuaded to join him on runs or circuit training and also support the College's religious life. Brought up in the Church of England tradition, he continued to observe its ethics firmly though gently. However, his decision to be teetotal did not arise from any moral convictions; rather, the unpleasant effects that he observed alcohol to have upon young men freshly escaped from home clutches inspired him to vow never to touch it.

The creative years

Post-graduate years at the Cambridge Observatories offered his fertile intellect a cornucopia of opportunities, the support of a well-equipped and staffed workshop, an electronics lab, and a Director (Professor R. O. Redman) who was himself a keen experimentalist. Redman was a staunch realist, his motto being, “do what science you can with what you’ve got”. Given Cambridge’s unreliable weather, Redman developed a scheme of ‘narrow-band photometry’ in which the absorption corresponding to a specific feature or features in a stellar spectrum was compared to that in a relatively clear region nearby. Comparisons of those ratios with ones obtained for standard stars could reveal correlations, if any, with temperature, luminosity, or space velocity in evolving stars, and thus avoid the need for absolute photometry. Despite struggling with post-war stringencies, the Cambridge Observatories (latterly the Institute of Astronomy) had gained funds for a major refurbishment which included a 36-inch reflector that was brought into service in 1955 (Redman, *QJRAS*, **1**, 10, 1960). Over time, Roger was to become its sole and persistent user; from 1967 he lived a mere 5-minute cycle ride away and could (and often did) observe on many a partly clear/cloudy night.

1. *The first spectrometer*

The subject of Roger’s PhD thesis (Cambridge University, 1960) involved the application of narrow-band spectroscopy of the blue CN band at λ4200Å and the λ4300Å G-band in late-type stars. Although only small dependencies were uncovered (*MNRAS*, **120**, 278, 1960), the experience gave ample opportunity to identify sources of random and systematic errors arising from how the telescope’s spectrometer had been conceived. His PhD research therefore included the design of an improved spectrometer which corrected or ameliorated many of the faults of its predecessor, and which it then replaced permanently. His measurements with it of line-strengths of the λ5250Å Fe I triplet and the Na *D*-lines in 111 and 103 G and K stars, respectively, revealed a strong correlation between Fe I-line strengths and luminosity that favoured its adoption as a luminosity criterion, though the *D*-line widths exhibited intrinsic variation from star to star that masked any underlying correlations (*MNRAS*, **122**, 181, 1961).

2. *Stellar radial velocities*

Tea at the Cambridge Observatories was a daily observance that gave the (few) students the opportunity to hear ideas and projects discussed by the (also few) permanent members of staff. One of the latter was Peter Fellgett, whose lively intellect suggested theoretical ideas for solutions to a broad range of scientific topics, among them the possibility — even in those pre-computer years — of applying cross-correlation to measure stellar radial velocities (Fellgett’s ideas stopped short of experimentation, though he was — as Roger quipped — by no means silent on the possibility). The timing here was of the essence. After obtaining his PhD in the latter half of 1960 Roger was awarded a Carnegie Fellowship for 1961 to work at what was then known as the Mount Wilson and Palomar Observatories in Pasadena (California), and with no obvious strings attached concerning the nature or topic of the work he might undertake. The conviction lingered that the method of cross-correlation could be successful if properly nurtured, and by the time he returned to Cambridge (and a junior staff position) in 1962 he had resolved to develop it himself. Close familiarity with the features of the coudé focus of the Cambridge 36-inch during his construction of its new spectrometer only two years earlier offered plenty of scope for thinking, planning, and designing.

The basic elements of the new spectrometer were already suitable, if not everywhere optimal, for the radial-velocity instrument that Roger planned. At its focus was a physical mask (or 'diaphragm', as it was usually called) that could pass or block features of a star's spectrum by design, and since the RV of a star caused the star's spectrum to be shifted *in toto* then he would need to scan the diaphragm past the observed spectrum and to record or display the moment of coincidence (manifested by a 'dip' in transmitted light) relative to a similar 'dip' obtained for a standard star. A complete overhaul of the camera end of the instrument was carried out, incorporating the innards of a large domestic refrigerator to cool the photomultipliers that measured the amount of light passing through the diaphragm — the nub of the whole instrument. By October of that year Roger succeeded in obtaining a signal that could meaningfully be described as a 'dip' when scanning the spectrum of a late-type star, but that was only the start of his final success; the dips had small amplitudes and would be barely detectable for faint stars, and so began the real meat of the task: to optimize the throughput of the whole assembly. The core of the problem lay in optimizing the diaphragm, which was initially a 4-cm piece of a photographic spectrum of Arcturus. There was space for the diaphragm to be 15 cm long, which would help a great deal, but it was the *contrast* of its spectrum that proved to be key. Rather than allowing the diaphragm to accept all the stellar features, he experimented first with eliminating blends, and then with ultra-high contrast ('soot and whitewash'), with a growing conviction that he was on the right track but still far from having the solution near to hand. The Observatories had a digitizing microphotometer whose carriage positions were displayed by a moiré-fringe device, and having first recorded manually the readout positions for prominent dark lines and continuum he placed a photographic plate on the microphotometer carriage and moved it slowly along, turning on or off a lamp that had been inserted behind the analyzing slit when the positional readouts were appropriate, and thereby exposed the plate to a kind of pseudo-spectrum. Though a wearisome task that took a great many hours in those pre-computer days, it paid off handsomely, and from then on he could obtain good cross-correlation dips for stars of 7th or 8th magnitude.

Although the machine was still an experiment in progress, he was confident that he would soon to have a full working prototype. Redman, who knew to his cost the difficulties of measuring stellar RVs accurately by the conventional photographic method, even on plates taken with a telescope twice the size of the Cambridge one (*viz.*, the DAO 72-inch), promised a magnum of champagne if he (Roger) could (as he was now hinting) measure 50 9th-magnitude late-type stars to a precision of 3 km/s in one night. It was another challenge that Roger couldn't refuse. Further optimizations of the RV diaphragm were made, one being to generate a diaphragm of the full 15-cm capacity and promising another magnitude in sensitivity; another was to fabricate a camera lens large enough to accommodate such a diaphragm. Creating a lens that would receive all of the much longer spectrum while also fitting faithfully the steep curvature of the camera's focal plane was a research exercise in itself, as it was very unlikely to find such lens on the shelf, and a customized product would be prohibitively expensive. Since its duty was only to collect light rather than to focus very cleanly on details, Roger obtained a large block of perspex, turned it to the necessary plano-convex shape on a lathe, and polished it using a household brass cleaner. The result was surprisingly good, its aberrations adding no more than about 1 mm to the diameter of the image that it produced on the photocathode.

The rest of that particular story is history, yet not the simple history that one might expect from such a drastic improvement to the task of measuring stellar RVs. The magnum of champagne was duly won, and Roger set about publishing the results of his efforts; a description of the RV spectrometer (*ApJ*, **148**, 465, 1967) was followed by a discussion of how the zero errors of the instrument were determined and applied (*MNRAS*, **145**, 165, 1969), and then followed sets of results (*e.g.*, *MNRAS*, **148**, 211, 1970) for a wide variety of programmes. But Roger was dogged by refereeing difficulties that often became protracted; his style of writing tended towards full and flowing, to some extent influenced by the style of Churchill (whose books about WW II he had read extensively in his earlier years), and he also sensed an underlying unease among those more established in the field that a relative junior should develop a method that was considerably more efficient than theirs and offered uniformly high precision. From Roger's viewpoint it was as if the community of RV measurers was unhappy to find that this new tool, which employed novel methodology (spectrum cross-correlation) and even hand-made components (a domestic refrigerator and a hand-turned perspex lens), could so upstage the arduous methods that had satisfied previous generations of observational astronomers. In his efforts to convince the astronomical world that his method was going to stand the test of time, and having failed to impress his peers adequately by producing RV orbits for some of the IAU standard-velocity stars, he decided to publish an SB1 orbit for as many of the spectroscopic binaries as his routine observing had discovered, or which he had followed and improved. Thus began the *The Observatory* series of *Spectroscopic binary orbits from photoelectric radial velocities*, his intention being to publish one orbit in each issue of the *Magazine* for as long as he had enough material to continue or until he was no longer able to maintain the work. However, by the time Paper 150 was in print he reckoned it unlikely that his large store of matured orbits would be exhausted at that rate, so he began publishing two, and eventually several, objects per paper. That style continued until 2018, but dwindled rather sadly to the final three publications (papers 263 to 265) in 2018–2019. His analyses were comprehensive: more than a mere list of RVs and the orbital elements which they supported, they presented a history of past observations, and the astrophysics which the orbital elements suggested, including predictions of the likely nature of the secondary or tertiary components and any possible eclipses which fitted his models. Roger used to remark jokingly that if an issue of *The Observatory* were to appear without including one of his SB papers his wife would start receiving flowers of condolence. In the end it wasn't flowers, but several kindly messages from concerned readers did arrive.

3. *The Palomar RV spectrometer*

In late 1970 Jim Gunn (then at Caltech) suggested that he and Roger collaborate to build an RV spectrometer for the Palomar 200-inch coudé (*ApJ*, **191**, 545, 1974). They made a formidable pair, Jim applying his abundant data-handling skills while Roger was in his element managing the mechanical department. Although the two parts were developed independently on different sides of the Atlantic, and communications were frustrated by an extensive postal strike, nevertheless when they were brought together four months later on the 200-inch the instrument worked first time as intended. One novel feature was a means of assessing the presence of 'Doppler mismatch', as was likely when switching observations to star clusters with large intrinsic velocities. By incorporating an array of ten shutters, different regions of the diaphragm could be isolated and the positions of the individual 'dips' checked for any disparity.

In true style Roger used Meccano motors to operate the shutters, their selection being accomplished by Jim's software. Roger greatly enjoyed working with 'the Big Eye', and Jim recalls how, on one night when incoming clouds had cut short even work on bright stars, Roger had insisted on observing Arcturus, to look for small RV variations and to check the instrument's zero, and refused to give up until the counting rate (and this a 200-inch telescope) had dropped to one photon per second. Observing time was infrequent because of high competition, so they settled on the Hyades cluster as their main target, first cleaning up the many different published records of members and possible members, identifying and analyzing numerous new binaries and multiple systems, and determining a precise distance modulus for the cluster — an important scaling quantity in Galactic physics — of 45·3 ± 2·3 pc which strongly consolidated the then current astrometric solutions and confirmed the need to update the traditionally accepted value of about 40 pc. When that project needed only a few more nights to complete it Roger explained the situation in his application to the Time Allocation Committee, only to be told, "You've done extremely well; you don't need any more data"!

The benefits of using cross-correlation to measure stellar RVs were gradually becoming accepted by the astronomical community, and brought Roger a few accolades: a five-year Mr. & Mrs. John Jaffé Research Fellowship of the Royal Society in 1965, and the Jackson-Gwilt Medal & Gift of the Royal Astronomical Society in 1980. Eleven years later, when his series in *The Observatory* had reached Paper 100, a conference was held in his honour in Switzerland. In 1971 Roger was approached by Michel Mayor (Geneva Observatory) asking whether he might scrutinize the operation of the RV spectrometer over a period of a month, as Geneva was hoping to build a similar but more mechanized version. The outcome was the *Coravel*, a popular and highly productive instrument. Then for a number of years, when his original Cambridge one was no longer competitive and was placed in the Science Museum, Roger had to rely on using other RV instruments upon request — chiefly the Geneva one, at l'Observatoire de Haute-Provence (France). In due course a group at University College London created their own version of the *Coravel* for use at Cambridge, and after some protracted local problems it was brought successfully into service in 1999.

4. *The Arcturus Atlas*

Another project, to which Wal Sargent (Caltech) introduced him at Mount Wilson in 1961, was high-dispersion photographic spectroscopy. This was a completely new direction for Roger at the time, but he excelled in the practical skills of adjusting a spectrograph correctly — even one of that vintage — and appreciated the aesthetic appearance of a late-type stellar spectrum well exposed and correctly calibrated. Until then the Utrecht *Photometric Atlas of the Solar Spectrum* by Minnaert, Mulders & Houtgast (1940) was the only major comprehensive atlas of any star; the Liège Solar Atlas by Delbouille & Roland (1963) was still two years away. Roger saw an opening for a photometric atlas of the spectrum of Arcturus, and commenced acquiring the necessary spectrograms in 1961, using a microphotometer at Caltech that was connected to an electro-mechanical 'curve-follower' to convert input densities measured on the spectrograms into direct intensities, and plotting the output onto 'Brown Recorder' charts. The tracings were thus linear in intensity but not in wavelength, though at the dispersions of 0·75 to 1·5 Å/mm that were involved the non-linearity changed only slowly along each plate (of length of approximately 150 Å). Further spectra were acquired in 1963, partly to provide a set of more even exposures and partly to knit the various plate joins neatly. The raw material was measured and analysed by a PhD student in Cambridge from 1963–66. Roger selected the best-looking tracings of each 15- or 20-Å region (depending on the dispersion) for publication (in 1968) in a loose-leaf binder; it was an immediate success, and still is popular.

The *Arcturus Atlas* was followed by the publication of the *Procyon Atlas* in 1979 — similar in concept and outline, and again based purely on Mount Wilson 100-inch coudé spectra, but significantly different as it was generated from digitized spectra. The wavelength scales, as well as direct intensities, were linear, and the tracings (except those showing telluric features) were formed by co-adding spectra. It was published by its authors, who personally fulfilled orders by sticking on postage stamps to the correct value, sometimes selecting enough of just the green and red penny and halfpenny stamps in order to write "α CMi" on the parcel. One recipient had the imagination to acknowledge his copy by writing "Ta!" in the same stamp combination on the envelope containing his letter of thanks.

Familiarity with the details of the Mount Wilson 100-inch coudé spectrograph led Roger to investigate its profile, as used in the *Arcturus Atlas*, by shining a laser down the polar axis and into the spectrograph and building a comprehensive map of the profile through exposures of different lengths. His diagram (*MNRAS*, **143**, 341, 1969) of the line wings and of Rowland ghosts (arising from irregularities in the rulings of the 144B [Babcock] grating) constitutes a scholarly and exhaustive examination of that grating–spectrograph combination, and the conclusions which he was able to draw, particularly in regard to the percentage damage by which the wings modify any measured equivalent widths, constitute a masterpiece. He was able to reproduce the profiles of the telluric oxygen bands faithfully as a test of the accuracy of the derived profile, and went on to determine the instrumental profiles of the Utrecht and the Liège Solar Atlases, though the Dutch unfortunately regarded his effort as misconceived.

5. *Precise stellar RVs*

A key innovation — this time a theoretical suggestion — that Roger made in 1973 (*MNRAS*, **162**, 243 and 255) was the assurance that one can measure stellar radial velocities to a precision of 10 m/s, given suitable pre-conditions. The catalyst was the use of superimposed telluric lines on high-resolution (red) spectra of Arcturus and Procyon for determining wavelength scales from measurements made with a Grant measuring machine. The novel use of the telluric spectrum as the fiducial reference gave rise to experiments elsewhere that settled on iodine as near to the ideal substitute, and encouraged projects in Australia, the USA, and Switzerland to build spectrometers that were optimized as far as possible in accordance with Roger's list of desiderata. The world then began to see indisputable evidence that a great many stars were orbited by planets, initiating whole new sub-disciplines to determine their masses and look for correlations between the properties of the planets and the element abundances in the atmospheres of the host stars (as a way of identifying readily the most likely sources to investigate). One has only to consider *Kepler* to appreciate the enormous scientific wealth which this new industry has generated. Yet remarkably few people recall that it was Roger who instigated it. A poster entitled *Roger F. Griffin, Grandfather of Modern Stellar Radial Velocities* on display at the Telc (2019) international conference, 'Universe of Binaries', chronicled Roger's achievement as the originator both of the *Coravel*-type spectrometer and the technique of high-precision RV measurements. It seemed high time to remind the astronomical community just who was responsible for those pivotal advances.

6. *Other associated activities*

(*i*) Eclipses of γ Persei

One of Roger's interesting contributions to knowledge *per se* is his discovery, through the application of his own high-precision RVs, that the well-known binary γ Persei (V = 2·9) undergoes eclipses (*IAPPP*, **57**, 31, 1994); in fact, totality lasts some 8 days, with falls of 0·28 mag in V and 0·54 mag in B. The long period of 14·5 years meant that its visual dimmings were probably too infrequent to get noticed by camel-back travellers beneath pristinely dark desert skies, while the orbits from the earlier part of the 20th Century were insufficiently precise to nail down the timings of conjunction to the point where eclipses could have been predicted confidently. The unsuitability of modern detectors to observe such bright stars also acted against the discovery. The exploit that he arranged to observe the system's 'eclipse' conjunction in 1990 September was quite typical: he requested (and was granted) 'morning twilight' time on the Palomar 200-inch coudé for 24 nights centred near September 15, the date of mid-conjunction given by his current orbit; γ Per would not have been available much earlier in the night. Since Palomar no longer supported photographic spectroscopy he took his own developing and calibration equipment, and a box of unexposed photographic plates donated by Calar Alto Observatory (SE Spain) where he was observing up to the morning of September 7, whence he flew *via* Madrid to Los Angeles. He needed to resurrect the darkroom before he could do any observing, and recruited help only in locating pieces that seemed to have gone astray. He *did* get things set up in time in suitable working mode, and the eclipse *did* occur — within a day of his prediction. Fortune certainly favoured the bold. γ Per now ranks as the third brightest known eclipsing binary, the second being (interestingly) β Per. [γ Velorum, at V = 1·95, is the first. — Ed.]

(*ii*) Domes and internal seeing

Roger took a keen interest in topics bordering on the observations and the attendant research that kept him otherwise fully occupied. Observing with the Mount Wilson 100-inch, where the seeing — mostly attributable to the laminar flow of air across the Pacific — could equal or frequently better that experienced elsewhere, enabled him to study visually the structure and characteristics of the image seen in the guiding eyepiece, and to describe his deductions in recorded discussions. The lack of interior heating in the 100-inch dome (and also its double outer shell) contributed to minimize the interior seeing such as was plaguing other large telescopes, but when he offered advice as to how to combat the inferior situations suffered elsewhere with appropriate ventilation and fans he was ridiculed ("Griffin wants windows in the dome!"), only to be proven right later on.

(*iii*) Accurate positions of radio sources

Those first 20 years of Roger's scientific career were without question his most creative, though they brought with them a number of frustrations. In his year as a Carnegie Fellow he had channelled his efforts into two different projects. One was high-dispersion spectroscopy (described above); the other was a programme to measure the optical positions of star-like images on certain Palomar Schmidt plates. This was the era of attempts to refine the celestial positions of radio sources, in the hope of identifying at least some with optical objects. The Cambridge 3C Catalogue was fresh off the press, so Roger spent part of his Pasadena stay measuring carefully-selected overlapping plates and learning how to determine both the positions and the associated errors of the images that he identified as of possible further interest — a major sub-discipline in itself. His results were written up when he returned to Cambridge, but although several colleagues expressed satisfaction and encouragement over the usefulness of what he had measured, the same could not be said for the referees of his paper, summarily dismissing his work as coming from only a novice in the well-established field of astrometry. The paper was eventually published in an American journal (*AJ*, **68**, 421, 1963), but only after a great many revisions and trans-Atlantic mail and with most of the discussion removed. One result that Roger found to be particularly fascinating was the apparent identity of several of the radio sources with very compact optical images ... this was when quasars were about to be discovered. But again Roger, as a fresh post-doc, was uncharacteristically unargumentative, even though that particular fruit was well within reach of his own grasp.

(*iv*) Publications and refereeing

Many of Roger's publications revealed on-going collaborations with astronomers from a wide selection of countries and almost exclusively in the field of radial velocities. Occasionally he received requests for RV data, and usually he responded very fully, often declining offered co-authorship. However, a perusal of his 540 papers reveals how broad his interests actually lay, ranging from short-term changes in Arcturus and other late-type giants (*The Observatory*, **83**, 255, 1963), suggesting surface activity or the existence of star-spots), to discussions of the duration of twilight (*The Observatory*, **120**, 62, 2000) and the specifics of midday shadows (*The Observatory*, **94**, 316, 1974) — interesting collaborations with Brian Marsden — *via* upholding the status of Albireo as an astrometric double (*JRASC*, **93**, 208, 1999) and of Arcturus as a single object (*The Observatory*, **118**, 299, 1998), and defending the unlikelihood of ever understanding stellar atmospheres when it seemed impossibly difficult to understand, and forecast, that of the Earth (*The Observatory*, **89**, 120, 1969), for which observational data were far more abundant and enormously more detailed. Some of his book reviews were bitingly critical (*e.g.*, *A&SS*, **271**, 205, 2000, or *The Observatory*, **120**, 331, 2000), others were more subdued attempts to deliver the records from ambiguities (*e.g.*, *JBAA*, **111**, 46, 2001), and not infrequently he introduced rather pointed humour to soften the criticism (*e.g.*, *The Observatory*, **120**, 331, 2000 — this one is a real gem).

The later years

Roger's contributions to the science of astronomy have been major and unique. His *Arcturus Atlas* found its way into almost every observatory library and onto the desks of innumerable researchers engaged in stellar spectroscopy, his photoelectric radial-velocity instrument revolutionized the art of determining RVs to the point that — in his own words — "no-one would dream of going back to the old traditional method", and he planted the essential seeds that got the world looking for tiny RV variations that signalled the presence of planets orbiting their host stars.

In 1968, soon after the Cambridge RV spectrometer had been launched successfully, Roger was offered a staff position at the University of Groningen (the Netherlands) on the strength of it, but he declined. An analyst of his career would identify that refusal as a kind of Faustian pact: his preference to continue his work within his own comfort zone brought penalties that were only realized, and suffered, some decades later. By the time he turned 60, when he felt he could have been at the pinnacle of his remarkably productive career, he saw only denial and rejection on the home front. By opting out of the chance to attract students and gain wider admiration for his unquestionable expertise with equipment, he had instead become a personification of the adage that "a prophet is not without honour save in his own country". He fought endless battles against plans to extend sports facilities near the Cambridge Observatories, anticipating deleterious floodlighting on winter evenings, and deplored departmental expansions of office buildings that seemed (to him) to pass over the requirements of an operating observatory whose main telescope was the second-largest in the UK. The hesitant post-doc who had been too shy to argue his case even when he knew he was right had matured into a well-informed yet static scientist who felt victimized by the inexorable marches of progress that had the misfortune to impinge upon his life's work. Yet it was only when the spark of enthusiasm for continuing the latter well into his 80s was damped and then extinguished by Alzheimer's Disease (assisted rather cruelly by the isolation of Covid-19 lockdown measures) that he finally lost the zest to fight any longer.

Roger the man

Roger was a person of enormous determination, gifted with a near-encyclopædic memory, an alarming capacity for mental arithmetic, a zeal for economy that saw him reusing old bits and pieces in the instruments he constructed, and a ready willingness to take on anyone who might challenge him in the areas of his own expertise — be they active ones like running, or more intellectual ones like memorizing the HD numbers of all the binaries that he had studied, quoting verses from the Bible, writing English as she should properly be writ, outlawing split infinitives, grooming nouns of multitude, and perfecting a skill at proof-reading that easily outdid any competitor. That determination urged him to run London Marathons when nearing 80, to edit *The Observatory* magazine for 22 years (longer than anyone had previously done), and to publish a series of papers that was way longer than any previous series.

Roger was endowed with unquenchable energy — and mischief. He travelled widely out of interest, visiting South Africa's observatories with the aid of a Sir Henry Strakosch award in 1958; he concluded his Carnegie Fellowship with a side-trip to the Antipodes by ship, and hiked most of Tasmania on the way. He walked up Mount Kilimanjaro (with his elder son) when pushing 70, cycled (with the same son) from Land's End to John O'Groats in his late 50s, and cycled to Haute-Provence Observatory in the south of France three times for observing runs (once with his younger son then 17), and voluntarily taking in some of the high Alpine cols. In 1961 he went on sometimes hair-raising trips to USA's western National Parks in the company of four other British post-docs (including cooking Christmas lunch on a primus stove at the bottom of Meteor Crater); he had driven an old car across the North American continent five times, and had hiked in most of the National Parks of western USA. He seemed to sense that he was indefatigable, and would work for hours over delicate adjustments to stellar spectrographs. He understood without being shown how to adjust the collimation of the 100-inch telescope, and on one occasion he introduced a carefully calculated modification to the mesh of its sidereal worm-drive to correct a recent maladjustment that was causing damage. It was remarked at Mount Wilson that whoever followed Roger Griffin in the observing schedule would be favoured with an instrument that had been left in perfect adjustment. He also possessed an enviable ability to sleep almost anywhere, and for as long as permitted; he didn't believe he still had a 'body clock'. Some of that original zest (aptly labelled "persistent childhood"; it could be both charming and aggravating) was captured exquisitely by Alison Rose in her documentary, *Star Men* (a replay of some of the outings of those British post-docs 50 years earlier), as she incorporated Roger's more laconic phrases and portrayed sensitively his reaction to discovering that some physical ploys were actually becoming just a bit too demanding.

Roger's idols were the great observers of the past (E. E. Barnard, in particular, and W. H. Steavenson), and it is no exaggeration to suggest that he has now joined their ranks. — ELIZABETH GRIFFIN.

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Here and There

A NEW MOLECULE?

The team observed the signatures of several molecules in its atmosphere, including lithium. — *Scientific American*, **325**, 33, 2021.