THE OBSERVATORY

A REVIEW OF ASTRONOMY

EDITED BY

D. J. STICKLAND

R. W. ARGYLE

S. J. FOSSEY

P. J. HELBIG

Q. STANLEY

Vol. 145 No. 1305

2025 APRIL

THE OBSERVATORY

Vol. 145 2025 APRIL No. 1305

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 October 11 at 16^{h} 00^{m}
in the Geological Society Lecture Theatre, Burlington House

Mike Lockwood, *President*

Mark Lester, *Senior Secretary*
in the Chair

The President. Good afternoon, everybody. I'm not going to crack any jokes because I have a cracked rib and making myself laugh is a very painful experience. I am not going to chair most of this meeting because getting in and out of one of these seats is going to be awful. Mark Lester has kindly agreed to chair most of the meeting. This is a hybrid meeting and if you are on Zoom you will be muted. At the end of the talks please put any questions you may have in the Q and A and they will be read out by Dr. Pam Rowden. I am now going to depart so I will hand over to Mark Lester.

The Senior Secretary. Thanks, Mike. The first speaker this afternoon is Professor Roberto Orosei from IRA/INAF in Bologna. He is on-line today. He has a long history in space experiments including being a science-team member of *Rosetta* and *JUICE* as well as *Cassini*, *Mars Reconnaissance Orbiter*, *Dawn*, and *JUNO*. He is currently the principal investigator in the *MARSIS* radar on ESA's *Mars Express* spacecraft which provided evidence of the presence of liquid water beneath the surface of the south polar cap on Mars, and Roberto is going to speak about 'Unveiling the interior of the Martian polar caps with radar'.

Professor Roberto Orosei. Mars is a cold desert where temperatures rise above the freezing point of water for only a few hours a day at the equator. The atmosphere is mainly CO_2 and is very thin, with a surface pressure that is less than 1% that of the Earth. As a consequence, the surface is bathed in ultraviolet radiation and cosmic particles that would be deadly for life as we know it. There is ample evidence that things were different in the past, however, as images acquired since the 1970s by probes at Mars show landforms that are obviously related to the erosive action of water, such as rivers and lakes. Scientists studying Mars concluded that there had to be liquid water flowing on its surface in the past, as this would be impossible under the present climate. It has been thus postulated that Mars used to be a much warmer planet, and that water, given the ample evidence of its presence, must have been much more abundant than it is today. This suggested that life could have been possible on Mars, at least in principle.

Determining if life ever arose on Mars, given that its early conditions appear to have been similar to those of the Earth, is the fundamental goal of Mars exploration. Achieving this goal requires an understanding of the history of water, a large fraction of which is thought to have been lost in space over billions of years because of the weak Martian gravity. The lack of a global magnetic field and the resulting erosion by the solar wind further accelerated the loss of the atmosphere, which was probably much denser and capable of warming the planet through a greenhouse effect. If life ever arose on Mars, could it have survived somehow? Where could it be found today? Probably life could survive under current Martian conditions only in the subsurface. Because Mars is a terrestrial planet similar to the Earth, its interior is still warm and heat flowing from it heats the upper layers of the crust. The increase of temperature with depth eventually reaches the point where liquid water might persist in spite of the freezing cold at the surface.

How do we find this water, which would be the starting point for looking for habitats on Mars? A radar instrument, called *MARSIS*, was proposed for the first European mission to Mars, *Mars Express*, at the end of the last century. Radar waves are capable of propagating through solid materials, and this is the reason why we are able to use cell phones in a closed room, for example. The lower the frequency, the greater the thickness of the material that can be passed through by an electromagnetic wave. This technique is routinely employed on Earth for tasks ranging from finding buried pipes to detecting subglacial lakes, such as those discovered under Antarctica's and Greenland's ice sheets. A low-frequency radar orbiting around Mars was deemed capable of detecting water, which is a strongly reflective material at these wavelengths, down to depths of a few kilometres. After *MARSIS*, which is still in operation today, a second radar, called *SHARAD*, was launched a few years later on NASA's *Mars Reconnaissance Orbiter*.

Water on the Martian surface is frozen, and most of it is contained in the two polar caps. The northern one, called Planum Boreum, consists mainly of a geological unit called the North Polar Layer Deposits, or NPLD for short. Layers within the NPLD are made of a mixture of dust and ice in variable proportions. Contrary to what happens on Earth, where polar caps are almost exclusively made of water ice, Planum Boreum is thought to contain a percentage of dust comprised between 5% and 10%. Beneath the NPLD lies another geological unit called the basal unit, which could be the remnant of older, more ancient, and dustier icy deposits. The internal structure of the NPLD, shown in great detail in radar sections, is thought to result from climate cycles determined in turn by the oscillation of the spin axis of the planet. On Mars, in the absence of a large moon, the inclination of the axis of rotation can reach up to 45 degrees. This produces extreme variations of climate and causes changes in the composition of the material accumulating in the polar caps. During periods of high obliquity, the polar caps are exposed to sunlight for extended periods of time and are in fact sublimating, leaving behind a lag deposit of dust. The South Polar Layered Deposits, constituting much of the southern polar cap, have a similar structure but a greater dust content.

Early attempts at identifying liquid water with *MARSIS* were based on the search for very strong radar echoes from the sub-surface, as water is highly reflective at radar frequencies. These first efforts were unsuccessful, however, as alternative explanations for the origin of bright sub-surface reflections could be convincingly presented. After almost a decade of attempts, liquid water was finally identified at a depth of about one-and-a-half kilometres beneath the

South Polar Layered Deposits. Success came only after enabling data downlink without on-board processing, which we could do with great technical difficulty and for very short observations.

Sub-surface liquid water at the poles is difficult to explain, as the mean surface temperature is around 160 K. Even if this value increases with depth thanks to the heat flux from the interior of the planet, it is difficult to imagine that it can go up by more than a few tens of K over one-and-a-half kilometres. There are two factors that can explain the presence of liquid water, however. One is the presence of salts, ubiquitous on the surface of Mars, which can lower the freezing temperature by more than 60 degrees C. The other is a thermally insulating layer in the polar cap. The surface of the south polar cap is covered by dust that could be several metres thick, and we know that a loose dust layer possesses low thermal conductivity.

There is evidence in radar sections that liquid water is also affecting the evolution of the internal structure of the South Polar Layered Deposits, causing deformations in the stratigraphy due to differential ice sliding over dry and wet basal surfaces. Images also reveal morphologies on the surface of the south polar cap that have been interpreted as listric faults, and could again be indicative of differential ice sliding. Such indirect geological evidence for basal liquid water is found also in areas where no strong sub-surface echoes were detected. This could be explained by a change in sub-surface conditions over time, which would have profound implications for the survivability of habitats in the sub-surface of Mars. Although no conclusions can be drawn at this time, this evidence is suggestive of the important role that liquid water played in the evolution of the polar caps, and is begging for further investigation.

The Senior Secretary. Are there any questions in the room, please? We have one on-line at least.

Dr. Pamela Rowden. The question is from someone called P. "Is the pulse-repetition frequency tuneable, for instance, to resolve interference between reflections from different materials and depth layers? Then there is a supplementary question: is it possible to derive the temperature of the ice?"

Professor Orosei. In reply to the second question, the answer is that it is not easy to do from radar data alone. We can only put constraints on the maximum temperature of ice by exploiting the different electromagnetic properties of the materials constituting the Martian polar caps. The polar deposits are a mixture of ices and dust. Water ice, which is by far the dominant component, is very transparent to radio waves below about 220 K, while it becomes increasingly attenuating as temperature approaches the melting point. Another characteristic of water ice is that attenuation is independent of frequency. Attenuation caused by dust, on the contrary, is independent of temperature but increases with frequency. Thus, in a dust–ice mixture, attenuation will be dominated by dust, and thus frequency-dependent, at low temperatures, while it will be frequency-independent when temperature increases above 220 K and water ice becomes the primary factor in determining radar penetration. As *MARSIS* can operate at different frequencies, we have been able to determine that attenuation increases with frequency, allowing us to infer that temperature in this part of the Martian southern polar cap should not exceed 220 K.

The first question is technically an interesting one. It's about the pulse-repetition frequency, PRF in short, and the problem of interferences, which were probably noticeable in some radar sections. Unfortunately the PRF is not tuneable, and thus we can only perform a post-processing similar to the one used in ground-penetrating radar and called migration. In airborne radars the corresponding method is called Synthetic Aperture Radar (SAR) processing, which we are experimenting with on raw *MARSIS* data. We are also working on integrated processing of multiple observations to obtain three-dimensional views of the interior of the polar caps, and perhaps there could be a possibility in the future even to merge data acquired at different frequencies to try and achieve greater resolution.

The Senior Secretary. Thank you, Roberto [applause].

Our next speaker is Dr. Dmitrii Kolotkov from the Centre for Fusion, Space and Astrophysics at the University of Warwick. His research interests span solar and stellar magnetohydrodynamics, non-linear dynamical systems, to helio- and asteroseismology as well as modern techniques for data analysis. He has recently been working on the use of MHD waves and oscillations for advanced seismological diagnostics of a plasma in the atmosphere of our Sun and in the atmospheres of other stars as potential hosts of habitable worlds. The title of his talk is 'What makes waves in the Sun's corona wavy?'

Dr. Dmitrii Kolotkov. Imagine a pond where a stone has just been tossed — ripples spread across the water, revealing the underlying properties of the pond's surface; or a violin string bowed steadily, producing acoustic tones at specific frequencies, which propagate through the air. These are well-known, nice and regular waves, resulting from initially aperiodic perturbations. But what exactly makes such initially aperiodic perturbations (*e.g.*, a stone tossed in a pond or a bow moving steadily across the violin string) to develop into an oscillatory pattern? It turns out that the Sun's corona, the glowing halo visible during total solar eclipses, also behaves much like an elastic and compressible material, responding to initially aperiodic impulsive or steady disturbances with a range of oscillatory motions.

The Sun's corona is more than just a stunning sight during solar eclipses — it is a window into the complex dynamics of the solar atmosphere made of the fourth state of matter, the plasma. Plasma makes up most of the visible Universe, and the Sun's corona is one of the most accessible places to study this state of matter. However, understanding the corona is not straightforward. This outer layer, extending millions of kilometres from the Sun's surface, is home to extreme physical conditions: temperatures above one-million Kelvin, and a very low density, dominated by the magnetic field. It is a natural laboratory where scientists can explore a broad variety of fundamental plasma-physics problems and observe the evolution of plasma and its dynamics almost in a live format. This research also goes beyond academic curiosity; it helps us understand the mechanisms behind solar flares, the most powerful explosions in the Solar System, and their potential impact on space weather, which can affect satellites, power grids, and even astronauts.

The plasma in the Sun's outer atmosphere is highly non-uniform, characterized by a wide range of structures — from coronal loops anchored to the solar surface, massive prominences suspended above the surface, thin current sheets triggering magnetic reconnection and large-scale eruptions, to coronal holes with the magnetic field extending towards the heliosphere. The presence of such plasma structures in the Sun's corona creates conditions ripe for hosting various oscillations and waves — they act as effective waveguides and/or resonators, providing a physical ground for an external perturbation to develop into a periodic or quasi-periodic wave structure self-consistently, *i.e.*, without the involvement of a periodic driver. Waves detected in the corona behave similarly to traditional water or sound waves, but with an important twist — the intricate interaction between the dynamics of electrically conducting gas (the coronal plasma) and electromagnetic fields, described by magnetohydrodynamic (MHD) theory. Notably, the striking similarity between MHD waves guided by coronal plasma structures and dispersive waveforms used in geodynamics and oceanography further exemplifies the effective transfer of knowledge across disciplines and the inherently cross-disciplinary nature of this research.

The study of coronal waves has dramatically evolved with the advent of space-borne observatories that capture detailed images of the solar corona in extreme-ultraviolet light (EUV) with unprecedented clarity and resolution. Since the launch of such space missions as the *Transition Region and Coronal Explorer* (*TRACE*) in 1998, the *Solar Dynamics Observatory* (*SDO*) in 2010, and the more recent *Solar Orbiter* (*SolO*) in 2020, our observational capabilities have improved significantly — from approximately 360 km per pixel every 75 seconds up to about 100 km per pixel every 2 seconds. For instance, the new-generation EUV imager on-board the *Solar Orbiter* mission can discern features in the Sun's corona as small as about 100–200 km (relative to the solar radius of about 700 000 km) every few seconds. Given that the characteristic spatiotemporal scales of coronal waves range typically from a thousand kilometres (a megametre, Mm, traditionally used in solar physics) to a few hundred thousand kilometres (hundreds of Mm) and from a few seconds to several tens of minutes, these waves can perhaps be regarded as the longest electromagnetic waves in the Universe that are fully resolved both in space and in time. Specific data-analysis techniques such as the time–distance analysis allow researchers not only to reveal the presence of waves but also to track their evolution over time as they propagate through the corona, measure characteristic parameters such as the oscillation period, damping time, apparent propagation speed and direction, *etc.* By comparing these observed wave parameters to theoretical models, scientists can better understand the physical conditions of the Sun's atmosphere, perform remote sensing of the coronal plasma, which is known as the original method of MHD coronal seismology — much like how seismic waves are used to probe the Earth's interior.

The phenomenon of quasi-periodic pulsations (QPPs) in solar and stellar flares represents another, indirect manifestation of waves and oscillations in coronal active regions, when observations with advanced spatial resolution are not available or are highly limited (which is especially relevant for stellar observations). QPPs are seen as patterns of repeated fluctuations in solar-flare radiation, usually short-lived, that hint at the presence of waves, although the exact QPP-formation mechanisms are yet to be revealed. Detected in the majority of flare events on the Sun, QPPs offer a way to probe the extreme physical conditions in flares, acting like a cosmic stethoscope that listens to the solar atmosphere's heartbeat. Their presence has even been detected in flares on other stars, suggesting that similar physical processes might be at work across the Universe, offering a potential bridge between solar and stellar studies. This connection between the Sun and other stars has far-reaching implications. For instance, understanding the dynamic processes in stellar flares through the prism of QPP and, more importantly, decoding the unique seismological information about stellar-flare plasma, carried by QPPs, could shed light on how these stars influence their surrounding planets. Such research is crucial for exploring exoplanets, especially those orbiting stars with intense flare activity that might affect habitability.

In conclusion, the waves in the Sun's corona are not just an interesting quirk of solar physics — they are key to understanding the fundamental physical problems of our Sun. From ripples on a pond and violin-string oscillations to electromagnetic waves in space, the universality of the wave theory as an overarching principle in physics, combined with careful observations and advanced theoretical modelling, help scientists unlock the secrets of solar activity and use it as a test-ground extending to other stars and the broader Universe.

The Senior Secretary. Thank you, Dmitrii. Are there any questions?

Dr. Ziri Younsi. One thing I couldn't help but notice was the mathematical form of your density solution. Those videos which show your simulations look awfully like solitons where there is a beautiful balance between non-linearity and dispersion. I wonder if you think that they are just solitary waves where the scale height of the medium shrinks over time?

Dr. Kolotkov. The wave phenomena discussed in this talk are mostly linear, and the generalized symmetric Epstein profile (determined by sech^2 indeed) is used for modelling the initial equilibrium density profile only. Similar waveguide profiles are used for modelling wave propagation in optical fibres, for example. For fast-mode MHD waves in solar coronal waveguides, the development of non-linearity is generally suppressed by strong geometric dispersion. However, large-amplitude standing kink oscillations of loops may manifest non-linear effects *via* Kelvin-Helmholtz instability (*e.g.*, formation of vortices and smaller scales). For slow-mode waves, the waveguide dispersion is less pronounced, which, in general, can result in steepening, but waves dissipate faster usually. The non-linear Schrödinger equation and Burger's equation are usually used for describing the propagation of weakly non-linear MHD waves in the corona.

Dr. Younsi. That solution is actually an analytic solution for the Korteweg–de Vries equation. If you did a non-linear analysis do you think that the density perturbations would be a solution of that?

Dr. Kolotkov. This is an equilibrium form. We did a non-linear analysis but it does not result in solitary solutions. Sometimes we model this in terms of Burger's equation where we observe the steepening of the wave. The beauty of solar physics is that it allows for the direct comparison of the analytical solution with observations.

Professor Eric Priest. What do you think is the nature of the quasi-periodic pulsations that you mentioned?

Dr. Kolotkov. In short, these are indirect signatures of waves and oscillations discussed today in flare-hosting active regions. We currently consider over a dozen specific mechanisms of how those oscillatory processes can modulate the flare electromagnetic emission (in different bands) and result in QPP, the detailed discussion of which would require a dedicated lecture.

The Senior Secretary. Thank you again [applause].

The final speaker this afternoon is Dr. Jan Röder who started his journey in physics and astronomy at Goethe University in Frankfurt where he worked on neutron stars and numerical simulations of radiative transport in exotic black-hole space-times. Afterwards he moved to the Max Planck Institute for Radioastronomy in Bonn, becoming a radio astronomer, and he recently completed his PhD. Congratulations! His interests are in the theory and radio observations of relativistic jets in AGN from event-horizon scales to extended jets. His talk is entitled 'A multi-frequency study of sub-parsec jets with the *Event Horizon Telescope*'.

Dr. Jan Röder. [Active galactic nuclei (AGN) are among the most powerful sources of energy in the Universe. In the direct vicinity of the supermassive black holes at their centres, hot plasma forms an accretion disc, from which highly collimated outflows are launched — relativistic jets. Moving with close to the speed of light, they can extend hundreds, or even thousands of light years into interstellar space. They have been subjects of active research for decades, and our understanding of the inner workings of AGN and jets has since been gradually advancing. With the *Event Horizon Telescope*, a global network of radio telescopes, we are able to study AGN jets at micro-arcsecond spatial resolution, close to the central black hole. In combination with observations at lower frequencies, we can test the established models of jets from the extended kilo-parsec structure, down to sub-parsec scales near the launching region.] [It is expected that a full summary of this talk will appear in *Astronomy & Geophysics*. — Ed.]

The Senior Secretary. Thank you, Jan. Questions?

Reverend Garth Barber. Many jets are just single and often that is because the opposite jet is hidden in some sense. Would you say that the jets are always in pairs, going either way?

Dr. Röder. Yes. The reason we see one side of the jets is because they are beamed. One side gets Doppler-boosted away from us — it gets Doppler-boosted so much that we just don't see it at most viewing angles. When you compare the geometry of a given jet across a range of scales you could, for example, see a one-sided jet at large scales and as you zoom in, you might have some change in viewing angle. You may then have a twin-jet system appear. Intrinsically, however, jets are always launched both ways from the black-hole accretion-disc system.

Professor Phil Charles. That was a great description of VLBI and how it all works but one thing you didn't mention is that there is an inherent assumption in there that the structure of your source remains constant during the time that you are compiling the data for the image. We know that Sgr A* does frequently have significant variations over a much shorter timescale so would you like to comment on that? Surely you are looking at an average process?

Dr. Röder. First, Sgr A* was not in this sample: we looked at AGN, and Sgr A* is Galactic. As for the variability, some sources do indeed vary more than others and the big surveys taken in single epochs may not reflect the typical state of a given source. On top of that, the higher you go in frequency the higher the variability in source geometry (typically). This is why we try to focus on the property of the cores, because this is something that over a larger time period remains robust. You are completely correct that many jets can undergo big variations over a matter of weeks, and we are prone to a systematic uncertainty based on source variability. It is discussed in more detail in the paper.

Professor Mike Cruise. The orange doughnut has become iconic. Could you say something about the pixel size on that picture of the orange doughnut and the resolution of the whole telescope array?

Dr. Röder. I'll take the last question first. There is a famous analogy that we have the resolution to see an orange on the Moon — that is about 20 μas on the sky. As for the pixel, that depends on the algorithm used to reconstruct the image from the data, so one sets the pixel size in many methods you use. The *EHT* images are about 200 μas in size. I believe they use 128 and 256 pixels per image. I was not yet in the collaboration when the first image was published. Ziri — do you know what was used initially for the reconstruction?

Dr. Younsi. Sixty-four to 128.

Professor Cruise. I thought I had read in the original paper that the image of the doughnut was a simulation not a reconstruction. Have I got that wrong?

Dr. Röder. It was surely a reconstruction from real data, from different algorithms. The theory component that came with the first few papers compared the images that were created to simulations, in order to extract physics from them. The doughnut is real — it exists.

Professor Mike Edmunds. You were telling us about the Blandford chemical model with $1/r$ and $1/r^2$ for tangential and parallel components. If you have an accelerating flow what would it do? Presumably people have modelled it since 1977?

Dr. Röder. That is true but I couldn't say off the top of my head.

Professor Edmunds. We can work it out. If the thing is accelerating then you are going to lower densities essentially; does the magnetic field just go with the density?

Dr. Röder. I would assume that it is not necessarily tied to the particle number density; if everything stretches out then it will also dissipate faster, I would guess.

Professor Edmunds. I'm just surprised that there isn't a modelling that has done that.

The Senior Secretary. Are there any other questions? Thank you very much again for an excellent talk [applause]. It just leaves me to give notice that the next A & G Highlights meeting of the Society will be Friday, November 8th at 4 pm and I believe it will be here. Finally there is a small drinks reception in the Council Room immediately after we finish and you are all welcome to attend. Thanks very much again to all our speakers and questioners.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 23: THE F-TYPE TWIN SYSTEM RZ CHAMAELEONTIS

By John Southworth

Astrophysics Group, Keele University

RZ Cha is a detached eclipsing binary containing two slightly evolved F5 stars in a circular orbit of period 2·832 d. We use new light-curves from the *Transiting Exoplanet Survey Satellite* (*TESS*) and spectroscopic orbits from *Gaia* DR3 to measure the physical properties of the component stars. We obtain masses of $1{\cdot}488 \pm 0{\cdot}011\ M_\odot$ and $1{\cdot}482 \pm 0{\cdot}011\ M_\odot$, and radii of $2{\cdot}150 \pm 0{\cdot}006\ R_\odot$ and $2{\cdot}271 \pm 0{\cdot}006\ R_\odot$. An orbital ephemeris from the *TESS* data does not match published times of mid-eclipse from the 1970s, suggesting the period is not constant. We measure a distance to the system of $176{\cdot}7 \pm 3{\cdot}7$ pc, which agrees with the *Gaia* DR3 value. A comparison with theoretical models finds agreement for metal abundances of $Z = 0{\cdot}014$ and $Z = 0{\cdot}017$ and an age of 2·3 Gyr. No evidence for pulsations was found in the light-curves. Future data from *TESS* and *Gaia* will provide more precise masses and constraints on any changes in orbital period.

Introduction

The current series of papers[1] is concerned with determining the physical properties of detached eclipsing binary systems (dEBs) to sufficient precision to be useful for testing the predictions of theoretical stellar models. The intended precision is 2% or better in the masses and radii of the component stars[2,3], although precisions in the region of 0·2% can be achieved in the best cases[4]. Our work uses published spectroscopic radial-velocity (RV) measurements combined with new photometry from space missions such as *Kepler*[5] and *TESS*[6], which have revolutionized our understanding of binary stars[7].

In this work we turn our attention to the system RZ Chamaeleontis (Table I), a partially-eclipsing dEB containing two almost identical F-stars on a circular orbit of period 2·828 d. Its variability was discovered by Strohmeier, Knigge & Ott[8] under the moniker of BV 473, from Bamberg photographic patrol plates. Popper[9] obtained nine photographic spectra and commented that there were lines of two components with approximately equal intensity. Geyer & Knigge[10] refined the period to 2·832093(61) d from *UBV* observations of most of one eclipse.

Jørgensen & Gyldenkerne[11] presented extensive photometry of RZ Cha obtained with the Copenhagen 50-cm telescope sited at ESO La Silla, Chile. They used the Strömgren photometer to obtain simultaneous observations in the *uvby* passbands, totalling 775 points in each band. They fitted the light-curves using a rectification procedure[12,13], finding the ratio of the radii (k) to be close to unity but poorly determined due to the eclipses being partial. They thus fixed $k = 1$ to present results for the mean component of the system. The Strömgren colour indices were found to be practically the same for the two stars, supporting the imposition of $k = 1$ on the light-curve solution, and to indicate that they have an approximately solar metallicity ([Fe/H] $= -0{\cdot}02 \pm 0{\cdot}15$). They also found an effective temperature of $T_{\rm eff} = 6580 \pm 150$ K for the two stars, and that they had evolved beyond the end of the main sequence.

In an accompanying paper, Andersen *et al.*[14] (hereafter AGI75) presented photographic spectroscopic observations of RZ Cha from which the masses and radii of the mean component were deduced to 1–2% precision. A modest

TABLE I

Basic information on RZ Chamaeleontis. The BV magnitudes are each the mean of 129 individual measurements[18] *distributed approximately randomly in orbital phase. The JHK_s magnitudes are from 2MASS*[19] *and were obtained at an orbital phase 0·30.*

Property	*Value*	*Reference*
Right ascension (J2000)	$10^{\rm h}42^{\rm m}24^{\rm s}{\cdot}11$	20
Declination (J2000)	$-82°02'14''{\cdot}2$	20
Henry Draper designation	HD 93486	21
Gaia DR3 designation	5198334162577657984	22
Gaia DR3 parallax	$5{\cdot}7404 \pm 0{\cdot}0186$ mas	22
TESS Input Catalog designation	TIC 394730113	23
B magnitude	$8{\cdot}54 \pm 0{\cdot}02$	18
V magnitude	$8{\cdot}09 \pm 0{\cdot}01$	18
J magnitude	$7{\cdot}131 \pm 0{\cdot}030$	19
H magnitude	$6{\cdot}941 \pm 0{\cdot}036$	19
K_s magnitude	$6{\cdot}904 \pm 0{\cdot}038$	19
Spectral type	F5 IV–V + F5 IV–V	14

disagreement was found between the two sets of photographic plates obtained, with the F-series (reciprocal dispersion 20 Å mm^{-1}) yielding slightly smaller and more uncertain velocity amplitudes than the G-series (12·3 Å mm^{-1}) plates. AGI75 found the two stars to be almost identical, with a magnitude difference between the spectral-line strengths of the components of 0·02 ± 0·02 mag (mean error from five spectral lines).

Giuricin *et al.*[15] reanalysed the *uvby* light-curves using the WINK program[16], finding that they could differentiate between the two stars. Their results point towards one star being slightly hotter (by 50 K) and also slightly smaller (with $k = 1{\cdot}061 \pm 0{\cdot}020$ where the error bar neglects some sources of uncertainty such as limb darkening). This is plausible in a system where both components are evolved far from the zero-age main sequence. Giuricin *et al.* modelled the four light-curves separately and obtained very different results for the *y* band *versus* the others (for example, a ratio of the radii of 1·40 instead of 1·06), but did not even comment on this discrepancy. The small but detectable difference between the stars was restated by Graczyk *et al.*[17], who included RZ Cha in a sample of 35 dEBs constructed to calibrate relations between surface brightness and colour.

Photometric observations

RZ Cha has been observed in seven sectors by the NASA *Transiting Exoplanet Survey Satellite*[6,24] (*TESS*), at a variety of sampling rates. The data from sectors 11, 12, and 13 were obtained at a cadence of 1800 s, from sectors 38 and 39 at 600-s cadence, and from sectors 65 and 66 at both 120-s and 200-s cadence. An eighth set of observations is scheduled in the near future: sector 93 will be observed in 2025 June. In this work we concentrate on the data obtained at the highest available cadence.

We downloaded data for all sectors from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[25]. We specified the quality flag "hard" to retain only the best data, and used the simple aperture photometry (SAP) light-curves from the SPOC data-reduction pipeline[26]. The data points were converted into differential magnitudes and the median magnitude was subtracted from each sector to normalize the data.

We show the resulting light-curves in Fig. 1. The temporal coverage in the final two sectors, on which we concentrate our efforts, is excellent. A total of 19 515 and 18 604 data points are available in sectors 65 and 66, respectively.

We queried the *Gaia* DR3 database† for all sources within 2 arcmin of RZ Cha. All of the 92 sources returned as a response to our query are fainter than RZ Cha by at least 5·01 mag in the *Gaia* $G_{\rm RP}$ passband. We therefore expect the amount of light contaminating the light-curve to be negligible. As a confirmation of this, the TICv8 catalogue[23] indicates that less than 1% of the light in the *TESS* light-curve of RZ Cha may be ascribed to contamination from nearby point sources.

Light-curve analysis

We combined together the 120-s cadence data of RZ Cha from *TESS* sectors 65 and 66 for a detailed analysis of the photometric variations due to binarity. The primary and secondary eclipses are of similar depth (approximately 0·4 mag)

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

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

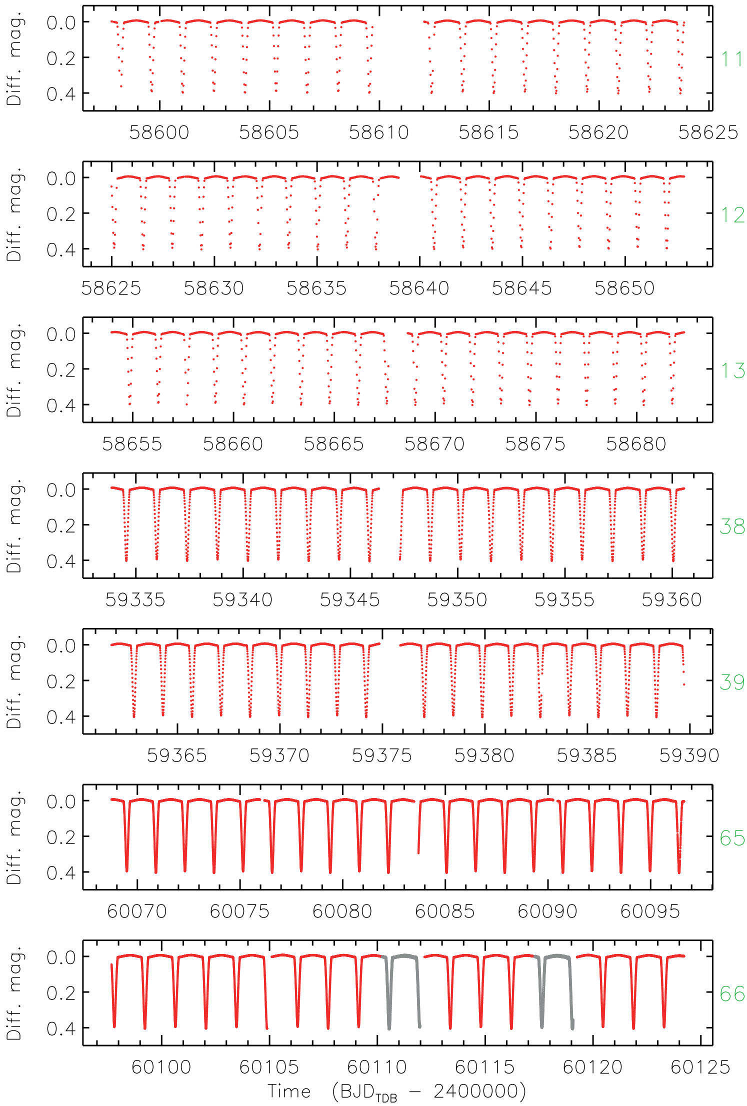

FIG. 1

TESS short-cadence SAP photometry of RZ Cha. The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median. Rejected observations are shown as grey open circles. The sector number is shown in green to the right of each panel.

but a difference in depth is apparent on visual inspection. We assigned a time of primary minimum close to the midpoint of the light-curve as our reference time of primary minimum (T_0) and define star A to be the star eclipsed at that time. Star A is therefore hotter than its companion, star B; it is also the smaller of the two. Their masses are not significantly different (see below).

We modelled the light-curve using version 43 of the JKTEBOP★ code[27,28], fitting for the fractional radii of the stars (r_A and r_B), expressed as their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$), the central-surface-brightness ratio ($\mathcal{J}$), third light (L_3), orbital inclination (i), orbital period (P), and the reference time of primary minimum (T_0). Limb-darkening (LD) was included in the fit using the power-2 law[29–31], with the same coefficients used for both stars due to their strong similarity. The linear coefficient (c) was fitted and the non-linear coefficient (α) was fixed to a suitable theoretical value[32,33].

After some experimentation it became clear that there were two time intervals where the data had a significantly larger scatter. The affected data points were culled from the analysis and are shown in a different colour in Fig. 1. It was also apparent that there were slight discontinuities in flux associated with three gaps in the data for each of the two sectors. We therefore applied a total of eight quadratic functions to normalize the out-of-eclipse brightness of the system — four for each *TESS* sector. Once these adjustments were made we obtained an excellent fit to the *TESS* observations (Fig. 2). Our results consistently indicate that star A is hotter but smaller than star B.

To obtain error bars for the fitted parameters we decreased the size of the data errors from the *TESS* data-reduction pipeline to force a reduced χ^2 of unity, then ran the Monte-Carlo and residual-permutation simulations implemented in JKTEBOP[27,34]. The measured parameter values and their error bars are given in Table II, and in all cases correspond to the residual-permutation values as they are larger than the Monte-Carlo error bars.

TABLE II

Photometric parameters of RZ Cha measured using JKTEBOP from the light-curves from TESS sectors 65 and 66. The error bars are 1σ and were obtained from a residual-permutation analysis.

Parameter	*Value*
Fitted parameters:	
Orbital period (d)	2·8320896 ± 0·0000013
Reference time (BJD_{TDB})	2460096·389351 ± 0·000012
Orbital inclination (°)	83·2920 ± 0·0060
Sum of the fractional radii	0·36509 ± 0·00012
Ratio of the radii	1·0562 ± 0·0025
Central-surface-brightness ratio	0·98075 ± 0·00008
Third light	0·01641 ± 0·00075
LD coefficient c	0·5901 ± 0·0063
LD coefficient α	0·4898 (fixed)
Derived parameters:	
Fractional radius of star A	0·17755 ± 0·00023
Fractional radius of star B	0·18753 ± 0·00019
Light ratio ℓ_B/ℓ_A	1·0972 ± 0·0052

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

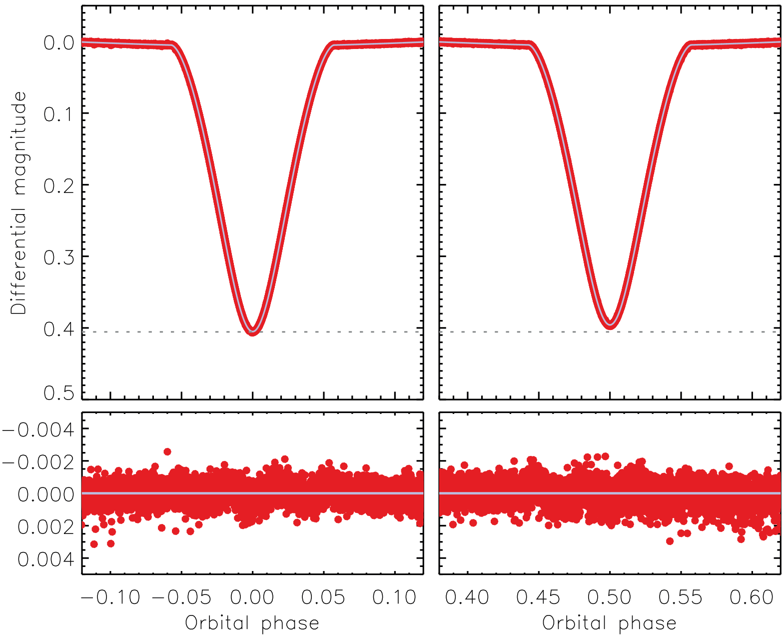

FIG. 2

JKTEBOP best fit to the 120-s cadence light-curves of RZ Cha from *TESS* sectors 65 and 66. The data are shown as filled red circles and the best fit as a light-blue solid line. A dotted line shows the brightness of the system at the midpoint of primary eclipse, and is a visual indicator of the slight difference in depths between the two eclipses. The residuals are shown on an enlarged scale in the lower panel.

Our results are in good agreement with previous analyses[11,15] but with much smaller error bars. However, our light ratio is slightly inconsistent with the one given by AGI75 from their photographic spectra; the level of disagreement is ambiguous because AGI75 did not specify which star was which in the evaluation of their light ratio.

Orbital ephemeris

The analysis so far has used only two consecutive sectors of *TESS* observations, so P and T_0 are not as precise as they could be. We therefore fitted each of the *TESS* sectors individually using JKTEBOP to determine times of eclipse. We chose the primary eclipse closest to the midpoint of each sector as best representative of the full sector. We did not obtain any times of secondary eclipse, or times of individual eclipses, as this exceeds the scope of the current work. The times of minimum light used are given in Table III.

The orbital ephemeris from the six times of minimum light is

$$\text{Min I} = \text{BJD}_{\text{TDB}}\ 2459374{\cdot}206471(3) + 2{\cdot}832089764(13)E \qquad (1)$$

and the residuals *versus* the best fit are plotted in Fig. 3. The times are measured

TABLE III

Times of primary eclipse for RZ Cha and their residuals versus the fitted ephemeris.

Orbital cycle	*Eclipse time* (BJD_{TDB})	*Uncertainty* (*d*)	*Residual* (*d*)
−260·0	2458637·863128	0·000012	−0·000004
−250·0	2458666·184023	0·000009	−0·000007
−10·0	2459345·885586	0·000008	0·000013
0·0	2459374·206474	0·000010	0·000003
250·0	2460082·228909	0·000007	−0·000003
260·0	2460110·549807	0·000007	−0·000003

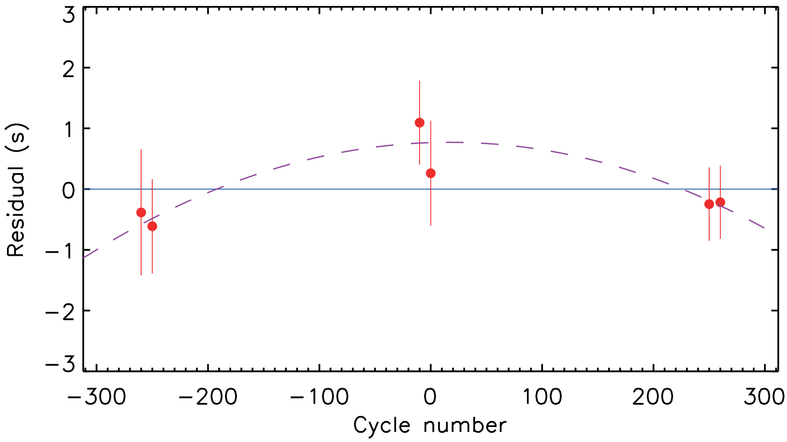

FIG. 3

Residuals of the times of minimum light from Table III (red circles) *versus* the best-fitting ephemerides. The blue solid line and purple dashed line indicate residuals of zero for the linear and quadratic ephemeris, respectively. Note the extremely small scale on the *y*-axis.

to an extraordinary precision, with a root-mean-square (rms) residual of only 0·56 s.

We then tried to project the orbital ephemeris back to the times of eclipse given by Jørgensen & Gyldenkerne[11], including also the time of minimum given by Mallama[35]. This was unsuccessful because the gap of almost exactly 46 years between our timings and that of Mallama means we cannot confidently assign orbital cycle counts to the older data. We therefore rely on the ephemeris above, which is valid for the duration of the *TESS* data only.

RZ Cha may exhibit low-amplitude period variations. There is a hint of this in our own timings (Table III), where the addition of a quadratic term to the ephemeris lowers the r.m.s. of the residuals from 0·56 s to 0·27 s (Fig. 3), and it would also explain our difficulty in adding historical times of minimum to the analysis. Further support for this notion comes from a plot of the residuals *versus* an orbital ephemeris of RZ Cha on the TIDAK website*[36]. We leave this matter to the future, where additional insight is expected from the extra sector of data from *TESS* as well as more extensive compilations of published times of minimum.

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

Radial-velocity analysis

It is important to check the results of the RV analysis presented by AGI75 to ensure consistency with the numbers in the current work. AGI75 noticed an inconsistency between their results from the two series of photographic plates they used, the 20 Å mm^{-1} plates giving slightly lower velocity amplitudes (K_A and K_B) than the 12 Å mm^{-1} plates. The differences between measurements of the same plates by the various co-authors of the paper using their own methods* are smaller than both the inconsistency and the uncertainties. We have collected the various values of K_A and K_B in Table IV.

TABLE IV

Velocity amplitudes measured in different ways for RZ Cha. The person who performed the analysis is given in parentheses in each case.

Source	K_A (*km s*$^{-1}$)	K_B (*km s*$^{-1}$)
20 Å mm^{-1} plates (Imbert)	105·3 ± 2·7	103·6 ± 1·7
20 Å mm^{-1} plates (Andersen)	106·4 ± 0·8	106·5 ± 1·0
12 Å mm^{-1} plates (Gjerløff)	108·5 ± 0·6	108·7 ± 0·9
12 Å mm^{-1} plates (Andersen)	108·4 ± 0·7	107·0 ± 0·9
AGI75 adopted value	108·2 ± 0·6	107·6 ± 0·9
20 Å mm^{-1} plates (this work)	106·2 ± 1·3	105·5 ± 1·0
12 Å mm^{-1} plates (this work)	108·5 ± 0·6	107·8 ± 0·8
20 Å mm^{-1} and 12 Å mm^{-1} (this work)	108·0 ± 0·6	106·7 ± 0·7
Gaia DR3 tbosb2	107·8 ± 0·4	108·2 ± 0·4

We also extracted the RVs from table 1 of AGI75 to perform our own fits. It is not stated which co-author produced the tabulated RVs, but it is likely to have been Johannes Andersen as he was the only author to analyse both sets of photographic plates. As fitted parameters we specified K_A, K_B, the systemic velocity (assumed to be the same for both stars), and a phase offset with respect to our ephemeris in Table II. Uncertainties were calculated using Monte Carlo simulations, and the velocity amplitudes we found are given in Table IV.

Our first conclusion is that the phase offset is small, hence the primary star adopted by AGI75 is probably the same as our star A. This conclusion is valid only if changes in the orbital period in the system are small. We fitted the 20 Å mm^{-1} RVs, finding an r.m.s. scatter of 3·2 km s^{-1} for star A and 2·5 km s^{-1} for star B. We then fitted the 12 Å mm^{-1} RVs, obtaining scatters of 2·1 km s^{-1} and 3·4 km s^{-1} respectively. With these r.m.s. scatters applied as error bars to the RVs, we then fitted all the AGI75 RVs together (see Fig. 4). The systemic velocities in these fits were all in good agreement, so need not be discussed further.

RZ Cha has also been observed spectroscopically using the *RVS* instrument[37] on the *Gaia* mission, and the parameters of its spectroscopic orbit are given in the tbosb2 catalogue†[38]. Fifteen RVs were automatically measured and fitted for each star; the orbit has the correct period and a very small and negligible[39] eccentricity. We verified that the primary star in tbosb2 corresponds to our star A. The velocity amplitudes from tbosb2 are given in Table IV, are consistent with previous determinations, and have a smaller error bar. It is also clear that K_A is smaller and K_B is larger than previously found, to the extent that $K_B > K_A$.

*This author confesses he is far too young to have ever used a Grant comparator, although he vaguely remembers seeing one in a store-room at an observatory somewhere.

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

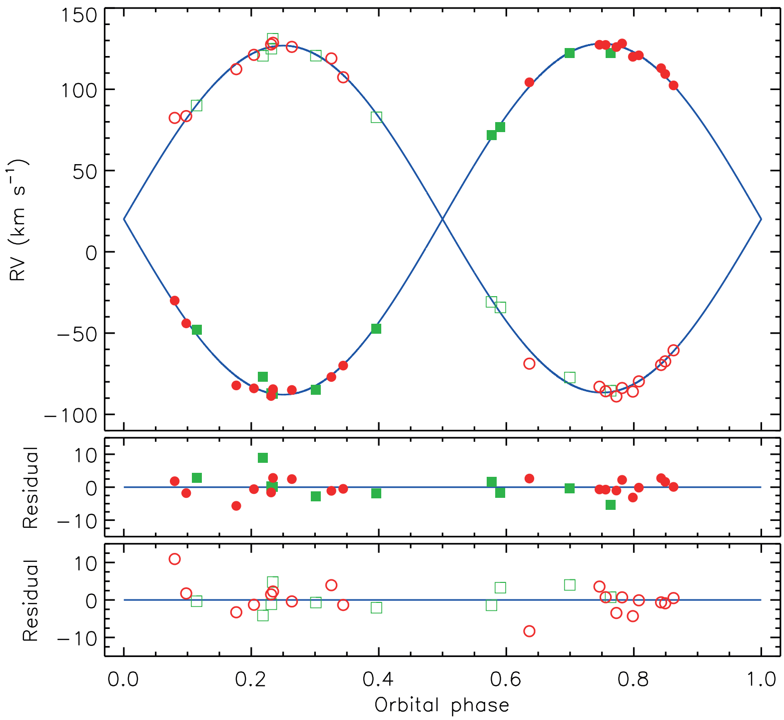

FIG. 4

RVs of RZ Cha from AGI75 compared to the best fit from JKTEBOP (solid-blue lines). The RVs for star A are shown with red filled circles for the 20 Å mm^{-1} photographic plates and green filled squares for the 12 Å mm^{-1} plates. The RVs for star B are shown with red open circles for the 20 Å mm^{-1} photographic plates and green open squares for the 12 Å mm^{-1} plates. The residuals are given in the lower panels separately for the two components.

We are thus faced with a choice between adopting the results based on the RVs of AGI75, which are derived from photographic observations and show some inconsistencies, or the orbit given in the tbosb2 catalogue based on RVs which are not public and thus cannot be verified. Issues with the tbosb2 orbits have previously been noted[40–44], but in the case of RZ Cha the orbital parameters are close to the values known from other sources. We have therefore decided to adopt the K_A and K_B from tbosb2, and note that this can be checked in the near future (late 2026) when *Gaia* DR4 becomes available*.

Physical properties and distance to RZ Cha

The physical properties of RZ Cha were determined using the JKTABSDIM code[46] and the results from the analyses described above. The masses are measured to a precision of 0·7%, are not significantly different from each other,

*https://www.cosmos.esa.int/web/Gaia/release and may be improved once *Gaia* DR4 is published. The radii are measured to a precision of 0·3%, and star B is larger and more evolved than star A. The masses and radii agree well with previous measurements[11,14,15], but are significantly more precise. There is an apparent inconsistency in that the less-massive star B is more evolved than its companion, but the significance of this is too low to be concerning: the mass ratio is only 0·8σ below unity.

We adopted a $T_{\rm eff}$ of the system of 6580 ± 150 K[11] and used the surface-brightness ratio and equations from Southworth[47] to convert this to individual $T_{\rm eff}$ values (Table V). These $T_{\rm eff}$ values were used with the surface-brightness calibrations by Kervella *et al.*[48] and the apparent magnitudes in Table I to determine the distance to the system. A small amount of interstellar reddening of $E(B-V) = 0{\cdot}05 \pm 0{\cdot}02$ mag was needed to align the distances from the optical and infrared passbands. Our best distance estimate is 176·7 ± 3·7 pc in the $K_{\rm s}$-band, which is in agreement with the 174·2 ± 0·6 pc from the *Gaia* DR3 parallax.

TABLE V

Physical properties of RZ Cha defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 45).

Parameter	*Star A*	*Star B*
Mass ratio $M_{\rm B}/M_{\rm A}$	0·9963 ± 0·0047	
Semi-major axis of relative orbit ($R^{\rm N}_{\odot}$)	12·109 ± 0·029	
Mass ($M^{\rm N}_{\odot}$)	1·488 ± 0·011	1·482 ± 0·011
Radius ($R^{\rm N}_{\odot}$)	2·1499 ± 0·0058	2·2708 ± 0·0058
Surface gravity (log[cgs])	3·9458 ± 0·0018	3·8967 ± 0·0017
Density ($\rho_{\odot}$)	0·1497 ± 0·0007	0·1266 ± 0·0005
Synchronous rotational velocity (km s^{-1})	38·41 ± 0·10	40·57 ± 0·10
Effective temperature (K)	6596 ± 150	6564 ± 150
Luminosity $\log(L/L^{\rm N}_{\odot})$	0·897 ± 0·040	0·936 ± 0·040
$M_{\rm bol}$ (mag)	2·50 ± 0·10	2·40 ± 0·11
Interstellar reddening $E(B-V)$ (mag)	0·05 ± 0·02	
Distance (pc)	176·0 ± 3·7	

Comparison with theoretical models

We compared the properties of RZ Cha to the predictions of the PARSEC 1·2S theoretical stellar-evolutionary models[50,49] in the mass–radius and mass–$T_{\rm eff}$ diagrams. We obtained an acceptable fit for a metal abundance of $Z = 0{\cdot}017$ and an age of 2·35 ± 0·10 Gyr, in the sense that the theoretical isochrones passed within 1σ of the measured properties. A slightly lower metal abundance of $Z = 0{\cdot}014$ gave a better fit for an age of 2·20 ± 0·10 Gyr, in that the $T_{\rm eff}$ values were matched almost exactly rather than at the 1σ lower error bar.

Jørgensen & Gyldenkerne[11] found that the components of RZ Cha have evolved beyond the main sequence by comparing their properties with the theoretical models of Hejlesen[51,52]. AGI75 confirmed the conclusion that both component stars were in the subgiant phase. We investigated this by plotting a Hertzsprung–Russell diagram (Fig. 5) with the stars and PARSEC evolutionary tracks for a range of masses. This clearly shows that both components are within the main-sequence band, and that an age of 2·05 Gyr is the best match. We find a younger age than in the previous paragraph because we have striven to match $T_{\rm eff}$ and luminosity rather than mass, radius, and $T_{\rm eff}$. That we find the components to be main-sequence stars rather than subgiants is due to the inclusion of convective-core overshooting in more modern theoretical models, which causes the main-sequence band to extend to higher luminosities[53,54].

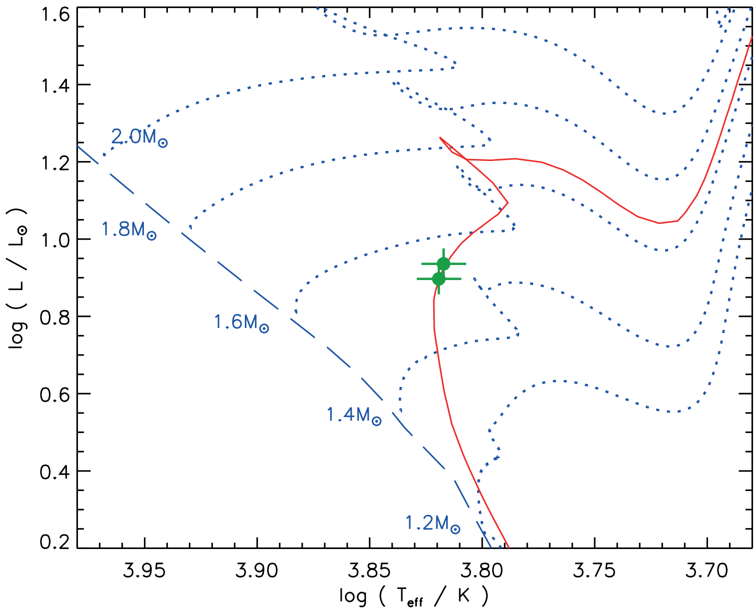

FIG. 5

Hertzsprung–Russell diagram for the components of RZ Cha (filled green circles) and the predictions of the PARSEC 1·2S models[49] for selected masses (dotted blue lines with masses labelled) and the zero-age main sequence (dashed blue line), for a metal abundance of $Z = 0{\cdot}017$. The isochrone for an age of 2·05 Gyr is shown with a solid red line.

Summary and conclusions

RZ Cha is a dEB containing two F5 stars in a circular orbit of period 2·832 d. We used light-curves from the *TESS* mission and spectroscopic orbits from *Gaia* DR3 to determine the masses and radii of the component stars. With the addition of a published $T_{\rm eff}$ measurement and surface-brightness calibrations we determined their luminosities and the distance to the system. The distance we find, 176·7 ± 3·7 pc, agrees with the value of 174·2 ± 0·6 pc from *Gaia* DR3. The two stars are very similar, having almost identical masses and $T_{\rm eff}$ values, but star B is larger and thus brighter. We find a mass ratio below unity, in modest disagreement with published values from ground-based spectroscopy, and this result can be checked in the near future when the *Gaia* RVs are published.

Both components are in the upper part of the main-sequence band in the Hertzsprung–Russell diagram, in contrast to previous claims that they have evolved beyond the main-sequence stage. We find acceptable matches to the masses, radii, $T_{\rm eff}$ values, and luminosities of the stars for a metal abundance around or slightly below solar, and an age in the region of 2·3 Gyr.

Both components of RZ Cha are within the region of the Hertzsprung–Russell diagram where g-mode pulsations can be found[55,56], and relatively few g-mode pulsators in dEBs are known[57,58]. We therefore checked the *TESS* light-curves for signs of pulsations by fitting them with JKTEBOP to remove the signals of binarity, then calculating periodograms using the PERIOD04 code[59]. This was done for *TESS* sectors 11–13, 38 and 39, and 65 and 66. Several possible low-amplitude pulsation frequencies below 3 d^{-1} were found, but none were consistently present in the three periodograms. A periodogram to the Nyquist frequency of 360 d^{-1} was calculated for sectors 65 and 66, and showed no significant power beyond 3 d^{-1}. We therefore conclude that there is no evidence for pulsations in RZ Cha.

Acknowledgements

We are grateful to Dr. Pierre Maxted for calculating which star is the primary component in the *Gaia* spectroscopic orbit, and to the anonymous referee for a positive and prompt report. This paper includes data collected by the *TESS* mission and obtained from the MAST data archive at the Space Telescope Science Institute (STScI). Funding for the *TESS* mission is provided by the NASA's Science Mission Directorate. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555. This work has made use of data from the European Space Agency (ESA) mission *Gaia*[★], processed by the *Gaia* Data Processing and Analysis Consortium (DPAC[†]). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arχiv scientific-paper preprint service operated by Cornell University.

References

(1) J. Southworth, *The Observatory*, **140**, 247, 2020.
(2) J. Andersen, *A&ARv*, **3**, 91, 1991.
(3) G. Torres, J. Andersen & A. Giménez, *A&ARv*, **18**, 67, 2010.
(4) P. F. L. Maxted *et al.*, *MNRAS*, **498**, 332, 2020.
(5) W. J. Borucki, *Reports on Progress in Physics*, **79**, 036901, 2016.
(6) G. R. Ricker *et al.*, *Journal of Astronomical Telescopes, Instruments, and Systems*, **1**, 014003, 2015.
(7) J. Southworth, *Universe*, **7**, 369, 2021.
(8) W. Strohmeier, R. Knigge & H. Ott, *IBVS*, **66**, 1, 1964.
(9) D. M. Popper, *AJ*, **71**, 175, 1966.
(10) E. H. Geyer & R. Knigge, *IBVS*, **941**, 1, 1974.
(11) H. E. Jørgensen & K. Gyldenkerne, *A&A*, **44**, 343, 1975.
(12) H. N. Russell & J. E. Merrill, *The determination of the elements of eclipsing binaries* (Contributions from the Princeton University Observatory, Princeton), 1952.
(13) K. Gyldenkerne, H. E. Jørgensen & E. Carstensen, *A&A*, **42**, 303, 1975.
(14) J. Andersen, H. Gjerløff & M. Imbert, *A&A*, **44**, 349, 1975.
(15) G. Giuricin *et al.*, *A&A*, **85**, 259, 1980.
(16) D. B. Wood, *PASP*, **85**, 253, 1973.
(17) D. Graczyk *et al.*, *ApJ*, **837**, 7, 2017.
(18) E. Høg *et al.*, *A&A*, **355**, L27, 2000.
(19) R. M. Cutri *et al.*, *2MASS All Sky Catalogue of Point Sources* (The IRSA 2MASS All-Sky Point Source Catalogue, NASA/IPAC Infrared Science Archive, Caltech, US), 2003.
(20) *Gaia* Collaboration, *A&A*, **674**, A1, 2023.
(21) A. J. Cannon & E. C. Pickering, *Annals of Harvard College Observatory*, **94**, 1, 1919.
(22) *Gaia* Collaboration, *A&A*, **649**, A1, 2021.
(23) K. G. Stassun *et al.*, *AJ*, **158**, 138, 2019.
(24) J. N. Winn, chapter in the *Handbook of Exoplanets*, arXiv:2410.12905, 2024.

★ https://www.cosmos.esa.int/Gaia

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

(25) Lightkurve Collaboration, 'Lightkurve: Kepler and TESS time series analysis in Python', Astrophysics Source Code Library, 2018.
(26) J. M. Jenkins *et al.*, in *Proc. SPIE*, 2016, *Society of Photo-Optical Instrumentation Engineers* (*SPIE*) *Conference Series*, vol. 9913, p. 99133E.
(27) J. Southworth, P. F. L. Maxted & B. Smalley, *MNRAS*, **351**, 1277, 2004.
(28) J. Southworth, *A&A*, **557**, A119, 2013.
(29) D. Hestroffer, *A&A*, **327**, 199, 1997.
(30) P. F. L. Maxted, *A&A*, **616**, A39, 2018.
(31) J. Southworth, *The Observatory*, **143**, 71, 2023.
(32) A. Claret & J. Southworth, *A&A*, **664**, A128, 2022.
(33) A. Claret & J. Southworth, *A&A*, **674**, A63, 2023.
(34) J. Southworth, *MNRAS*, **386**, 1644, 2008.
(35) A. Mallama, *PASP*, **93**, 774, 1981.
(36) J. M. Kreiner, C.-H. Kim & I.-S. Nha, *An atlas of O-C diagrams of eclipsing binary stars*, 2001.
(37) M. Cropper *et al.*, *A&A*, **616**, A5, 2018.
(38) Gaia Collaboration, *A&A*, **674**, A34, 2023.
(39) L. B. Lucy & M. A. Sweeney, *AJ*, **76**, 544, 1971.
(40) D. Bashi *et al.*, *MNRAS*, **517**, 3888, 2022.
(41) A. Tokovinin, *AJ*, **165**, 220, 2023.
(42) M. L. Marcussen & S. H. Albrecht, *AJ*, **165**, 266, 2023.
(43) J. Southworth, *The Observatory*, **143**, 165, 2023.
(44) J. Southworth, *The Observatory*, **144**, 242, 2024.
(45) A. Prša *et al.*, *AJ*, **152**, 41, 2016.
(46) J. Southworth, P. F. L. Maxted & B. Smalley, *A&A*, **429**, 645, 2005.
(47) J. Southworth, *The Observatory*, **144**, 181, 2024.
(48) P. Kervella *et al.*, *A&A*, **426**, 297, 2004.
(49) Y. Chen *et al.*, *MNRAS*, **444**, 2525, 2014.
(50) A. Bressan *et al.*, *MNRAS*, **427**, 127, 2012.
(51) P. M. Hejlesen, *A&A*, **84**, 135, 1980.
(52) P. M. Hejlesen, *A&AS*, **39**, 347, 1980.
(53) A. Maeder & G. Meynet, *A&A*, **210**, 155, 1989.
(54) R. B. Stothers, *ApJ*, **383**, 820, 1991.
(55) L. A. Balona & D. Ozuyar, *MNRAS*, **493**, 5871, 2020.
(56) J. S. G. Mombarg *et al.*, *A&A*, **691**, A131, 2024.
(57) P. Gaulme & J. A. Guzik, *A&A*, **630**, A106, 2019.
(58) J. Southworth & T. Van Reeth, *MNRAS*, **515**, 2755, 2022.
(59) P. Lenz & M. Breger, *Communications in Asteroseismology*, **146**, 53, 2005.

REVIEWS

Attention is Discovery. The Life and Legacy of Astronomer Henrietta Leavitt, by Anna Von Mertens (MIT Press), 2024. Pp. 256, 26 × 21 cm. Price £32/$34·95 (hardbound; ISBN 978 0 262 04938 2).

This is a biography with a difference: a life in science seen through the eyes of an artist. Henrietta Swan Leavitt is internationally known as the discoverer of what has long been known as the period–luminosity relation for Cepheid variables (officially renamed by the IAU in 2008 as Leavitt's Law), but this book makes it very clear what a laborious task it was to discover it — first noticed and published in 1908 (as a single sentence in a paper recording details of 1177 variables, with 16 variables in Table VI: "It is worthy of notice that in Table VI the brighter variables have the longer periods"), and confirmed four years later after more detailed study with more Cepheids.

In our day, it is hard to remember the revolution caused by the replacement of photographic records by digital ones recorded by CCDs. Miss Leavitt was one of the famous women 'computers' at Harvard College Observatory in the early 1900s who meticulously studied and recorded information contained on many of the more than half-a-million 8×10-inch glass plates in the Harvard Plate Stacks. The plates cover both the northern and southern hemispheres, the latter being taken at the Observatory's outstation at Arequipa in Peru, from where the plates were shipped back to Boston in many stages: mule train to the Pacific coast, by ship to Panama, over the isthmus by land, and finally by ship to Boston, providing many opportunities for damage; amazingly, very few plates were broken.

Von Mertens stresses the distinction between looking and seeing. Looking is a passive approach, seeing takes intensive and careful inspection and understanding. Seeing requires total concentration for hours at a time and must have taken its toll, physically, mentally, and emotionally. The results were faithfully recorded by Leavitt and her colleagues in many volumes of handwritten notebooks, all of which survive; many were consulted by the author. The plates were annotated by Leavitt, writing in pen on the reverse side of the plate, separated from the emulsion by a millimetre of glass. The plates are now being digitized and initially these markings were erased to give a clearer starfield, but their historical and archival importance has now been recognized and the most important ones are being preserved.

The book is lavishly illustrated by many photographs of plates (mostly negative), meticulous drawings of plates by the artist Jennifer L. Roberts (who also provides a ten-page illustrated essay on Leavitt), and by Von Mertens herself. There are also illustrations of Von Mertens' own artwork and photographs of Leavitt and her colleagues, some including their percipient and supportive Director, Edward Pickering. An essay by João Alves recounts his accidental discovery of Leavitt's work in the 1943 edition of Shapley's book *Galaxies*. He quotes Shapley as writing "Leavitt … had the gift of seeing things and of making useful records of her measures". Later, he says "It would only later dawn on me that looking at an image over a long period is far from an exercise in boredom: it's a *technique*. Repeated looking, day after day, gazing, contemplating. Looking for a sign, no matter how small." In his PhD thesis, he used this technique to uncover what he calls the Radcliffe Wave — the alignment of many very faint gas clouds running from the Orion Nebula towards the Galactic plane. It runs for more than 10 000 light-years from Taurus to Cepheus, unsuspected until Alves' painstaking work that followed Leavitt's technique of looking until you see.

There is so much in this book that I can't cover it all. But I really enjoyed the very different perspective and can strongly recommend it to anyone with an interest in art and/or the history of astronomy. At the modest price, it would make a good present for someone. At the very least, it would be a beautiful coffee-table book. — Robert Connon Smith.

The Milky Way Smells of Rum and Raspberries … and Other Amazing Cosmic Facts, by Jillian Scudder (Icon Books), 2023 (originally published 2022). Pp. 255, 19·7 × 13 cm. Price £10·99 (paperback; ISBN 978 1 83773 101 5).

Jillian Scudder is associate professor of physics and astronomy at Oberlin College, Ohio. As one might expect from the title, the book is a collection of interesting facts, the thirty-four chapters of about four to eight pages each discussing them in turn, starting with the entire Universe and moving in through galaxies, stars, and black holes to the Solar System (with which somewhat more than half of the chapters are concerned). Although chosen to be interesting, they are used as jumping-off points to explain various aspects of astrophysics.

Some examples: 'The Universe is beige, on average', 'The galaxy is flatter than a credit card', 'It rains iron on some brown dwarfs', 'Europa might glow in the dark'. Forty-five pages of small-print endnotes point the reader to more details, either technical papers (standard bibliographic references but including DOIs) or URLs; footnotes are proper footnotes. It is thus similar to other books[1–8] which select a (small, medium, or large) number of topics and discuss them in some detail without trying to cover too much ground, a welcome alternative to introductory books which cover all of (some branch of) astronomy but necessarily at a rather superficial level. There are a few black-and-white figures scattered throughout the book, but no index. This is a nice book suitable as an introduction to those interested in astronomy but with pointers to more information, but probably everyone could learn something new from it. — PHILLIP HELBIG.

References

(1) G. Sparrow, *50 Astronomy Ideas You Really Need to Know* (Quercus), 2016.
(2) P. Helbig, *The Observatory*, **137**, 30, 2017.
(3) G. Sparrow, *The History of Our Universe in 21 Stars (That You Can Spot in the Night Sky)* (Welbeck), 2023.
(4) P. Helbig, *The Observatory*, **145**, 40, 2025.
(5) A. Cohen, *The Universe* (William Collins), 2023.
(6) P. Helbig, *The Observatory*, **145**, 78, 2025.
(7) G. Lavender, *The Short History of the Universe: A Pocket Guide to the History, Structure, Theories & Building Blocks of the Cosmos* (Laurence King), 2022.
(8) P. Helbig, *The Observatory*, **145**, 77, 2025.

Honoring Charlotte Moore Sitterly: Astronomical Spectroscopy in the 21st Century, edited by David R. Soderblom & Gillian Nave (Cambridge University Press), 2024. Pp.133, 25·5 × 18 cm. Price £110/$145 (hardbound; ISBN 978 1 009 35192 8).

I suppose it might just be possible, if you are not at all involved in spectroscopy, that you might not be entirely familiar with the name Charlotte Moore-Sitterly. I think, however, that anyone who has done any work in atomic spectroscopy would agree that Charlotte Moore-Sitterly was one of the greatest spectroscopists of the 20th Century, and, as this volume shows, her pioneering work extends far into the 21st. It is probably not possible to make any attempt at interpreting an astronomical spectrum without extensive reference to her tables of *Atomic Energy Levels* (*AEL*) and her *Revised Multiplet Table* (*RMT*) *of Astrophysical Interest*. The spectroscopic notations of atomic energy levels, terms, and multiplets, with which we are today so familiar, is largely the work of Moore-Sitterly, who, as Donald Menzel wrote, "turned chaos into order"

This slim (but exceedingly important) volume represents the Proceedings of the 371st Symposium of the International Astronomical Union, held in Busan, South Korea, in 2022.

The first two plenary papers in the volume are first, a brief biography of Moore-Sitterly (about whom relatively little has previously been written) and how her legacy extends into the present century. These two papers alone are surely of great interest to any spectroscopist interested in the history and development of the subject, and of Moore-Sitterly's role. How often has Moore-Sitterly's work been cited? That is impossible to calculate. For one reason, according to this volume, about 2500 different spellings of *Atomic Energy Levels* are to be found in the literature. Furthermore, since about 1995, the work started by Moore-Sitterly in her three *AEL* volumes has now been hugely expanded into and cited as NIST ASD (National Institute of Standards and Technology, Atomic Spectra Database).

Of course there have been tremendous advances this century and literally billions of spectrum lines have been measured or calculated by someone or other. How far have we succeeded this century in turning "chaos into order", as Moore-Sitterly did in the last? There have been many compilations, some small, some vast, of spectroscopic data, and the modern user of spectra has to know where to turn to find these data. It is for this reason that any user of laboratory astrophysical data (atomic and molecular spectroscopy, astrochemistry of small and large molecules, oscillator strengths, collision rates, aerosol data) will need this book. Herein are to be found descriptions and whereabouts of all such compilations and how to use them. Also described are the many intrinsically useful quantities for which accurate laboratory data are not yet determined. There is much work yet to be done in laboratory astrophysics, and this volume should give young researchers some profitable ideas.

I have only one tiny disappointment. I see that most of the authors are still using the old term "transition probabilities" for what are better termed Einstein A coefficients. The Einstein coefficient is not in any sense a "transition probability" such as is used in probability theory. It is much more akin to the decay constant of a radioactive nuclide with dimensions T^{-1}.

Included as well as compilations of laboratory data are the capabilities of large telescopes (such as the *Very Large Telescope* (*VLT*) and the *Extremely Large Telescope* (*ELT*)) and their associated spectrographs. For example, one of the échelle spectrographs of the *VLT* is capable of measuring radial velocities with a precision of 10 cm s^{-1}. In units that we can understand, that is about 0·22 miles per hour, corresponding to a Maxwell–Boltzmann kinetic temperature of hydrogen atoms of 0·4 μK. I don't know whether astronomers can really make use of such exquisite precision.

This book will cost you about 83 pence or US$1·45 per page, and it is well worth every penny of it. I don't know how many copies were printed in excess of those needed by delegates to the symposium, but you should hurry to get a copy before they run out. — JEREMY B. TATUM.

Robert Hooke's Experimental Philosophy, by Felicity Henderson (Reaktion), 2024. Pp. 183, 22 × 14·5 cm. Price £17·95 (hardbound; ISBN 978 1 78914 954 8).

The latter part of the 17th Century was an exciting time for science in Britain. The freedom of thought encouraged by the Restoration led to many things, including the foundation of the Royal Society, the establishment of the Royal Observatory at Greenwich, and the remarkable advances made by Isaac Newton. It also witnessed the rise to prominence of the amazing polymath Robert Hooke, often just remembered for his Law (on the extension of springs) and the row he is said to have had with Newton over the Law of Gravity. There was, however, much more to Hooke than that. He was interested in *everything* and his Experimental Philosophy was built on applying his vast knowledge to every problem. His practical expertise came from his work as the Curator for the Royal Society, which meant demonstrating all manner of experiments and processes before an audience of his peers; for that task he was perhaps the first salaried scientist. He gained insights from innumerable conversations with manufacturers in their factories and fellow scientists in the coffee houses of London. And he was a first-rate artist as shown by the astonishing drawings of a range of subjects viewed through his microscope.

The present delightful book by Felicity Henderson details Hooke's career from his birth on the Isle of Wight to his death in London at the age of 67. It's a fascinating read and very modestly priced — DAVID STICKLAND.

Lunar. A History of the Moon in Myths, Maps + Matter, edited by Matthew Shindell (Thames & Hudson), 2024. Pp. 256, 37 × 27 cm. Price £50 (hardbound; ISBN 978 0 500 02714 1).

This is a very magnificent book to own in terms of its historical coverage, Moon lore, graphics, and the sheer scale of this work. You certainly need widely vertically spaced shelves in order to fit this book onto a book shelf, and it's good value at just £50. The main theme of the book celebrates the pioneering efforts by United States Geological Survey (USGS) geologists and cartographers to map the Moon's geology in the 1960s–1970s, initially through Earth-based telescopes, and later using *Lunar Orbiter* and Apollo imagery. So these maps are not surprisingly the main colourful theme pervading the book; I only wish they were larger at times in order to make their wealth of detail more visible. But in view of the large size of the original maps, this is not possible. Interspersed between the map pages are nuggets of fascinating information about old telescopic observations, spacecraft imagery, the Moon in multi-cultural folklore, paintings, and movies, *etc*. Unsurprisingly, with modern-era lunar missions, there are now more up-to-date geological maps, but what is shown here is still a good basis for selenophiles to brush up on their geology and a great place to find nuggets of interesting facts for lectures or the media. Although the book is very comprehensive and wide-ranging in terms of its coverage, it may have missed out, though, on the opportunity to mention the work of US Army and USAF cartographers, such as James Greenacre, who, spent many hundreds of hours, often during very cold nights, sketching the Moon at the eyepiece end of the Clark refractor at Lowell Observatory, Flagstaff. Their work formed the basemaps on which the colourful geological maps were overlaid. However, I guess it is not possible to mention everyone who contributed to the USGS map series and the author had to be very selective.

Anyway, I am sure that *Lunar*, through its addictive graphics and illustrations, will inspire many readers to take a greater interest in the Moon, especially now with the run up to Project Artemis in the next few years. — ANTHONY C. COOK.

Einstein and the Quantum Revolutions, by Alain Aspect (University of Chicago Press), 2024. Pp. 95, 19 × 12·5 cm. Price £13/$16 (hardbound; ISBN 978 0 226 83201 2).

Alain Aspect shared the 2022 Nobel Prize in physics with John Clauser and Anton Zeilinger for their independent but complementary work involving entangled photons, which experimentally demonstrated the Bell inequalities and led the way to quantum information science. That is certainly one reason for the publication of this little book (less than eighty pages of main text, small format, large print). However, it was originally published as an essay, in French, in 2019 in the collection *Les Grands Voix de la Recherche* which presents the work of the winners of the CNRS Gold Medal (given in all fields of science and one of the highest scientific awards in France). It is nice to have a description of this very topical subject in the (translated) words of one of the main players in the field. It is aimed at a very general readership and in terms of style, level of content, and even with regard to the physical book, reminds me of another book[1] reviewed in these pages[2], also a book for a general readership written by a practising physicist.

There were two quantum revolutions, in both of which Einstein played an important role. The first was quantum mechanics itself, in particular the aspect of wave–particle duality, as developed during the first three decades or so of the 20th Century. The second can be defined to start with John Bell's publication of his famous inequalities; measurements on entangled particles more correlated than the upper limit set by Bell's inequality demonstrate that quantum mechanics is not compatible with local realism, though the latter was the hope of Einstein, Schrödinger, and Bell himself. Einstein had laid the groundwork for the second quantum revolution in his famous paper[3] with Podolsky and Rosen (EPR) almost thirty years earlier, though their hope was that a hidden-variable theory could be constructed in order to avoid spooky action at a distance. Bohr is famous for rebutting Einstein's arguments about Bohr's view of quantum mechanics, and most physicists agree with Bohr in that respect. Aspect makes the point that Bohr's rebuttal of the EPR arguments is much less convincing, but nevertheless there was little further debate during the next thirty years or so due to the practical successes of quantum mechanics, which are independent of its philosophical interpretation.

There is a bit more material on the second quantum revolution, also covering topics such as the manipulation of quantum objects (*e.g.*, single ions), quantum cryptography, and the question whether experiments similar to those discussed will show a limitation to quantum theory. I haven't read the original, but it all seems to have been translated well. There are a few black-and-white figures, but no notes, bibliography, or index; the book is very well produced and would make a nice gift. Those wanting to explore the themes of this book in more detail should read *Quantum Drama*[4] (reviewed in these pages[5]), which is a bit longer and more technical than a typical popular-science book, while this book is a bit shorter and less technical, but provides an easily digestible summary of the topic, in keeping with Einstein's dictum to make everything as simple as possible but not simpler. — Phillip Helbig.

References

(1) C. Rovelli, *Seven Brief Lessons on Physics* (Allen Lane), 2015.
(2) P. Helbig, *The Observatory*, **136**, 155, 2016.
(3) A. Einstein, B. Podolsky & N. Rosen, *Physical Review*, **47**, 777, 1935.
(4) Jim Baggott & John L. Heilbron, *Quantum Drama: From the Bohr–Einstein Debate to the Riddle of Entanglement* (Oxford University Press), 2024.
(5) P. Helbig, *The Observatory*, **144**, 257, 2024.

Parallel Lives of Astronomers: Percival Lowell and Edward Emerson Barnard, by William Sheehan (Springer), 2024. Pp. 687, 24 × 16 cm. Price £44·99 (hardbound; ISBN 978 3 031 68799 0).

In this massive and copiously illustrated biography, William Sheehan constructs a meticulous comparison of the lives of two very different personalities. Percival Lowell (1855–1916) was born with the proverbial silver spoon in his mouth into a Boston family that had grown rich upon the textile industry, and for whose education no expense was spared, whereas E. E. Barnard (1857–1923) had an extremely humble origin in Nashville, with almost no schooling, and he would become a self-made man through sheer necessity. His employment as a photographer's assistant was to prove fortuitous.

Lowell started his career as an Orientalist, but after reading Flammarion's monumental Mars book, turned his attention to the heavens. A born wordsmith and superb mathematician, yet hampered by his preconceived ideas about the

Red Planet, he extended the existing Schiaparellian canal network far beyond its credible limits, and thereby came into conflict with many leading scientific figures. But Lowell won lasting popular acclaim through his compelling and voluminous writings, which would continue to influence gullible American (and other) readers decades after the canal question had been settled in 1909.

Starting off as an amateur astronomer, Barnard began his professional career at Lick Observatory, where he used his considerable experience in photography and visual observation to good effect. His visual discovery of Amalthea and his comet and Milky Way photographs soon won him scientific acclaim. Barnard never saw canals upon Mars, but with the Lick 36-inch refractor under excellent seeing he had a glimpse of the true nature of its irregular surface.

Neither he nor Lowell had any children, and both were completely devoted to their Muse, often at the expense of their health. Spending entire sub-zero nights in the dome at Yerkes took their toll upon Barnard, while Lowell had a complete nervous breakdown from overwork only a few years after his observatory had opened.

Barnard could never get on with E. S. Holden at Lick, the Director being more of an antiquarian than an astronomer. His move to the new Yerkes Observatory was timely, even if he would never again enjoy excellent seeing for his planetary work. Instead he obtained access to state-of-the-art facilities for wide-field deep-sky photography. Lowell of course never had to work for anybody. Some of his assistants at Flagstaff had very short careers there, unable to deal with their autocratic master's bouts of bad temper, or for being unable to see the planets in the approved Lowellian manner.

All of this detail and far more is described in a story in which the parallel lives of the two great astronomers are cleverly woven together and critically examined. Sheehan has previously given us a biography of Barnard, and has written extensively about Lowell and the history of Mars observations generally, and so is well placed to have produced such a comprehensive study. But still it must have required a monumental amount of research.

With the benefit of hindsight, we might ask why Lowell blindly accepted the diagrammatic Mars of Schiaparelli and not the natural-looking world sketched by other astronomers. But Lowell was always sure of himself, and his version of the Solar System was a hierarchical one in terms of age. Mars must have cooled faster than the Earth, and its civilisation must therefore be older and wiser, and had of course become canal-builders out of necessity. We might ask many questions about Lowell. What if he had discarded social norms of his day to marry his devoted Secretary and assistant Wrexie Louise Leonard, rather than the lady who would prove such a financial disaster to the Observatory after his death? Despite all of Lowell's wealth and education, in the end it was the poor boy from Nashville who not only found the perfect life partner in Rhoda Calvert, but who would better comprehend the true nature of the Martian surface.

Under Lowell's directorship Flagstaff became a centre of excellence in the fledgling field of planetary photography. And he conducted a serious search for a trans-Neptunian planet. Pluto, discovered years after his death at his own observatory, would bear his initials, PL. And the radial-velocity work upon extragalactic nebulae conducted at Flagstaff by V. M. Slipher would pave the way towards an understanding of the expanding Universe. For his part, Barnard produced the most accurate micrometrical measures of the bodies of the Solar System, made several cometary discoveries, gave accurate descriptions of planetary features, and undertook important contributions to stellar astronomy with his numerous papers and Milky Way photography which mapped out so clearly its structure, and the intricate dark patches and lanes of interstellar dust. We also remember him for the discovery of Barnard's Star, with its record-breaking proper motion.

Parallel Lives is always fascinating, and is a real work of reference. There are plenty of striking illustrations, including many not previously seen. Just in a few instances the publisher has slipped up with the placing of an illustration, or has left an unexplained gap, on part of a page. Nor has the publisher provided an index; given the enormous number of names (let alone events) scattered throughout the text, I would have considered one essential. Apart from its coverage of the lives of Lowell and Barnard, this book addresses so many aspects and personalities of the astronomy of a century ago that it must have a wide appeal to institutions and individuals. I can warmly recommend it. — Richard McKim.

Origins: The Cosmos in Verse, by Joseph Conlon (Oneworld), 2024. Pp. 158, 19·7 × 13 cm. Price £11·99 (hardbound; ISBN 978 086154 911 5).

At the 2024 Moriond cosmology meeting, Joseph Conlon, professor of theoretical physics at the University of Oxford, gave an invited talk on string theory, a topic rather far removed from the work of most of those at the conference. My impression, and that of many others, was that it was the best talk of the conference. Still looking much younger than his forty-three years and sometimes mistaken for a student, before a rather traditional career with BA and PhD from Cambridge then moving to Oxford as a Royal Society Research Fellow and moving up the ranks, Conlon had obtained a BSc in mathematics from the University of Reading (part-time alongside schoolwork). His popular-science book *Why String Theory?*[1] (near the top of my pile of books to read) was the *Physics World* Book of the Year in 2016. I was thus intrigued when I learned that he had written a book of poetry. The book contains two long poems about physics. Although currently out of fashion (though Max Tegmark does have an *ApJ* paper with the abstract in couplets[2]), poetry about science has a long tradition, going back at least to Lucretius's *On the Nature of Things*. Both Dante and Kepler wrote poetry about astronomy and cosmology[3,4], and Milton visited Galileo; Maxwell and Lovelace wrote poetry, and Keats was a licensed surgeon[5].

So what do we get? The first, somewhat longer, poem is 'Elements', which covers Big-Bang nucleosynthesis, star formation, basics of stars, Cecilia Payne (-Gaposchkin), B^{2}FH (ref. 6), the production of elements heavier than iron, life, and the author himself. 'Galaxies' starts off with some history of astronomy (especially the homogeneity of the Universe on large scales) before moving to inflation, General Relativity, and the cosmological constant, then moves down the scale to the subatomic realm and a discussion of quantum mechanics (important for inflation, spectroscopy, and X-rays, among other things) and its history, followed by a coda ("an extended simile") covering everything from Oxfordshire pubs to social networks to galaxies. Each poem is preceded by a preface of a page or so describing the structure and contents. The poems are followed by twenty-eight pages of notes adding more conventional scientific detail to the pages indicated (except for the coda in 'Galaxies'). Of course, like jokes, most poetry works best when nothing has to be explained, though some will find the notes helpful. A four-paragraph note on the formation of elements heavier than iron reads in part "...there are two possible ways the r-process can occur, both associated with exploding stars, and it is not yet fully known how each contributes to the formation of heavy elements in the present universe."

Though set in stanzas making the 'abab' rhyming scheme and the (mostly) iambic pentameter obvious, if formatted differently it would sound almost like normal prose — no mean feat! As such, this is a unique book, at least in modern times; I certainly haven't come across anything similar. At times, the style reminded me of Pope, Ginsberg, Whitman, Wordsworth, Blake, or Carroll (Lewis, not Sean). It is not clear to me who the target readership is: the union of those interested in poetry and physics? The intersection? Those who want to try everything? A nice gift for the person who has everything else? I'm not sure, but I think that many will get something out of this book. — PHILLIP HELBIG.

References

(1) J. Conlon, *Why String Theory?* (CRC Press), 2016.
(2) M. Tegmark, *ApJ*, **470**, L81, 1996.
(3) L. Rimpau, *Visionen neuer Wissenschaft: Zur dialogischen Dichtung von Dante Alighieri und Johannes Kepler* (Universitätsverlag Winter), 2021.
(4) P. Helbig, *JAHH*, **27**, 232, 2024.
(5) K. Wright, *Physics Magazine*, **13**, 150, 2020.
(6) E. M. Burbidge *et al.*, *Rev. Mod. Phys.*, **29**, 547, 1957.

Cosmic Masers: Proper Motion toward the Next-Generation Large Projects, edited by Tomoya Hirota, Hiroshi Imai, Karl Menten & Yiva Pihlström (Cambridge University Press), 2024. Pp. 514, 25·5 × 18 cm. Price £120/$155 (hardbound; ISBN 978 0 009 39892 3).

The purpose of this review of IAUS 380 is presumably to give those who did not attend an impression and overview of the current state of the field. For this your reviewer is familiar enough with maser astronomy but has been away from the centre of action for some time. He therefore apologises for any misapprehensions in what follows. The overall personal impression is that work on, and using, celestial masers is very much in line with the astonishing change and progress in physics and astrophysics over the last half-century.

The structure of the volume reporting on IAUS 380 is that it comes in seven chapters relating to separate topics plus Chapter 8, 'Concluding Remarks'. Each chapter opens with a longer review paper and for the most part the succeeding papers report more individual work mentioned in the review. The work described in all of the chapters except Chapter 6 is concerned with the use of celestial masers as astrophysical probes rather than with the masers themselves. I attempt to make some comments about each chapter.

Chapter 1: 'Cosmic Distance Scale and the Hubble Constant'. There are just three papers in this chapter. The chief result is that megamasers may be used to measure the distance to some edge-on galaxies directly without using standard candles or distance ladders. H_0 for the late Universe is given as 73·9 km/s/Mpc with 4% precision. We are told that 1% precision is in prospect. This is important for work to resolve the so-called "Hubble Tension".

Chapter 2: 'Black-Hole Masses and the M-Sigma relationship'. The key point here is that super-massive black holes appear to be a feature of most, if not all, galaxies. Interesting relationships are discussed between these black holes, AGN, and rapid star formation in starbursts, which may co-evolve. Very high luminosities are made possible by the high energy-generation efficiency of mass accretion, tens of percent compared with 0·7% for nuclear fusion. However, all this is a bit obscure — literally. The surrounding medium is often optically thick to visible and IR radiation and the properties of the SMBH must be inferred from observations at sub-millimetre and longer wavelengths. Fortunately there are megamasers of water at 22 GHz, 183 GHz, and 321 GHz, which turn out to be useful. The M-Sigma relation is not much discussed.

Chapter 3: 'Structure of the Milky Way'. This opens with a masterful and full review by K. Rygl. The following papers are concerned with astrometry and measurements of distances to objects within the Galaxy. Both of these aspects are obviously crucial to understanding its structure, dynamics, and evolution. Currently we are short of data about the 1st and 4th quadrants of the Galaxy, *i.e.*, those that lie largely on the far side, beyond the Galactic Centre. The paper by Mark Reid is therefore of interest, 'Mapping the Far Side of the Milky Way'. The novel method uses "3-D kinematic distance estimates" requiring "only Doppler velocities and proper motions".

Chapter 4: 'Dynamics of Formation of Massive Stars'. The opening review paper by J. S. Urquhart highlights the importance of understanding high-mass, and therefore bright, stars because their properties are likely to dominate our observations of other galaxies and therefore on cosmological models that may depend on those observations. Unfortunately it is not so easy from our point of view, as there are few high-mass stars close by, and anyway they tend to form in clusters. Good progress has therefore depended on various Galactic Plane surveys and a useful table of 22 of those is presented. There follow more than 30 papers presenting various observations and aspects of this important topic.

Chapter 5: 'Pulsation and Outflows in Evolved Stars'. This section consists of some two dozen varied and interesting papers beautifully introduced by the review of L. D. Matthews, 'Mass Loss in Evolved Stars'. Although the basic framework for understanding mass loss from AGB stars is now half a century old, challenges remain. Winds are believed to be driven by radiation pressure on opaque dust grains formed in the cool outer atmospheres of such stars. Whilst this model works well enough for carbon stars as the carbonaceous grains have high opacity, this is not true for the majority of AGB stars that have oxygen chemistries. It is not clear what determines whether the C/O is greater or less than unity in the first place. Furthermore, the outward flow is not uniform but is subject to turbulent variations. It may be not possible to model this in detail but only in terms of scales in time and space. Nevertheless the overall process has regularities as shown by the famous movie of TX Cam by Gionidakis *et al.* of SiO maser emission over 78 epochs. Indeed, studies of both maser emission and thermal radio-line and continuum radiation are needed to observe these winds. Winds from AGB stars are believed to be a major mechanism by which the ISM becomes enriched with all elements up to iron. It is perhaps good to note that our own existence therefore depends on such processes in the past.

Chapter 6: 'Maser Theory'. This section has six interesting talks on the physics of masers rather than how they might help in understanding celestial objects. The opening talk revisits Dicke's super-radiance theory and discusses its complementarity with maser emission. This work is reflected in modelling maser flares in real sources: S255IR-NIRS3 with results shown and G9·62+0·2E with work in progress. The other papers discuss maser effects in recombination lines, the pumping of flaring masers, and two papers on polarization of maser emission, modelling and simulation.

Chapter 7: 'New Projects and Future Telescopes'. The opening paper discusses the valuable work of the Maser Monitoring Organization (M2O), set up around the time of the previous IAUS devoted to masers. As discussed in Chapter 6, flaring is a notable feature of celestial maser emission. By its very nature, it is easy to miss them unless they are watched for. The M2O has found an average of 1 to 2 per year. The new facilities and upgrades to present ones discussed in the following papers are a sign of a lively research community and interesting results to be expected in the future.

Chapter 8: 'Concluding Remarks'. In some ways, this section does the work of a reviewer for them. Two quotations may suffice: (*i*) "Seven major topics on maser sciences were presented and discussed: theory, cosmology, galaxies, Milky Way, star-formation, evolved stars and future prospects. Just as in previous meetings, the details of high-mass star formation continue to stimulate extensive research through primarily methanol and water maser studies. …"; and (*ii*) "In recent years, accurate Galactic astrometry has been done and the Milky Way rotation curve has been verified (*e.g.*, Rygl, Honma, Reid, Ellingsen). It is clear that we can now study the 'unreachable' — *e.g.*, the Bulge (Sjouwerman, Lewis), the Long Bar (Kumar), the Galactic Centre (Paine, Sakai) and we can learn about kinematics in extremely obscured Luminous Infra-Red Galaxies (*e.g.*, Aalto)."

The book itself is nicely produced by CUP, but there are serious downsides when it comes to the reproduction of the figures which are so important to the text. A large fraction of them are quite complex and authors have used colour to simplify matters. Having them reproduced in black and white makes them much less than easy to interpret. Also in some cases the figures are made too small making it hard to read text on them, although this may be due to how the authors presented their papers for publication. In all cases the figures are at least as important as the text and they deserve to be shown in the same clear style as the text. — M. R. W. Masheder.

Before the Big Bang: Our Origins in the Multiverse, by Laura Mersini-Houghton (Vintage), 2023 (first published 2022). Pp. 248, 19·7 × 13 cm. Price £10·99 (paperback; ISBN978 1 784 70934 1).

Laura Mersini-Houghton's doubled-barrelled surname reflects her Albanian origin and her British husband. That would normally not be worth mentioning in a book review, but in this case the book is not only a popular-science book with an emphasis on the author's own work, but also something of a personal memoir, recounting her life in Albania (where she received her BS degree), the USA (MSc and PhD), and Italy (postdoc) before moving up the ranks from non-tenured assistant to tenured full professor at the University of North Carolina at Chapel Hill. The book starts out asking whether our Universe is special, particularly with respect to the low entropy at the beginning. Following that is a standard discussion of inflation and the early Universe and then an overview of quantum mechanics. The next three chapters discuss fine-tuning, the many-worlds interpretation of quantum mechanics, and the string-theory landscape. Those first six chapters (of eleven altogether) are necessary background for the introduction of her own idea: "quantum mechanics on the landscape of string theory".

She arrives at the conclusion that our Universe is, in contrast to the famous objection by Penrose[1], not unlikely despite its low entropy at the beginning, the difference due essentially to taking quantum de-coherence into account. I don't know whether her book will convince anyone that her reasoning is correct, but I, despite familiarity with concepts such as cosmology in general, the Multiverse, fine-tuning, the Anthropic Principle, and so on[2], found her argument hard to follow. Of course, her technical papers should be the deciding factor, but in a popular book it should be possible at least to make the case so convincingly that readers with the necessary background are moved to explore it in more detail (whether or not they are still convinced after such an exploration). Neither is it the case that her many papers on such topics have led to a consensus in the field. That doesn't mean that they are wrong, but readers might get the impression that they are more mainstream than they are. When cheering for one's own theory, it is important to avoid the impression that one is being deliberately side-lined, since that is usually not the case. However, though she sometimes mentions swimming upstream, it seems to me that Mersini-Houghton goes too far in the other direction, claiming support for her particular view from some who work on anything involving the Multiverse, quantum cosmology, or whatever. Her claim that Hawking was sympathetic to the Multiverse towards the end of his life is in contrast to that of Hertog[3,4], Hawking's closest collaborator up intil the latter's death. (There are many types of Multiverses[5–10]; Mersini-Houghton mentions those due to eternal inflation, the many worlds of Everett's interpretation of quantum mechanics, and the string-theory landscape. Evidence for one type is not necessarily evidence for another type. An understanding of the relationship between different types of Multiverse, a topic which is still evolving, would be of help in understanding how her ideas related to other ideas involving the Multiverse.)

Of course, experimental confirmation is the gold standard by which any scientific theory should be judged. After a chapter on 'The Origin of the Universe' which brings all of the strands together, she discusses the possibility that interactions between various bubble universes could leave traces in the cosmic microwave background (CMB). Several anomalies in the CMB have been known for a couple of decades now and are the topic of a large number of papers. Mersini-Houghton points out that she had predicted six of them, all of which were later confirmed by observations. Though she does mention cosmic variance and the fact that the statistical significance of such anomalies is marginal, the message is that her theory has been confirmed observationally. My impression as an outsider who has followed the discussion somewhat is that her idea is one of many and the jury is still out. Again, that doesn't mean that it is wrong, and certainly confirmation of a firm prediction belongs in the 'interesting if true' category. I'll continue to follow the field, and the status of her ideas, but am somewhat put off by the sound of an axe very obviously being ground. For example, her discussion of the Anthropic Principle essentially amounts to dismissing a cardboard version of it, and connecting it to Descartes seems far-fetched; similar remarks apply to the discussion of Boltzmann brains.

For some reason, her description of the standard Big Bang picture gives too much space to Gamow; he was an important figure, but one of many in the story. The idea that not just his but all Big Bang models "[depend] on hot radiation to make the universe expand" is garbled at best. I recently reviewed[7] a book[8] about the history of the idea of the Multiverse, and more recently read another[9,10] going back over several millennia; though I read the latter book after this one, still I found her claim of a strong rejection of the Multiverse throughout history at best exaggerated, and doubt that the fate of Hugh Everett III is what persuaded most who didn't work on it to avoid it. (Interestingly, while she alludes to Everett's fate several times, it is not clear what she means: his early death (mainly due to an unhealthy lifestyle)? the fact that he didn't have an academic career after his doctorate (something which shouldn't necessarily be regarded as a failure*)? his daughter's suicide (long after her father's death)?) I found her discussion of quantum entanglement too vague to

*Both Alpher and Herman, who had worked with Gamow on early Big Bang ideas, left academic employment (though not research entirely, and both returned to academia to some extent later in life), but I don't think that their fate turned anyone away from working on Big Bang cosmology.

be useful, though of course that is an inherently difficult topic. The statement that Planck, Einstein, Bohr, Heisenberg, and Schrödinger all "laboured until the end of [their lives] to disprove the implications of quantum theory" is at best very misleading. Statements about Big Bang nucleosynthesis, the size of the horizon of the Universe, spatial curvature, and so on are, as stated, just wrong, but I'm willing to put them down to oversimplifying and/or bad editing, but perhaps they are due to unfamiliarity with other branches of astrophysics than quantum cosmology; certainly there is no other explanation for claiming that Tycho found that the Earth moves around the Sun. (That last claim is found in the epilogue, which contains a history of cosmology in a few pages. That is otherwise more or less correct, though the tendency to interpret some current debates in the light of that history seems dubious to me.)

My usual complaints about style apply, and there are a few nasty typos (I'm sure that a universe complex enough to support life must have many more than 10^{15} particles). There are a few black-and-white figures scattered throughout the book, which fortunately has footnotes rather than endnotes and ends with a seven-page small-print index. Despite my qualms, I found the book to be an interesting read, both with respect to her work and to her personal odyssey, though in both cases I wouldn't draw the same conclusions in all cases. — Phillip Helbig.

References

(1) R. Penrose, in E. J. Fenyves (ed.), *Fourteenth Texas Symposium on Relativistic Astrophysics* (New York Academy of Sciences), 1989.
(2) P. Helbig, *Foundations of Physics*, **53**, 93, 2023.
(3) T. Hertog, *On the Origin of Time: Stephen Hawking's Final Theory* (Transworld), 2023.
(4) P. Helbig, *The Observatory*, **144**, 201, 2024.
(5) M. Tegmark, *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality* (Allen Lane), 2014.
(6) P. Helbig, *The Observatory*, **134**, 150, 2014.
(7) P. Halpern, *The Allure of the Multiverse: Extra Dimensions, Other Worlds, and Parallel Universes* (Basic Books), 2024.
(8) P. Helbig, *The Observatory*, **144**, 197, 2024.
(9) T. Siegfried, *The Number of the Heavens: A History of the Multiverse and the Quest to Understand the Cosmos* (Harvard University Press), 2019.
(10) J. Overduin, *The Observatory*, **140**, 107, 2020.

Annual Review of Astronomy and Astrophysics, Volume 62, 2024, edited by E. van Dishoeck & Robert C. Kennicutt (Annual Reviews), 2024. Pp. 645, 24 × 19·5 cm. Price from $460 (print and on-line for institutions; about £357), $126 (print and on-line for individuals; about £98) (hardbound; ISBN 978 0 8243 0962 6).

Annual Review was a particular treat this year since it seemed to be mainly about *stars*, which is the pond in which I dabbled as a young astronomer, and indeed for the remainder of my career. And it begins in splendid fashion with an autobiographical account by Michel Mayor, famed not only as the discoverer of the first star to show signs of an exoplanet but honoured with a Nobel Prize for his work. Based on the principles of radial-velocity measurement pioneered by long-time Editor of, and contributor to, this *Magazine* Roger Griffin, Professor Mayor and his colleagues have pushed the technique to amazing precision — less than 1 m s^{-1}.

Starting with our own private star, the Sun, Fletcher gives an in-depth account of solar activity revealed by spectroscopic examination of flares over a range of wavelengths. Then staying with stars even cooler than the Sun, Henry

& Jao pick over the characteristics of M-type dwarfs, stars that have not really started to evolve in any dramatic way yet. The composition of such stars and any putative Earth-like exoplanets is discussed by Teske. And spectrum synthesis of stellar spectra is described by Lind & Amarsi in which many factors, like convection, are included — so much more sophisticated than my dabblings in the late 1970s.

Star and planet formation is considered in several chapters. Schinnerer & Leyroy start with the examination of molecular gas in nearby galaxies, while Hunter *et al.* study the ISM in dwarf irregular galaxies, and Birnstiel looks at dust growth in planetary discs, with *ALMA* now a valuable tool; related work on proto-stellar systems is reviewed by Tobin & Sheehan. And at the end of it all, *Gaia* results examined by Hennebelle & Grudić give us the IMF that should be produced!

On the larger scale, how galactic development is affected by the products of massive-binary evolution is described by Marchant & Bodensteiner, with Thompson & Heckman viewing an even bigger picture featuring winds from star-forming galaxies.

Away from the observatory and in the laboratory, Cuppen *et al.* make a study of the ices found in the ISM, adding detail for the observers to hunt down.

And last but not least it is time to see, in the company of Verde *et al.*, where we are in the determination of the Hubble Constant. Not a pond in which I ever poked a toe! — David Stickland.

The Short Story of the Universe: A Pocket Guide to the History, Structure, Theories & Building Blocks of the Cosmos, by Gemma Lavender (Laurence King), 2022. Pp. 224, 21·5 × 15·5 cm. Price £14·99 (paperback; ISBN 978 0 85782 938 2).

After studying astrophysics in Cardiff and holding various jobs in publishing, Lavender now works in Communications, Content & Outreach at the European Space Agency and has written a few other books. This book is one of a series 'The Short Story of...', others including photography, architecture, film, *etc.* Obviously, such topics, much less the Universe, will not fit into one book, especially if it's just the short story. The strategy is to choose a wide range of topics and offer a summary of each. It is thus similar to other books[1–8] which select a (small, medium, or, as in this case, large) number of topics and discuss them in some detail without trying to cover too much ground, a welcome alternative to introductory books which cover all of (some branch of) astronomy but necessarily at a rather superficial level. The many chapters are collected into four parts: 'Structure' (two pages per chapter), 'History and Future' (one), 'Components' (usually two), and 'Theories' (one). Some examples: 'Spacetime', 'Stars', 'Elements'; 'Forging the Elements', 'Birth of the Moon', 'The Future of the Universe'; 'Elliptical Galaxies', 'Wolf-Rayet Stars', 'Uranus'; 'Multiverse', 'Stellar Spectroscopy', 'Galaxy Evolution'; the second part is by far the longest.

Each chapter contains a picture (usually colour; exceptions are historical black-and-white images) and a few paragraphs of text. At the bottom of the page are references to related chapters. Otherwise, the format depends on the part. In the 'Structure' part, each chapter mentions one or more scientists together with a relevant topic, place, and time; a brief biography (sometimes of a 'key scientist', sometimes of some other relevant person); and key publications (authors, titles, and years). 'History and Future' has key scientists and a key development as well as the time since the Big Bang of the corresponding event; 'Components' has a list of notable examples of the corresponding component and a brief biography of someone who has worked in that field; 'Theories' is like 'History and Future' but without the timeline. I'm reminded of the professor (whose main job was theoretical particle physics and who looked very much like James Clerk Maxwell) who taught me classical mechanics: for the exam at the end of the course, he allowed us to bring one sheet of paper containing anything we wished to write on it. (Of course, and that was probably the intent, the act of thinking about what is important and writing it down meant that it wasn't actually used as much as we might have thought would be necessary.) This book is similar but covers more than a hundred topics. All of the parts range over (but, of course, don't really cover) essentially the whole of astronomy in about the expected proportions except that 'Components' devotes about half of its chapters to the Solar System, which reminded me of the previous book I had read[7].

'Paperback' is a bit of a misnomer; the cardboard cover (with somewhat thinner front and back flaps) is a bit stiffer than is the case with most paperbacks, and the binding is more like a hardcover. The paper is slick, the images are in high resolution, there are almost no typos, and I noticed no factual mistakes. Apart from the chapters (including a couple of introductory ones) and the seven-page index, that's it, but that is all that is needed. This is a beautiful and well-produced book and would provide not only a good introduction to astronomy, astrophysics, and cosmology but also, despite the lack of full traditional references, enough information so that the interested reader could easily find further information on the topic. — PHILLIP HELBIG.

References

(1) G. Sparrow, *50 Astronomy Ideas You Really Need to Know* (Quercus), 2016.
(2) P. Helbig, *The Observatory*, **137**, 30, 2017.
(3) G. Sparrow, *The History of Our Universe in 21 Stars (That You Can Spot in the Night Sky)* (Welbeck), 2023.
(4) P. Helbig, *The Observatory*, **145**, 40, 2025.
(5) A. Cohen, *The Universe* (William Collins), 2023.
(6) P. Helbig, *The Observatory*, **145**, 78, 2025.
(7) J. Scudder, *The Milky Way Smells of Rum and Raspberries: …and Other Amazing Cosmic Facts* (Icon Books), 2023.
(8) P. Helbig, *The Observatory*, **145**, 65, 2025.

The Universe, by Andrew Cohen (William Collins), 2023 (originally published 2021). Pp. 272, 19·5 × 13 cm. Price £9·99 (paperback; ISBN 978 0 00 838935 2).

Andrew Cohen is Head of the BBC Studios Science Unit and this book is based on the BBC series of the same name, which is presented by Brian Cox (who contributes a foreword). I haven't seen the programme, but the book stands well on its own. The title is something of an exaggeration, as there are only five major topics (each with its own chapter). However, any book broad enough to cover the entire Universe would be very shallow. It is thus similar to other books[1–8] which select a (small, medium, or large) number of topics and discuss them in some detail without trying to cover too much ground, a welcome alternative to introductory books which cover all of (some branch of) astronomy but necessarily at a rather superficial level. The areas covered — exoplanets, stars, galaxies, black holes, and the early Universe — are a mixture of major subjects in the field and those with a large public interest (or both). At about fifty pages each, the chapters are long enough to explore the corresponding topics in some detail. Of those covered, I know the least about exoplanets, and learned a lot from the corresponding chapter. The book is a good introduction to various fields of research, some of which some readers might want to explore further *via* more detailed books on one or more subjects.

Like the book with respect to the included chapters, each chapter concentrates on a few aspects rather than trying to cover too much. The chapter on exoplanets concentrates on the *Kepler* mission, water, and life; 'Stars' is mainly about stellar nucleosynthesis, the lives of the stars (including the Hertzsprung–Russell diagram), the Sun, and the final stages of stellar evolution. 'Galaxies' is of course a very big topic; the chapter concentrates on *Gaia*, the dynamics of galaxies, dwarf galaxies, collisions, tidal tails, and so on. The chapter on black holes covers the most ground: Sgr A*, X-ray binaries, the Schwarzschild solution, the Chandrasekhar mass limit, gravitational waves, the *Event Horizon Telescope*, Nobel Prize winners Andrea Ghez and Reinhard Genzel and the Milky Way's central black hole, the presumably related *Fermi* bubbles, and Hawking radiation (the corresponding equation for the Hawking temperature is one of only two in the book). The emphasis is mainly on astrophysics rather than the mathematical aspects of black holes. The final chapter delves into the early Universe and its evolution: high-redshift galaxies, the Hubble constant and the Hubble tension, Lemaître's ideas of the early Universe, the singularity theorems of Penrose and Hawking, and inflation. The story of Koichi Itagaki and the discovery of SN 2018gv in NGC 2525 is recounted in some detail, leading on to more general discussion of supernovae and their use in cosmology.

The book is very well written, has comparatively few typos or other goofs, and, though non-technical, does not oversimplify. There are twenty-six colour figures on ten plates about two-thirds of the way through the book (one of which, showing a galaxy cluster acting as a gravitational lens, mistakenly has a caption about globular clusters). There are a few black-and-white figures scattered throughout the text as well as a few boxes, which are long quotations from various people on a subject discussed in the neighbouring text. There are neither footnotes nor endnotes. The book ends with an eight-page small-print index. A few things are a bit confusing, such as that the Sun is more than a hundred times larger than the Earth — its *diameter* is somewhat more than a hundred times larger than that of the Earth, but most readers would probably think of the much larger difference in volume. Somewhat annoying is referring to the equivalence of mass and energy in Special Relativity as the 'equivalence principle', which of course has a different meaning in General Relativity, and the garbled idea that microlensing is caused by "a massive object like a supernova" as the gravitational lens — supernovae as *sources* in gravitational-lens systems exist but are rare, but there are no cases of them being *lenses*. While it is true a star with about half of the mass of the Sun has a lifetime of about a hundred billion years (actually somewhat more), the smallest hydrogen-burning stars are an order of magnitude smaller with much longer lifetimes.

Despite my few quibbles I recommend the book as a good introduction to those interested in various aspects of our Universe which, by limiting the breadth of topics covered, goes into somewhat more depth than is usually the case in otherwise similar books. — Phillip Helbig.

References

(1) G. Sparrow, *50 Astronomy Ideas You Really Need to Know* (Quercus), 2016.
(2) P. Helbig, *The Observatory*, **137**, 30, 2017.
(3) G. Sparrow, *The History of Our Universe in 21 Stars (That You Can Spot in the Night Sky)* (Welbeck), 2023.
(4) P. Helbig, *The Observatory*, **145**, 40, 2025.

(5) J. Scudder, *The Milky Way Smells of Rum and Raspberries … and Other Amazing Cosmic Facts* (Icon Books), 2023.
(6) P. Helbig, *The Observatory*, **145**, 65, 2025.
(7) G. Lavender, *The Short History of the Universe: A Pocket Guide to the History, Structure, Theories & Building Blocks of the Cosmos* (Laurence King), 2022.
(8) P. Helbig, *The Observatory*, **145**, 77, 2025.

OBITUARY NOTICE

Helmut Arthur Abt (*1925–2024*)

One of the most prolific astronomical spectroscopic observers of the last century, Helmut Abt passed away peacefully on 2024 November 22 at the ripe old age of 99. Born in Germany, Helmut arrived in the United States as a child and went on to be awarded the first PhD in astrophysics at Caltech in 1952. Known for his work on metallic-line stars, I first met him at a workshop in Tucson in 1969 dedicated to Am and Ap stars. Later I was to encounter his many papers on radial velocities, binary stars, and other stellar topics, so many of which were invaluable in much of my work. But his herculean observational work was accompanied by his long stint as Managing Editor of the *Astrophysical Journal* and its *Supplement* series and his work with the American Astronomical Society and the Kitt Peak National Observatory. His autobiography is presented in *A Stellar Life*, which was reviewed in these pages by Virginia Trimble (**142**, 13, 2022). A truly stellar astronomer indeed. — David Stickland.

[A more substantial obituary can be found at https://baas.aas.org/pub/2024i023/release/1]

Advice to Contributors

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

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

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

REFERENCES: Authors are requested to pay particular attention to the reference style of the *Magazine*. References are quoted in the text by superscript numbers, starting at 1 and running sequentially in order of first appearance; at the end of the text the references are identified in the bibliography by the number, in parentheses. The format for journals is:

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

and for books:

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

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

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

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

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

SUBMISSION: Material may be submitted as 'hard copy', or (preferably) by electronic mail to the address on the back cover.

Hard copy: *Three* copies should be submitted. Photocopies are acceptable only if they are of high quality.

Email: contributions may be submitted by email, as standard (LA)TEX files. REFERENCE TO PERSONAL MACROS MUST BE AVOIDED. Word files are also welcome provided they conform to the *Magazine*'s style.

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

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

CHECKLIST: Double-spaced? Reference style? Three copies?

CONTENTS

NOTES TO CONTRIBUTORS

'THE OBSERVATORY' is an independent magazine, owned and managed by its Editors, although the views expressed in submitted contributions are not necessarily shared by the Editors. All communications should be addressed to

The Managing Editor of 'THE OBSERVATORY'
16 Swan Close, Grove
Wantage, Oxon., OX12 0QE
Telephone +44 (0) 1235 200266
Email: manager@obsmag.org
URL: www.obsmag.org

Publication date is nominally the first day of the month and the issue will normally include contributions accepted three months before that date.

Publishers: The Editors of 'THE OBSERVATORY'
Typeset by Wild Boar Design, Oxford

ISSN 0029–7704