THE OBSERVATORY

Vol. 141 | 2021 APRIL | No. 1281

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2020 October 9 at $16^h\ 00^m$
held on-line

Emma Bunce, *President*
in the Chair

The President. I can see that people are streaming in to our virtual room, so I'm going to get started. A very warm welcome to you all and to the new session of meetings. We are delighted to bring you the first meeting of the 2020/2021 session *via* webinar, and it's just great that so many of you can join us for this new experience of the RAS Ordinary Meetings on-line. Without further ado then, we will begin the programme for this meeting.

The President. We are going to hear this year's George Darwin Lecture, and this is going to be given by Professor Ofer Lahav from University College London. He is Perren Chair of Astronomy at UCL and his research area of expertise is observational cosmology and in particular probing and characterizing dark matter and dark energy. He is also an expert in machine-learning methods within his research and he's currently co-director of the Centre for Doctoral Training for Data-Intensive Science. Today Ofer is going to talk about both these aspects as he presents the George Darwin Lecture entitled 'Darkness Visible: AI in Cosmological Experiments'. I'm going to hand over to you, Ofer, to take the stage. Thank you very much.

Professor O. Lahav. It is a pleasure to give this lecture in memory of George Darwin (1845–1912). His work in astronomy and in other fields demonstrated interdisciplinarity, an inspiration for today's research. I shall first summarize the status of large galaxy surveys and 'tensions' in the standard cosmological ΛCDM model. I will then describe the important role of artificial intelligence and machine learning in analysing the next generation of surveys of billions of objects, and the training of the next generation of astronomers for the big data challenges. We advocate for our field the approach of 'augmented intelligence', to enhance human intelligence rather than replacing it.

[It is expected that a full summary of this talk will appear in a future issue of *A & G*. The recorded version of the lecture is at https://ras.ac.uk/events-and-meetings/ras-meetings/george-darwin-lecture-2020-ofer-lahav]

The President. Thank you so much for that wonderful lecture and for the insight into such an exciting topic and your significant contributions to this field. It was really great to see you highlighting work from your students and post-docs and all the great messages in there about the applications of this work beyond the field of astronomy as well. We do have time for some questions so I'm going to hand over to Dr. Sheona Urquhart, who is going to facilitate the Q&A session.

Dr. Sheona Urquhart. We do have a few questions, so hopefully we'll try and get through as many of them as possible. The first one, from Professor Roberto Trotta, starts with "Congratulations on your award and thank you for a magnificent lecture". The question that he asks is "Given the increasing complexity of the numerical and statistical approaches to cosmological data analysis, what role do you see for pen-and-paper theoretical cosmology for the future?"

Professor Lahav. I see a lot of room for paper-and-pen work and I can explain it very quickly. With this approach of generating lots of simulations there's one big limitation: how many simulations should you produce? Could you cover the entire parameter space of nature in any field? What about magnetic fields? What about neutrinos in a particular model? I think you can ask yourself a hypothetical question: imagine there was no General Relativity; you give the machine all the data, would it come up with General Relativity? I doubt it. But maybe some people are more optimistic but I'm a great supporter of paper and pen.

Dr. Urquhart. Thank you, we've got another question, "What really is Dark Energy? Do you think we can understand it fundamentally using current theories or is it not likely until we have a fully-fledged quantum description of gravitational phenomena?"

Professor Lahav. Well, it's a big question and there are theoreticians who have thought about it much deeper than me. I'd say the following: first, the data currently indicate quite strongly that this $w = -1 \pm 5\%$, give or take. Some of my colleagues think there is something hidden in this 5%, while others think the game is over, $w = -1$, *i.e.*, it's Einstein's cosmological constant Λ, just the way it appears in General Relativity in 1917. But what is this Λ, why's it got this strange value? You know, when I was a student it was believed to be zero. There's a whole range of ideas — maybe it is just like another constant of nature like big *G*. Some people think it's some manifestation of quantum fluctuations, vacuum energy, but there is a big embarrassment there because according to particle physics it should have been much, much bigger, by 10^{120}. So it's actually very embarrassing that it's so small. We don't know. If you remember, the Einstein equation showed it on the left-hand side, but it could be on the right-hand side, and that's part of the mystery. Some people resort to the anthropic principle, for example, that we live in one of many, many universes that happens to have this particular set of constants; that's a very intriguing idea as well. I think your question is exactly what has attracted me and many other people to work on it because what I like about it is the deep philosophical questions. We still don't know what it is and yet in order to deal with it you have to work very hard, build instruments, develop software, do a careful job on that journey and you learn new things. Although we designed the survey to search for dark energy it also discovered a flash from a gravitational-wave event, so there are spin-offs.

Dr. Urquhart. Another one for you. "Do you think that the current technology we have is a hindrance for the increasing complexity of physics?"

Professor Lahav. Technology is sometimes ahead of the game, sometimes it is behind; that's a general comment to make especially for colleagues who are in the space-research business. You plan something based on technology and the thing only starts working 10 or 20 years later, when technology has moved on. What do you do? You plan the next mission. Even with ground-based astronomy, things which we started doing 15 years ago we see only now coming to fruition. I think you do the best you can, questions keep coming, and maybe what was sufficiently good to get 5% precision is not good enough to get 1%, so you need new technology. But I'll also say that the good thing about the software side is that you can still play with the data and improve the algorithms along the way.

Dr. Urquhart. Another question, this time from Dr. G. Q. G. Stanley: "Do you see augmented intelligence progressing to the point where it will give the result of the simulations from the input parameters but without running the simulation, for example, the millennium simulation?"

Professor Lahav. There is a new area, which I haven't quite covered, which comes under 'emulation'. In simple words emulation is an interpolation. It's what you can do instead of running the millennium simulation over a grid of hundreds or thousands of points; you want to change Ω_m by very small intervals which is very expensive. I am just making it up but you get the idea — imagine you can run it for ten scenarios and you can interpolate it in-between. There is quite a range of papers in the literature doing exactly that. You can use ten simulations to create hundreds and millions which are based on those ten, but they're quite rich. Of course you have to be a bit careful about using too many fake universes. You've probably seen examples; in fact I just heard a talk yesterday by our CDT (Centre for Doctoral Training) students about fake images. You may know there is a website called, 'This person does not exist', so you can take people who exist and create images of people who are interpolations, and some people who never existed, they're just fake. Now there is software that has to discover the fake. When you run your ten millennium simulations, you have to be careful that what you get in between is quite realistic.

Dr. Urquhart. Somebody else asks "Most of the limitations of machine learning you mentioned are related to insufficient training in the case of supervised learning. Couldn't these shortcomings be solved using unsupervised learning algorithms like genetic algorithms?"

Professor Lahav. Yes, this is, I think, from the early days of machine learning. This is traditional: if you open a text book, even from twenty years ago, you'll see that there is supervised learning, unsupervised learning, and we all use them. A technique like principal-component analysis, which is now very common, is an example of unsupervised learning: I tell the algorithm nothing and it might discover some features or nearest neighbours. Yes, I think all these are very important. I'll put it in the augmented-intelligence language that it's wonderful to show algorithms, let the data speak for themselves, and then come to the expert and say "Does it make sense to you that these galaxies actually form two different classes, blue galaxies, red galaxies, and the green valley that is very topical?" The astronomer may say it doesn't make sense at all, it contradicts all the papers I've written the past twenty years, but actually you know the data showed me something new here, and I think this is the way. It would be very nice to see the field evolving.

The President. Thank you so much, Ofer, that was again a wonderful lecture, thank you for taking the time to answer the great questions coming in. Thanks to the audience as well for posting your questions, it's been a really good, interesting Q&A to have here. As Ofer has mentioned, if there are questions that we haven't had time to cover in the Q&A then he's willing to respond to some of those which we will discuss with him about putting some answers on the website where the advert for the meeting is. Just to let you know that the next monthly A&G Open Meeting of the Society will be on Friday the 13th of November, again *via* Zoom, and I look forward to seeing many of you again then.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 3: THE INTERFEROMETRIC, SPECTROSCOPIC, AND ECLIPSING BINARY V1022 CASSIOPEIAE

By John Southworth

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V1022 Cas has been known as a spectroscopic binary for a century. It was found to be eclipsing based on photometry from the *Hipparcos* satellite, and an astrometric orbit was recently obtained from near-infrared interferometry. We present the first high-precision measurement of the radii of the stars based on light-curves obtained by the *TESS* satellite. Combined with published radial velocities from high-resolution spectra, we measure the masses of the stars to be 1·626 ± 0·001 $M_{\odot}$ and 1·609 ± 0·001 $M_{\odot}$, and the radii to be 2·591 ± 0·026 $R_{\odot}$ and 2·472 ± 0·027 $R_{\odot}$. The $12^{d}\cdot16$ orbit is eccentric and the stars rotate sub-synchronously, so the system is tidally unevolved. A good match to these masses and radii, and published temperatures of the stars, is found for several sets of theoretical stellar evolutionary models, for a solar metallicity and an age of approximately 2 Gyr. Four separate distance determinations to the system are available, and are in good agreement. The distances are based on surface-brightness calibrations, theoretical bolometric corrections, the *Gaia* parallax, and the angular size of the astrometric orbit. A detailed spectroscopic analysis of the system to measure chemical abundances and more precise temperatures would be helpful.

Introduction

The study of binary stars is one of the oldest areas of astronomy. It can be traced back as far as John Michell[1], who in 1767 concluded that the celestial positions of the bright stars were statistically improbable unless they were "placed near together". William Herschel[2,3] confirmed this by detecting orbital motion in several double stars that were visually resolved on the sky. This class of binary system is now typically referred to as visual binaries (if they are visually separable), astrometric binaries (if an astrometric orbit has been obtained), or interferometric binaries (if the stars have been spatially resolved using interferometry), although these terms are often interchanged.

A second type of binary system is the eclipsing binaries (EBs). The correct explanation for the periodic dimmings was originally suggested by John Goodricke[4], but observations of these can be traced back to antiquity[5]. A third type is the spectroscopic binaries, whose explanation is comparatively more recent as it required the development of astronomical spectroscopy. Vogel[6] proved that the star Algol was a close binary by measuring the change in radial velocity (RV) of the primary star before and after a primary eclipse.

The definitions of these three types of binary system are observational, and this same nature determines what physical properties are measurable[7].

An astrometric orbit for stars of a known distance gives the semi-major axis and the sum of the masses. The RV measurements that comprise a spectroscopic orbit gives lower limits on the masses of the stars*. Observations of eclipses give the fractional radii of the stars (their radii divided by the semi-major axis of the relative orbit).

When a binary system can be studied using two methods, it is possible to determine many more physical properties. Astrometry and RVs together give the individual masses of the stars plus a direct geometric measurement of the distance to the system[8,9]. Eclipses and RVs allow the masses and radii of the stars to be measured to high precision[10,11].

A small number of binary systems are simultaneously astrometric, spectroscopic, and eclipsing. For these objects it is possible to measure their masses, radii, and distance to high precision through geometrical arguments alone. This list includes β Aurigae[12–14], β Persei[6,15,16], TZ For[17,18], and six other EBs recently studied by Gallenne *et al.*[19].

V1022 Cassiopeiae

The current series of papers was conceived with the primary aim of measuring precise masses and radii of EBs that could then be included in *DEBCat*† (*Detached Eclipsing Binary Catalogue*), a compilation of EBs with masses and radii measured to precisions of 2% or better[26]. Previous papers in this series have studied the B-type system ζ Phoenicis[27] and the solar-type system KX Cancri[28]. In the current work the aim is to analyze the binary system V1022 Cassiopeiae, one of a small number of spectroscopic–astrometric–eclipsing binaries, in order to determine its masses and radii to sufficient precision for inclusion in *DEBCat*. V1022 Cas is a bright (V = 5·6) binary system with an eccentric orbit of period 12^{d}·16. The two stars are very similar, slightly evolved, and have spectral types of F6 V[25].

V1022 Cas (Table I) was found to be a double-lined spectroscopic binary by Plaskett *et al.*[29] and several spectroscopic orbits have been published[30–32]. The last of these, by Fekel *et al.*[32], is of very high quality.

TABLE I

Basic information on V1022 Cas

Property	*Value*	*Reference*
Bright Star Catalogue	HR 9059	20
Henry Draper designation	HD 224355	21
Gaia DR2 ID	1994714276926012416	22
Gaia parallax	15·767 ± 0·088 mas	22
B magnitude	6·033 ± 0·014	23
V magnitude	5·561 ± 0·009	23
J magnitude	4·618 ± 0·035	24
H magnitude	4·429 ± 0·176	24
K_s magnitude	4·381 ± 0·021	24
Spectral Type	F6V + F6V	25

*For the purposes of this discussion it is assumed that RVs of both stars are available.

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

Otero *et al.*[33] found the system to be eclipsing using photometry from the *Hipparcos* satellite[34,35], which included four points around times of primary eclipse that were significantly fainter than the rest. No secondary eclipse was observed, although there is a marginal detection based on two data points[32]. The *New Catalogue of Suspected Variable Stars*[36] listed it as a suspected EB with an eclipse depth of only $0^{m}\cdot05$[33].

Lester *et al.*[37] have recently presented *K*-band interferometry of V1022 Cas using the CHARA array, from which they obtained the first astrometric orbit of the system. They spatially resolved the two stars on nine occasions and, together with new and published RVs, determined the masses of the stars and the distance to the system to high precision.

Observational material

The main observational material for our analysis comes from the NASA *TESS* satellite[38], which is discussed in more detail in Paper 1[27]. V1022 Cas was observed twice, with a gap of five months in between, both times at a cadence of 120 s. Sector 17 was observed between 2019/10/07 and 2019/11/02 and light from V1022 Cas was incident on camera 2; Sector 24 covered 2020/04/16 to 2020/05/13 and V1022 Cas was observed using camera 4. There are breaks in the data for download to Earth, and in places where the data are of lower quality. We used the simple aperture photometry (SAP) light-curve[39] for both sectors. For Sector 24 we used only the 17060 data points with no flagged problems (QUALITY = 0). For Sector 17 we relaxed the quality criteria in order to retain the data around the secondary eclipse at JD 2458774, resulting in a total of 12891 data points. The light-curves from both sectors are shown in Fig. 1.

The majority of data points are outside eclipse so contain negligible information on the properties of the system. We therefore trimmed away data points more than 1·5 eclipse durations from the midpoint of an eclipse, leaving behind 5444 data points in the region of four primary and four secondary eclipses. The error bars were then scaled so the best fit to the data (see below) has a reduced χ^2 of $\chi^2_\nu \approx 1\cdot0$.

In our analysis we have also made use of the RVs measured by Fekel *et al.*[32], which were obtained from 110 high-resolution spectra from three spectrographs. Fekel *et al.*[32] quoted relative weights for their observations and we have converted these into uncertainties by taking the inverse. This is because inverse-squared uncertainties were too pessimistic for the lower-weighted observations. The error bars were then scaled to obtain $\chi^2_\nu \approx 1\cdot0$ separately for each star *versus* the best fit calculated below.

Light ratio

Initial analyses of the light-curve indicated that the ratio of the radii of the stars was measured to insufficient precision to reach error bars of 2% in radius. The ratio of the radii is highly correlated with the light ratio, so an independent measurement of the light ratio can be used to constrain the ratio and thus individual radii (*e.g.*, refs. 40 and 14).

Fekel *et al.*[32] measured a continuum light ratio of $\ell_B/\ell_A = 0\cdot898$ (where ℓ_A and ℓ_B are the wavelength-dependent relative light contributions of the primary and secondary stars, respectively) at 6430 Å. However, this measurement does not have an associated error bar.

Lester *et al.*[37] measured the light ratio of the stars in two ways. First, their interferometric observations give a weighted average of $0\cdot94 \pm 0\cdot04$ in the K'

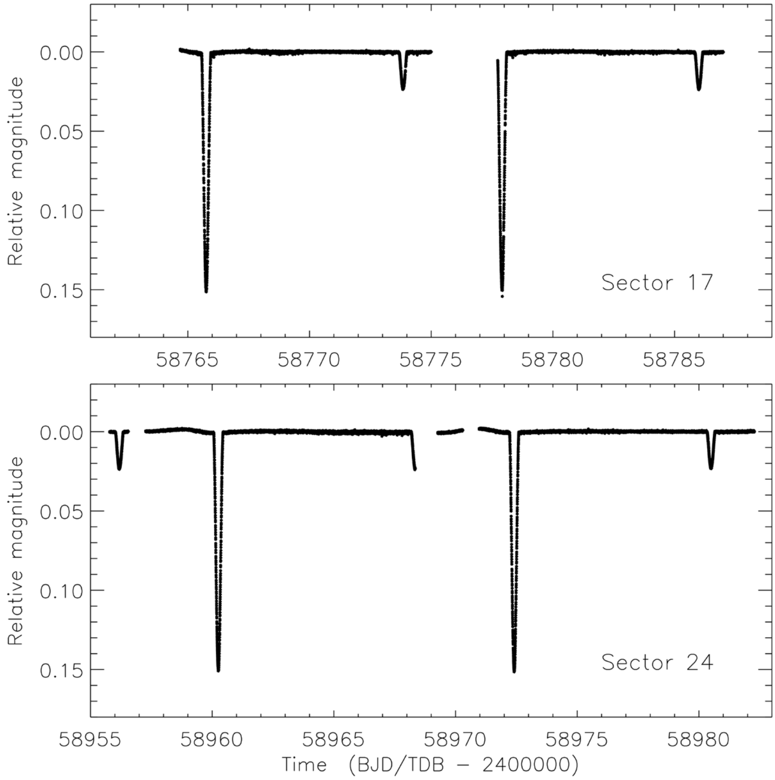

FIG. 1

TESS simple aperture photometry of V1022 Cas. The upper plot shows observations from Sector 17 and the lower plot shows observations from Sector 24.

band. Our own calculation from the individual measurements is 0·939 ± 0·026, and we have used this value in the following analysis. Second, they found $\ell_B/\ell_A = 0{\cdot}95 \pm 0{\cdot}06$ for the spectral-line stengths using the TODCOR algorithm[41] on the Hα order in their échelle spectra.

The interferometric light ratio must be propagated from the K' passband to the *TESS* passband in order to apply it directly to the *TESS* light-curve. For this we used a code developed to perform this task for contaminating light in transiting planetary systems[42–45] that accounts for uncertainties in the light ratio and the effective temperature ($T_{\rm eff}$) values of the two stars. Using theoretical spectra from the ATLAS9 model atmospheres[46] we determined a light ratio of 0·981 ± 0·057 in the *TESS* band, and using spectra from the BT-NEXTGEN model atmospheres[47] we found 0·984 ± 0·062. This consistency is encouraging, and also in good agreement with the light ratio from Hα. However, the resulting light ratio cannot be regarded as entirely empirical because of the use of theoretical spectra to propagate it between passbands.

Light-curve analysis

Due to the relatively long orbital period of V1022 Cas, the stars are approximately spherical so can be modelled using the JKTEBOP code*[48,49], for which we used version 41. This code has been shown to agree very well with other codes on well-detached EBs[50].

We adopted the standard definition that the primary star is the one eclipsed at the deeper (primary) eclipse. In an EB with a circular orbit, the same area of a star is obscured at both primary and secondary eclipse, so the relative eclipse depths are dictated only by the ratio of the surface brightnesses of the two stars. Hence the primary star is by definition hotter than the secondary star. However, when the orbit is eccentric, the distance between the stars varies and thus the area of star obscured differs between the primary and secondary eclipses. In that case, it is possible for the secondary star to be hotter than the primary. This is the situation for V1022 Cas, where the primary (star A) is larger and more massive, but the secondary (star B) is hotter.

JKTEBOP parametrizes the fractional radii ($r_A = R_A/a$ and $r_B = R_B/a$, where R_A and R_B are the true radii and a is the semimajor axis of the relative orbit) using their sum ($r_A + r_B$) and ratio ($k = r_B / r_A$), and the orbital shape as $e \cos \omega$ and $e \sin \omega$ where e is the eccentricity and ω is the argument of periastron.

These four quantities were included as fitted parameters, as were the orbital inclination, central-surface-brightness ratio, orbital period, and reference time of primary mid-eclipse. We used the quadratic law for limb darkening, fitted for the linear coefficient, and fixed the quadratic coefficient at a theoretical value[51]. Due to the similarity of the stars we required them to have the same limb-darkening coefficients.

The *TESS* data give a very precise ephemeris because the EB was observed in two sectors separated by five months. We fitted the out-of-eclipse brightness of each eclipse using a straight line, in order to avoid systematic errors from any slow variations in brightness remaining in the data. The secondary eclipse occurs at a phase of 0·6641.

In the initial fit, the fractional radii were measured to precisions of only 3·5% due to the eclipses being partial and the fractional radii being similar. We therefore added both the spectroscopic and the interferometric light ratios discussed above. We made no adjustment from the Hα line to the *TESS* passband because the stars are very similar and the Hα line is within the *TESS* passband. JKTEBOP implements this by treating each external light ratio as an observational data point in the least-squares fit. The best fit is shown in Fig. 2. The final results greatly benefit from the inclusion of the external light ratios in the light-curve solution.

We then added the RVs from Fekel *et al.*[32] to the fit. The velocity amplitudes and systemic velocities of each star were fitted separately. The best fit to these data is shown in Fig. 3. We did not include the RVs measured by Lester *et al.*[37] as they are less numerous and less precise than those from Fekel *et al.*[32] The fitted spectroscopic orbit is shown in Fig. 3.

The uncertainties of the fit were obtained using the Monte Carlo and residual-permutation algorithms[52,53] implemented in JKTEBOP. The Monte Carlo algorithm returned significantly larger uncertainties, so these were used as the final uncertainties. This is because there is no way to account for the uncertainties in the external light ratios in the residual-permutation approach, resulting in underestimated error bars in this case. The distribution of parameters found

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

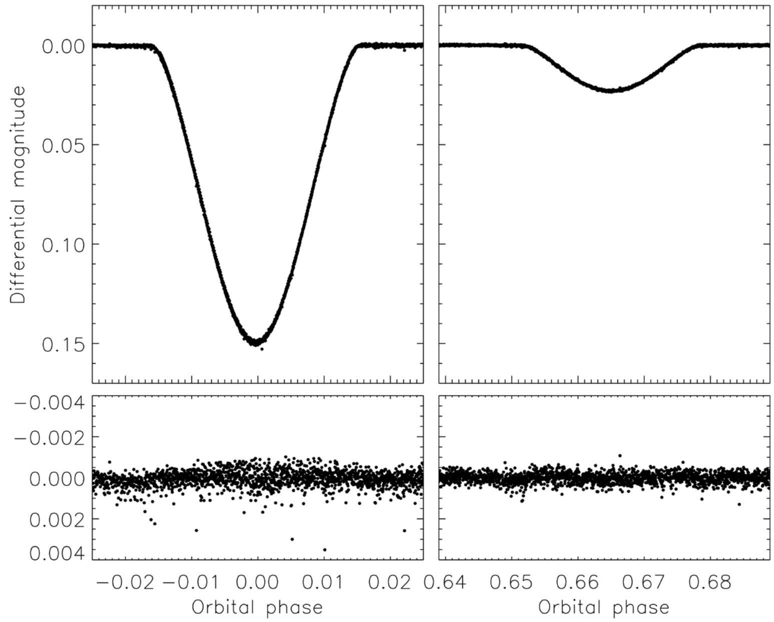

FIG. 2

The *TESS* light-curve of V1022 Cas around the primary (left) and secondary (right) eclipses. The JKTEBOP best fit is shown using a solid line, but is obscured by the data. The lower panels show the residuals of the fit on a larger scale.

in the Monte Carlo analysis is bimodal, with the secondary solution having a larger $r_1 + r_2$, i, $e \cos \omega$, and $e \sin \omega$. This solution corresponds to a slightly different system configuration but can safely be rejected because it is a much worse fit to the observational data ($\chi^2_\nu \approx 2{\cdot}0$ *versus* 1·0 for the main solution). The final parameter values and uncertainties are based on the main solution and are given in Table II. The orbital inclination measured from the *TESS* data is in good agreement with that found by Lester *et al.*[37] from their interferometric observations ($97^\circ{\cdot}1 \pm 0^\circ{\cdot}3$) once the conversion $i \rightarrow (90^\circ - i)$ is applied to conform to the convention of $0 \leq i \leq 90^\circ$ for light-curve analyses.

For illustration, Fig. 4 shows correlation plots for several combinations of parameters of the light-curve fits. The left plots are without, and the right plots are with, inclusion of the light-ratio constraints. It can be seen that including the light ratios leads to a narrower spread of parameters, and thus more precise measurements of the parameters. It can also be seen that r_1 and r_2 are very strongly correlated — this arises because $r_1 + r_2$ is much better constrained than k and is the motivation for fitting for the latter parameter combination. The external light ratios help the situation but remain the dominant source of uncertainty in the radii of the stars.

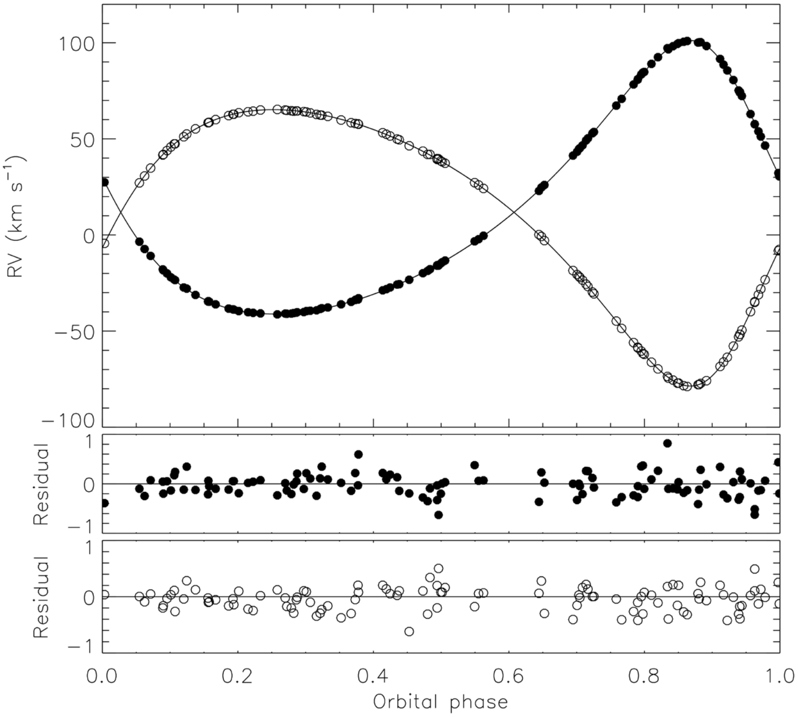

Fig. 3

Spectroscopic orbit of V1022 Cas using the RVs from Fekel *et al.*[32]. RVs of the primary and secondary stars are shown with filled and open circles, respectively. The best fits from JKTEBOP are shown using solid lines. The lower panels show the residuals of the fit.

Physical properties of V1022 Cas

Although JKTEBOP returned the masses and radii of the components of V1022 Cas corresponding to the best joint fit of the *TESS* light-curve, ground-based RVs, and spectroscopic and interferometric light ratios, we then turned to the JKTABSDIM code[55] to calculate these properties as well as other quantities such as luminosity and distance. For this we used the $T_{\rm eff}$ values of the stars given by Lester *et al.*[37]: $T_{\rm eff,A} = 6450 \pm 120$ K and $T_{\rm eff,B} = 6590 \pm 110$ K.

JKTABSDIM was used to calculate the full physical properties of the EB using standard formulae, with uncertainties propagated by a perturbation approach. These are given in Table III. They are in good agreement with previous measurements[32,37] and represent the first determination of the radii of these stars to high precision. The masses are determined to better than 0·1%, and the radii to approximately 1% precision. Further improvements in radius measurement could be made by obtaining more precise spectroscopic or interferometric light ratios, which would not be an easy task.

TABLE II

Best JKTEBOP fit to the TESS light-curve and ground-based RVs of V1022 Cas. The 1σ uncertainties have been calculated using a Monte Carlo algorithm. The same limb-darkening coefficients were used for both stars. The uncertainties in the systemic velocities do not include any transformation onto a standard system.

Parameter	*Value*
Fitted parameters:	
Primary eclipse time (BJD/TDB)	2458777·91391 ± 0·00002
Orbital period (d)	12·1561598 ± 0·0000008
Orbital inclination (°)	82·886 ± 0·006
Sum of the fractional radii	0·15387 ± 0·000055
Ratio of the radii	0·954 ± 0·020
Central surface-brightness ratio	1·0391 ± 0·0035
Linear limb-darkening coefficient	0·2636 ± 0·0061
Quadratic limb-darkening coefficient	0·227 (fixed)
$e \cos \omega$	0·256608 ± 0·000014
$e \sin \omega$	0·17660 ± 0·00022
Velocity amplitude of star A (kms^{-1})	71·112 ± 0·024
Velocity amplitude of star B (kms^{-1})	71·894 ± 0·021
Systemic velocity of star A (kms^{-1})	11·775 ± 0·019
Systemic velocity of star B (kms^{-1})	11·754 ± 0·017
Derived parameters:	
Fractional radius of star A	0·07875 ± 0·00080
Fractional radius of star B	0·07512 ± 0·00081
Orbital eccentricity	0·31150 ± 0·00011
Argument of periastron (°)	34·535 ± 0·0034
Light ratio	0·946 ± 0·042

TABLE III

Physical properties of V1022 Cas.

The T_{eff} values are from Lester et al.[37].
Units superscripted with an 'N' are defined by IAU 2015 Resolution B3[54].

Parameter	*Star A*	*Star B*
Mass ratio	0·98912 ± 0·00044	
Semi-major axis ($R^{N}_{\odot}$)	32·9045 ± 0·0074	
Mass ($M^{N}_{\odot}$)	1·6263 ± 0·0011	1·6086 ± 0·0012
Radius ($R^{N}_{\odot}$)	2·591 ± 0·026	2·472 ± 0·027
Surface gravity (log[cgs])	3·822 ± 0·009	3·858 ± 0·009
Density ($\rho_{\odot}$)	0·0935 ± 0·0028	0·1065 ± 0·0034
Synchronous rotational velocity (kms^{-1})	10·78 ± 0·11	10·29 ± 0·11
Effective temperature (K)	6450 ± 120	6590 ± 110
Luminosity $\log(L/L^{N}_{\odot})$	1·020 ± 0·034	1·016 ± 0·030
M_{bol} (mag)	2·19 ± 0·08	2·20 ± 0·08

The synchronous rotational velocities for the two stars are 10·8 km s^{-1} and 10·2 km s^{-1}. The pseudo-synchronous velocities are 21·6 km s^{-1} and 20·4 km s^{-1} (see eq. 41 from Hut[56]).

The measured rotational velocities are $v_A \sin i = 10{\cdot}9 \pm 1{\cdot}2$ km s^{-1} and $v_B \sin i = 7{\cdot}0 \pm 1{\cdot}3$ km s^{-1} (ref. 37), and correcting these to equatorial values gives 11·0 ± 1·2 km s^{-1} and 7·1 ± 1·3 km s^{-1} (assuming axial alignment). The primary star is rotating synchronously with the orbit, although tidal effects should act to make it rotate pseudosynchronously. Both stars are therefore rotating more slowly than expected from tidal interactions. Together with the significant orbital eccentricity, this means that the system is tidally unevolved.

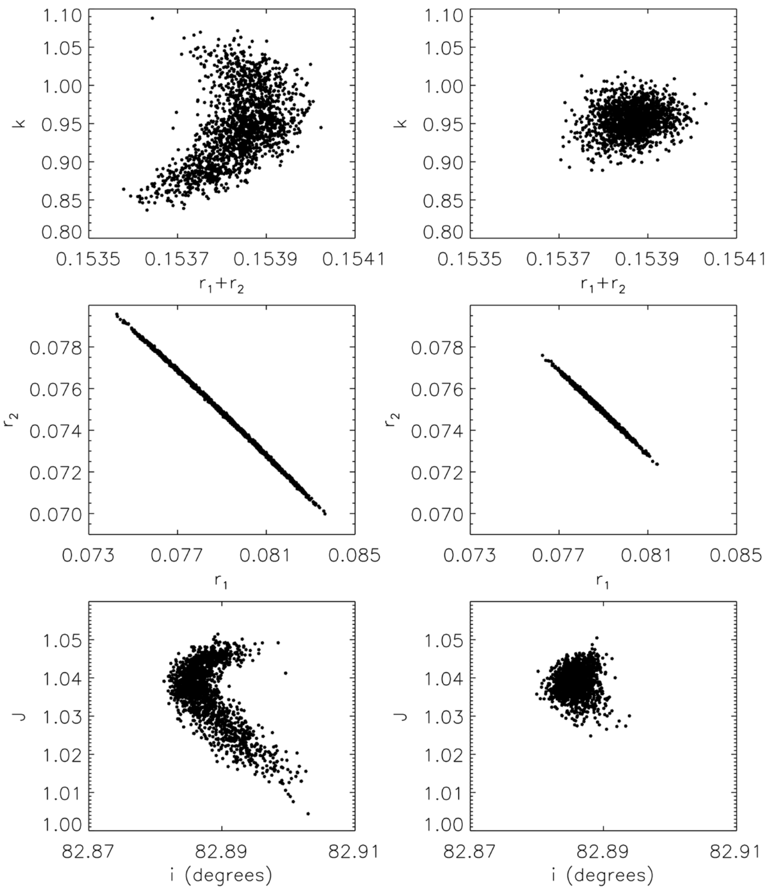

FIG. 4

Plots of the best-fitting values of some light-curve parameters from the Monte Carlo simulations. The left- and right-hand plots show simulations without and with inclusion of the constraints on the light ratio of the stars.

Distance to V1022 Cas

To determine the distance to the EB we used the *BV* apparent magnitudes from *Tycho*[23], the *JHK*$_s$ magnitudes from 2MASS[24], and the radii and $T_{\rm eff}$ values of the stars. We used two methods[55,57]: *via* the surface-brightness calibrations of Kervella *et al.*[58], and from theoretical bolometric corrections from Girardi *et al.*[59]. The optical and near-infrared distances needed a small amount of interstellar reddening to bring them into good agreement — we found that

$E(B-V) = 0{\cdot}04 \pm 0{\cdot}04$ (conservative error bar) is sufficient. The surface-brightness and bolometric-corrections distances agree extremely well. The most precise distance is obtained in the K_s band and is $63{\cdot}2 \pm 1{\cdot}1$ pc from the surface-brightness calibration, or $62{\cdot}7 \pm 1{\cdot}0$ pc from theoretical bolometric corrections. The largest contribution to the uncertainties in these values is the K-band magnitude, closely followed by the fractional radii and $T_{\rm eff}$ values of the stars. These distances compare well with the value of $63{\cdot}42 \pm 0{\cdot}35$ pc found from the *Gaia* DR2 parallax of the system.

A fourth distance estimate is available in this case, using the interferometrically-measured orbital semi-major axis in angular units from Lester *et al.*[37]. Using the small-angle formula and the definition of the parsec, it can be shown that the semi-major axes in angular and physical units are related to the distance according to $(a/{\rm AU}) = (a/{\rm arcsec})\ (d/{\rm pc})$. The semi-major axis in angular units measured from the interferometry in isolation is $2{\cdot}390 \pm 0{\cdot}010$ mas[37]. When combined with the semi-major axis in Table III the distance is found to be $64{\cdot}02 \pm 0{\cdot}27$ pc. This agrees with the K_s-band distance to within 0.7σ and with the parallax distance to within $1{\cdot}4\sigma$. The four distances are thus consistent and mutually support the measurement principles underlying each. This good agreement between independent distance determinations is similar to the situation for β Aur[14]. TZ For has distance determinations from orbital interferometry ($185{\cdot}9 \pm 1{\cdot}9$ pc; ref. 18) and from *Gaia* DR2 ($183{\cdot}9 \pm 0{\cdot}9$ pc) which also agree to within 1σ. These three spectroscopic-astrometric-eclipsing binaries provide direct evidence of our good understanding of stellar physics and the local distance scale.

Comparison with theoretical models

We compared the measured masses, radii, and $T_{\rm eff}$ values to the predictions of several sets of theoretical models to see the level of agreement and to infer the age and metallicity of the EB. The stars are near the end of their main-sequence lifetimes where radius changes quickly, so the age estimates are very precise.

For the PARSEC models[60] we found a good fit for a solar metallicity and an age of 1930 ±40 Myr. For the Dartmouth models[61] we found the same except for an age younger by 10 Myr. The Yonsei–Yale models[62] prefer an age of 1975 Myr. In all three cases the solar-metallicity predictions match the observations well and other metallicities do not.

Balachandran[63] measured a metallicity of $[{\rm Fe/H}] = -0{\cdot}01 \pm 0{\cdot}17$ for V1022 Cas; she was aware that the star is binary but did not account for this in her analysis. This metallicity estimate is roughly solar, but uncertain and probably biassed due to neglect of the binarity of the system. It is nevertheless in good agreement with the preference for solar metallicity from the comparison with stellar models. A more discriminating analysis would be possible if higher-precision $T_{\rm eff}$ values and chemical-composition measurements were available.

Summary

V1022 Cas has been known to be a double-lined spectroscopic binary for a century[29]. It was discovered to be eclipsing from *Hipparcos* photometry[33], and an astrometric orbit has recently been published from near-infrared interferometry[37]. It is therefore one of the few spectroscopic–astrometric–eclipsing binaries known.

The *TESS* satellite has recently observed it twice, giving high-quality light-curves of the eclipses. We used these data, together with published RVs, to determine the masses and radii of the stars to high precision for the first time. The masses are measured to 0·1% using the excellent RVs from Fekel *et al.*[32]. The radii are determined to 1%, and the precision of these measurements is limited by the partial nature of the eclipses and the precision of the light-ratio measurements from spectroscopy and interferometry.

We have combined these results with published $T_{\rm eff}$ measurements[37] to determine the full physical properties of the system. They are well matched by the predictions of theoretical stellar evolutionary models for a solar metallicity and an age close to 2 Gyr. A more detailed comparison would benefit from a new spectroscopic analysis yielding photospheric chemical abundances and more precise $T_{\rm eff}$ measurements.

The distance to V1022 Cas was calculated in four ways: from calibrations of surface brightness *versus* $T_{\rm eff}$ (63·2 ± 1·1 pc), from theoretical bolometric corrections (62·7 ± 1·0 pc), from the interferometrically-measured angular size of the orbit (64·02 ± 0·27 pc), and from the *Gaia* DR2 trigonometric parallax (63·42 ± 0·35 pc). The agreement between these measurements, obtained in a variety of ways, is very encouraging.

Acknowledgements

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 arXiv scientific paper preprint service operated by Cornell University.

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IS 1RXS J012750·5+380830 A SUPERHUMPING INTERMEDIATE POLAR?

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The first time-series observations of the poorly observed X-ray transient 1RXS J012750·5+380830 are reported from the 2020 October outburst. The outburst was short, 3–4 days, and had an amplitude of $4^{m}\!\cdot\!7$. The system shows extreme flickering consistent

with a magnetic CV, and on one night periodic variations were also found at $P_{wd} = 454{\cdot}2 \pm 0{\cdot}5$ s or $f = 190{\cdot}2 \pm 0{\cdot}2$ c/d, and this could be interpreted as the white-dwarf-spin period. Periodic variations were also found near the orbital period, which could be interpreted as superhumps or orbital modulation.

Introduction

Intermediate polars (IP) or DQ Herculis stars are nova-like cataclysmic variables (CV) in which a strong magnetic field emanating from the white dwarf carves out the inner part of the accretion disc and directs material along the field lines to the magnetic poles. In the other major class of magnetic CVs, the AM Herculis stars or polars, the magnetic field is so strong that it prevents the formation of an accretion disc and material is swept up directly as it overflows from the cool companion through the inner Lagrangian point. Magnetic CVs are strong X-ray sources (see the recent review by Lutovinov *et al.*[1]) and tend to show strong and variable He II λ4686 from reprocessed X-ray emission. Polars tend to show high- and low-luminosity states in both the optical and X-rays, but of course do not show disc-instability outbursts. One important distinction between polars and IPs is that the stronger magnetic field forces the white dwarf to synchronize with the orbital period, while in IPs it tends to be much shorter, broadly 10% of the orbital period[2], and it is thought that the white-dwarf rotation synchronizes with the inner edge of the accretion disc[3]. One of Patterson's[4] significant clues to IPs is a stable modulation in the optical and X-ray light-curves at, or close to, the white-dwarf-spin period. In some systems half the spin period may be seen, or dominate, as material impacting both magnetic poles is seen[5–7].

Superhumps are a modulation of the optical light-curve at a period, generally within a few per cent of the orbital period, due to the 3:1 resonance between material in the outer part of the accretion disc and mass-losing secondary[8–11]. The tidal resonance creates an eccentric deformation of the disc which leads to a slow nodal precession and this in turn is modulated by the orbital period to produce a superhump, reflecting the changing visibility of the disc. These are a diagnostic feature of the SU Ursae Majoris class of dwarf novae during superoutbursts, but the same type of variation is also seen in nova-like CVs where it is not related to outbursts, and can persist for years. These are referred to as permanent superhumps. Despite Patterson's early optimism[12,13] at their prevalence in high-$\dot{M}$, short-period systems, they have been detected or suspected in only ~ 10% of nova-like CVs in the Ritter & Kolb Catalogue[14], so are still stubbornly rare.

1RXS J012750·5+380830 (= HS 0124+3752, $01^h\ 27^m\ 50^s{\cdot}58$ $+38^{\circ}\ 08'\ 11''{\cdot}9$), as its name suggests was originally identified as an X-ray source by *ROSAT*[15], initially as a QSO, but it was quickly found to be a $B \sim 17{\cdot}4$, $z = 0$ emission-line object, and was reclassified as a CV of unknown type (see Downes *et al.*[16] for the early details). It was also identified spectroscopically as a likely CV in the Hamburg Quasar Survey as HS 0124+3752, and later Gänsicke *et al.*[17] found it had a variable emission-line spectrum including He II λ4686. More recently Thorstensen *et al.*[18] found the period to be short, and included the system in a survey of candidate period bouncers[19]. These systems were presumed to be non-magnetic on the basis of their generally absent He II λ4686 emission, but although weak it is present in 1RXS J012750·5+380830. Thorstensen[19] gives the period as $P = 0^d{\cdot}06071$ but highlights a small uncertainty due to the cycle count between seasons, which means that the period could be close to 0·06064, 0·06069, 0·06071, or 0·06078 days, with little to choose between them. Thorstensen also found the emission lines to be broad, but not double peaked, and this can also be seen in the recent *LAMOST* spectra[20].

Photometric observations started shortly after discovery with a flurry of visual observations from 2001 to 2006, but these were generally bright upper limits and no outbursts were detected. These overlapped briefly with the Catalina Real-Time Transient Survey (CRTS)[21] which made 291 observations from 2005 to 2013, but all these showed the object at quiescence. The first outburst was detected in 2016 by the All Sky Automated Survey for Supernovae (ASAS-SN) project when it reached $V = 15{\cdot}2$, and is catalogued under the name ASASSN-V J012750·63+380812·4[22,23]. Two further outbursts were recorded in 2018 and 2019 by both ASAS-SN and the *Zwicky Transient Facility*[24], as ZTF18abtlrqu. The most recent outburst in 2020 October was reported by Kaneko[25] who found the system at magnitude 12·9, and it was also recorded by the ASAS-SN project at $g = 13{\cdot}49$, less than a day after the initial detection.

Observations

The observations were made with 0·25-0·40m class telescopes as detailed in Table I. All the images were bias-, dark-subtracted and flat fielded, and then reduced using aperture photometry software packages IRAF, API4WIN or LESVEPHOTOMETRY. The images were unfiltered so *CV* magnitudes were obtained by calibration relative to a *V*-band sequence of local comparison stars.

Five overlapping time-series runs were made over two days from 2020 October 26·8 (JD = 2459149·3) and the following day October 27·7 (JD = 2459150·2), and are the first of this system in outburst (Table II). A further two isolated observation were made a day later on October 28·8 (JD = 2459151·4) and two further time-series runs were made on November 5 and 11 (JD = 2459159 and 2459164) after the system had returned to quiescence.

TABLE I

List of equipment used

Observer	*Telescope*	*Camera*
Pickard	Shobdon LX 200 0·35-m	SXVF-H9
Tordai	CBA Hungary 0·25-m	QHY6
Vanmunster	CBA Extremadura 0·40-m	SX-46

TABLE II

List of the time-series observations

Date UT	*JD*	*Hrs.*	*N*	*Observer*
2020 Oct 26	2459149·250 – ·523	6·6	347	Tordai
2020 Oct 26	2459149·438 – ·588	3·6	86	Vanmunster
2020 Oct 27	2459150·195 – ·505	7·4	358	Tordai
2020 Oct 27	2459150·261 – ·425	3·9	222	Pickard
2020 Oct 27	2459150·436 – ·672	5·6	458	Vanmunster
2020 Oct 28	2459151·298 – ·430	3·2	2	Tordai
2020 Nov 05	2459159·414 – ·558	3·5	198	Pickard
2020 Nov 11	2459164·553 – ·683	3·1	62	Vanmunster

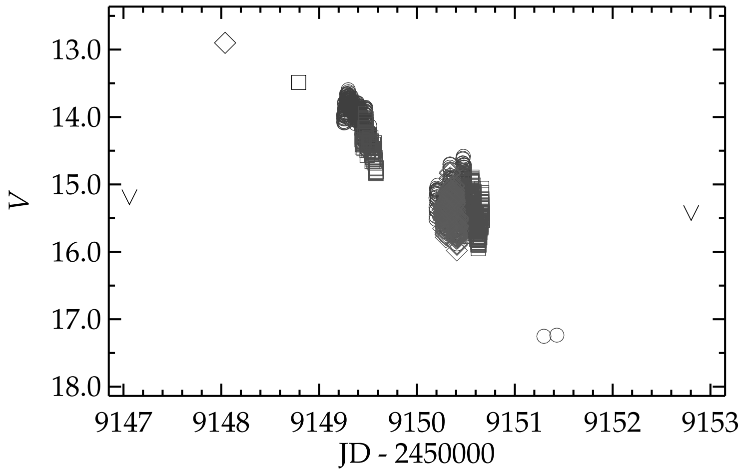


FIG. 1

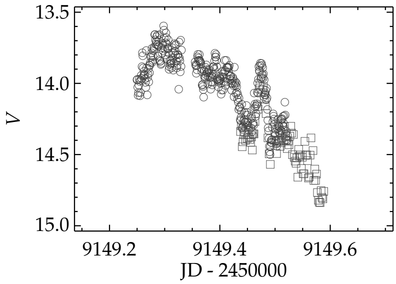
The light-curve around the time of the outburst. The pre-discovery upper limit and discovery observations are due to Kaneko, the next, and last upper limit to ASAS-SN, and the others to this paper. The time-series runs are shown in more detail in Figs. 2 and 3.

The outburst

All the observations around the time of the outburst are shown in Fig. 1 and, in keeping with most CVs, the rise is rapid, less than one day, and the decline is broadly linear, covering 4·3 magnitudes in 3·4 days, giving a rate of 1·3 magnitudes/day. The duration of the outburst is 3–4 days at $V = 16{\cdot}0$, and the amplitude is $4^{\rm m}{\cdot}7$. While the runs from the first night are consistent with the general rate of decline, those from the second are not, and show the star at approximately a constant mean magnitude, with excursions of ±0·5 magnitudes on a time scale of ~ 0·1 days. These two days are shown in detail in Figs. 2 and 3. The feature visible on the first night was initially taken to be a superhump and the star was provisionally identified as an SU Ursae Majoris system[26], effectively in real time, but it quickly became clear that this behaviour did not persist. The runs from the second night show similar behaviour, but with a larger amplitude. The large variations on both nights are not periodic but are almost continual on a range of time scales, and both are very suggestive of flickering. Flickering is a ubiquitous feature of CV optical and particularly X-ray light-curves and is diagnostic of the accretion process (see *e.g.*, Bruch[27] and Scaringi *et al.*[2]).

Flickering

The runs have been analysed for flickering using the wavelet-transform technique and parametrization of Fritz & Bruch[28]. The flickering power spectrum is shown in a 'scalegram' where the flickering presents as a power-law, and Fritz & Bruch define α as the gradient of the power-law and Σ as the power at some reference time-scale, in their case 3 minutes. Different classes of



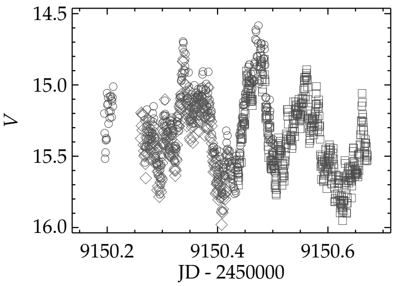


FIG. 2 (Left)

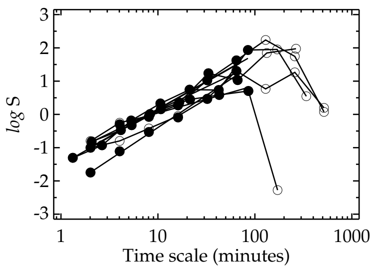
The two time-series runs from October 26. The first night is dominated by a steep decline with excursions of $\pm 0^{\rm m}\cdot 3$. Both these plots have the same horizontal and vertical scale. Different symbols indicate different runs.

FIG. 3 (Right)

The three time-series runs from October 27. The mean magnitude is essentially constant and there are excursions in excess of $\pm 0^{\rm m}\cdot 5$ on a variety of time-scales.

CVs tend to populate different regions of the $\alpha - \Sigma$ plane and the positions of systems can change between quiescence and outburst. Optically the classes of CVs with the strongest flickering are the SU UMa stars at quiescence and the magnetic systems.

In order to quantify the flickering realistically, the runs need to be as long as possible and have relatively low noise. Two runs did not give reliable results; these were the short run on October 26 and the run on November 5 when the system had returned to quiescence, although both show more power at longer time-scales. All the other runs show significant flickering as can be seen in the combined scalegram in Fig. 4 and in the $\alpha - \Sigma$ plot, in Fig. 5. The values of Σ lie at the extreme upper limit of the sample examined by Fritz & Bruch in a region



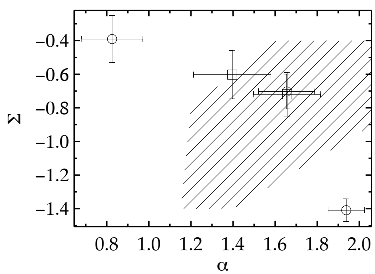


FIG. 4 (Left)

Combined scalegram plot of the best time-series runs. The points at longer time-scales correspond to the length of the runs, so are poorly sampled and are not used in the fit.

FIG. 5 (Right)

Plot of the α and Σ parameters derived from the scalegrams with the hatched area showing the region occupied by magnetic CVs. The point at the bottom right is from the first night and shows the weakest flickering but the steepest gradient. The three consistent points are all from the second night, and the point top left is from quiescence. The variation suggest evolution from steeper but weaker flickering to flatter, stronger flickering through the outburst to quiescence.

populated by magnetic CVs, in particular the intermediate polars BG CMi and EX Hya, and the polars VV Pup and V834 Cen. As the star is obviously not an SU UMa system in quiescence, the flickering suggests it is most likely a magnetic CV.

During the short outburst the characteristics of the flickering clearly changes. It starts relatively weakly — but this is still strong for most CVs — and it is more structured, that is, less random. As the star fades the flickering becomes stronger, and this is evident in the light-curves from the second night. Finally when the system returns to quiescence the flickering reaches a (relative) maximum but is less structured, more random. Similar behaviour is seen in SU UMa stars when the flickering becomes diluted by the additional luminosity of the outburst, but the change in α suggests that there are also other changes in the accretion process, and therefore the flickering.

Period analysis

Although most of the runs show clear flickering they have also been examined for residual periodic variations. The period search was made using a standard Discrete Fourier Transform (DFT) periodogram and fitted using a least-squares multi-frequency Fourier routine. It was said earlier that the large variations were not periodic and while this is correct it is not the whole story. The two combined runs from the first night show a clear and dominant periodic signal at $P = 0{\cdot}0613 \pm 0{\cdot}0005$ d and an amplitude of $\pm 0^{m}{\cdot}10 \pm 0^{m}{\cdot}01$, and the same period is found independently in both runs. Although this value is consistent with the orbital period, the uncertainty, which amounts to ~ 1%, means this may be a superhump period. The runs from the second night are clearly dominated by flickering so two different approaches were explored in the search for periodic variations. In the first, periods were removed successively as they arose, effectively pre-whitening the data on the dominant time-scales, and in the second the data were explicitly filtered by subtracting a simple boxcar moving average. In both cases a significant period emerged close to the orbital period, but in the midst of the flickering its origin is uncertain.

The second night also revealed a shorter period which was refined to $P = 454{\cdot}2 \pm 0{\cdot}5$ s or $f = 190{\cdot}2 \pm 0{\cdot}2$ c/d, with a semi-amplitude of $0^{m}{\cdot}038 \pm 0^{m}{\cdot}005$. The only likely candidate for a period in this range is the white-dwarf-spin period. There are two reasons for not immediately dismissing this signal as spurious. The first is that all three time-series runs from this night showed a feature near this value and it is the only feature to retain its strength in the combined data. Secondly, this period range is towards the noise-dominated part of the frequency spectrum so coherent flickering should be less of an issue. The DFT periodograms of the individual runs and the combined data are shown in Fig. 6. In the same way as with the nodal precession the orbital period can also modulate the spin period so the dominant variation may occur at a modulated frequency, $|\omega_{orb} - \omega_{wd}|$ or a sideband. In this case there are no obvious features near $2P_{wd}$ or $P_{wd}/2$, or sidebands above the noise.

At the quiescent magnitude of $V = 17{\cdot}6$ the noise level is substantially higher than during the outburst. The first run in quiescence on November 5 does not show flickering but as mentioned earlier the scalegram does reveal increased variation on longer time-scales. The period study shows that this is due to the dominant periodic variation with a semi-amplitude of $0^{m}{\cdot}18 \pm 0^{m}{\cdot}03$ which is again consistent with the orbital period. The 190 c/d feature is below the noise level of both the runs in quiescence and does not appear.

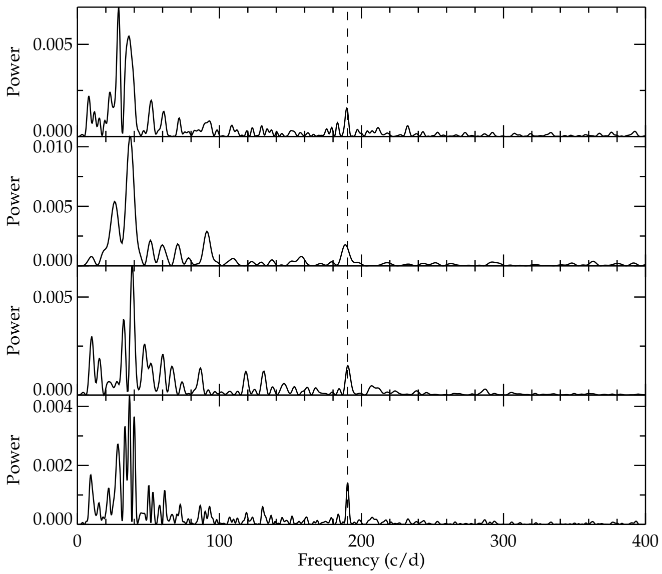


FIG. 6

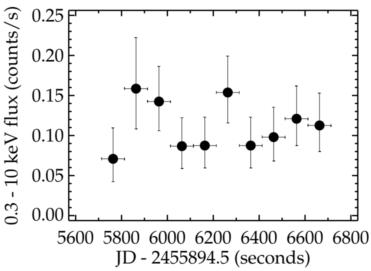
The DFT periodograms of the three individual runs on October 27 shown in Fig. 3, and the combined data (bottom). The data have been lightly filtered to suppress the large-amplitude, low-frequency features due to flickering, but these still dominate. Notice the change in scale for the combined data as the lack of coherence in the noise suppresses these features, and the suggested white-dwarf-spin period, indicated by the vertical line, is the only feature to retain its strength.

The long-term synoptic data have also been searched for periodic variations. The CRTS data are dominated by a long-term cyclical variation with a semi-amplitude of $0^{m}\cdot13$ and $P\sim7$ years, which is close to the length of the data, and may reflect long-term changes in the quiescent magnitude. At quiescence the system is at the limit of the ASAS-SN data and most of these values are upper limits. There are only 50 *V* and 175 *g* measurements and these provide an upper limit to any periodic variation of $\pm0^{m}\cdot14$ and $\pm0^{m}\cdot09$ in *V* and *g*, respectively. The *ZTF* data are available from 2018 with nearly 400 measurements, mostly in the *zg* and *zr* bands. The dominant period is an artefact at one sidereal day but the background noise level in the combined *ZTF* data is only $\pm0^{m}\cdot04$, and there are no likely periods. The *Swift* XRT has only one 900 s light-curve of 1RXS J012750·5+380830, which is shown in Fig. 7, but unfortunately this is relatively low signal to noise, and shows no significant variation.

Fig. 8 shows the white-dwarf-spin period, $P_{\rm wd}$ as a function of $P_{\rm orb}$ for IPs from the Ritter & Kolb Catalogue[14], and while 1RXS J012750·5+380830 has an average value of $P_{\rm wd}/P_{\rm orb}$ it does have a very low value of $P_{\rm orb}$.

Recurrence rate

Prior to the 2020 October outburst the transient had been seen eight times in the combined ASAS-SN and *ZTF* data, but these correspond to just three independent outbursts, two of which were detected by both projects. No outbursts at all were detected by the CRTS project. Although there are over



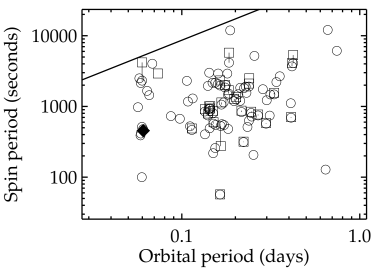


FIG. 7 (Left)

The single *Swift* XRT 0·3 – 10 keV light-curve for 1RXS J012750·5+380830, which shows no significant variation.

FIG. 8 (Right)

The white-dwarf-spin period, P_{wd} as a function of P_{orb} for known or suspected IPs. The squares show P_{wd} from X-ray observations while the circles are from the optical, and when both are available these are linked. The line is the synchronization line where $P_{wd} = P_{orb}$, and marks the locus of the AM Her stars. 1RXS J012750·5+380830 is the filled diamond.

2600 combined observations they tend to be in tight groups of three or four, so the number of independent opportunities to detect an outburst is considerably reduced. The median spacing of these observations is 14 days for CRTS, two days for ASAS-SN, and one day for the most recent combined ASAS-SN and *ZTF* data. Examining the data spacing in more detail provides a simple probability of detecting one three-day outburst in each of those sets as < 1%, 25%, and 60%, respectively. Given this, it is not surprising that the CRTS data do not show an outburst, and also that a significant number were potentially missed prior to the *ZTF* data. More recently with the combined coverage the number of missed outbursts should be low. Of the four known outbursts three occurred in the recent combined data and one in the ASAS-SN-only time-frame. From this discussion it means that the minimum separation of recent outbursts is probably one or perhaps two times the recurrence interval. The minimum interval is 313 days and the other timings suggest spacings in the proportion 3:1:2 leading to an outburst time-scale of 266 d, with the residuals having $\sigma = 21$ d. If the spacings are in the proportion 5:2:3 then the outburst time-scale becomes 159 d with $\sigma = 8$ d. The time-scale of CV outbursts varies enormously but for systems in the few-hundred-day range the standard deviation of the residuals is typically about 10% of the outburst interval. For the shorter time-scale the residuals are suspiciously small, probably because more degrees of freedom are available, but the longer time-scale is more consistent with other CV outbursts.

Discussion

Now to the question posed in the title, how does 1RXS J012750·5+380830 compare with other intermediate polars? It is a strong X-ray source and shows variable He II λ4686 emission, although this is relatively weak[17,19]. It shows very strong flickering consistent with a magnetic CV, but this does not differentiate

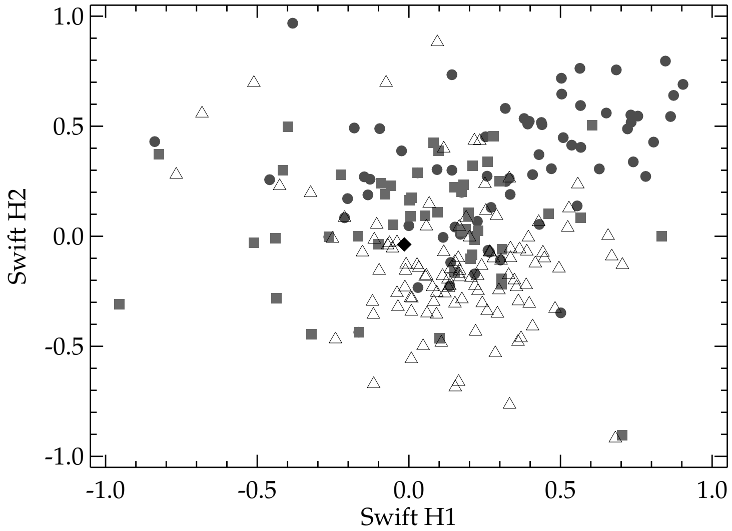


FIG. 9

The *Swift* hardness ratios H1 and H2 for systems in the Ritter & Kolb Catalogue: IPs (circles), AM Her stars (squares), and SU UMa stars (triangles). There is considerable overlap but the IPs are generally harder than the AM Her stars and the SU UMa stars for a more differentiated group at lower H2, but of course are generally much weaker. 1RXS J012750·5+380830 is the diamond in the centre of the distribution.

the type, although it also shows outbursts which points towards an IP. The most compelling evidence is the light-curve modulation at what can only be the white-dwarf-spin period, and this is generally regarded as diagnostic[4,5,29]. As an X-ray source the system is compared with others from the Ritter & Kolb Catalogue in Fig. 9, which shows the *Swift* hardness ratios from the (0·3–1), (1–2), and (2–10) keV ranges. The magnetic variables, IPs, and AM Her stars are shown together with the SU UMa stars for comparison. There is considerable overlap but the IPs are generally harder than the AM Her stars, and the SU UMa stars form a more differentiated group at lower H2, but of course are generally much weaker. 1RXS J012750·5+380830 lies at the centre of the distribution on the softer edge of the IP systems.

During the outburst 1RXS J012750·5+380830 showed a modulation close to the orbital period during the first night and again shortly after the system returned to quiescence. In both cases this was the dominant periodic variation, but it was detected against a background of flickering, so there is naturally some question about its reality. If it is an SU UMa-type common superhump then it should appear in a superoutburst, but in every way this outburst was ordinary. If it is a permanent superhump then it should be detectable during quiescence.

One curious feature of the outburst is the flattening of the light-curve part way through the decline, showing what, under other circumstances, might be called a plateau phase (see Fig. 3). The light-curve of the superhumping IP CC Scl shows a very similar feature, but this system also shows superoutbursts and common superhumps, as well as the tell-tale signature of the white dwarf[6].

Conclusions

The X-ray flux and hardness ratios, together with the variable He II λ4686 emission, and the very strong flickering all point towards 1RXS J012750·5+380830 being a magnetic CV. Given that it shows outbursts the likelihood is towards an IP. The diagnostic feature of an intermediate polar is detection of the white-dwarf-spin period and a likely candidate was found during the second night against a background of strong flickering. Unfortunately, it was not detected on the other nights and the limited X-ray light-curve provides no constraint either way.

During the outburst dominant periodic variations were found close to the orbital period on two nights, but due to the uncertainty in the period these could be interpreted as orbital or superhumps. The system has outbursts of $\sim 4^{m}\cdot 7$ on an average time-scale of 266 d, but these are short, 3–4 days, unlike the superoutbursts of other SU UMa/IP systems.

The status of this system remains unclear but given that it has such a short period and potentially shows both superhumps and a white-dwarf-spin period deserves to be followed up.

Acknowledgements

The authors are indebted to Dr. John Thorstensen for providing the velocities of 1RXS J012750·5+380830 and the mean spectrum of the system, and a helpful commentary. The authors would also like to thank the referee for helpful comments. The authors are pleased to acknowledge the use of the NASA/ADS, the *Simbad* database, and the *VizieR* catalogue access tool. This work made use of data supplied by the UK Swift Science Data Centre at the University of Leicester.

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REVIEWS

A Philosophical Approach to MOND: Assessing the Milgromian Research Program in Cosmology, by David Merritt (Cambridge University Press), 2020. Pp. 284, 25 × 17·4 cm. Price £49·99/$64·99 (hardbound, ISBN 978 1 108 49269 0).

Merritt's new book is something of a curate's egg: his discussion of MOND (MOdified Newtonian Dynamics, an alternative to dark matter which involves modifying the laws of gravity and/or inertia, originally proposed by Milgrom[1]) is knowledgeable and convincingly argued.

However, when comparing MOND with ΛCDM (the mainstream idea of structure formation in the Universe, Λ being the cosmological constant and CDM cold dark matter), the approach is too imbalanced.

Chapter 1 on the epistemology of science quotes Popper: "The trouble about people — uncritical people — who hold a theory is that they are inclined to take everything as supporting or 'verifying' it, and nothing as refuting it." That is actually a good summary of my impression of this book, though my target is of course Merritt and not standard cosmology. Otherwise, the chapter is mostly a good introduction to the topic. Chapter 2 on scientific research programmes begins with a comparison between the philosophies of Popper and Kuhn. In contrast to his article[2] (which I also reviewed[3]*), in his book Merritt takes a more critical approach to Kuhn, which is good; he also describes the ideas of Lakatos. The discussion of the development of the philosophy of science is actually quite good; my complaint is that he doesn't properly apply it in his main thesis, contrasting MOND and ΛCDM. Chapter 3, on the Milgromian research programme, starts by claiming that postulating dark matter to explain galaxy rotation curves is *ad hoc*. After spending two chapters on how the history of science has influenced the philosophy of science, Merritt ignores centuries of the history of dark matter, giving the impression that postulating dark matter in galaxies is somehow a radical suggestion. Otherwise, it is a good introduction to MOND.

Chapter 4 looks at MOND predictions. While the book includes a detailed description of and references to MOND, it does not contain the same for ΛCDM, thus it could be difficult for the reader to judge whether his criticism of the latter is correct. Chapter 5 examines non-relativistic extensions of the basic MOND idea, which allow it to conform to well-tested conservation laws; this chapter is a good introduction to the topic. Chapter 6 looks at relativistic

*I had read his article[2] before I knew about his book, and wrote a rebuttal of the former[3] before I had even glanced at his book. In the interest of space, I will mention here mainly points raised in the book but not in the article; taking that into account, my rebuttal can also be seen as a response to the contents of the book.

extensions to MOND and is probably the most misleading. Among other problems, Merritt confuses the cosmological constant with dark energy* and claims that "adjusting the assumed properties of 'dark energy' so as to maintain consistency of the observations ... is an active ... field of research". While there are people working on various models of dark energy, it is not part of the standard model of cosmology, simply because all observations are compatible with a simple cosmological constant (and hence there is no need to tune its properties).

The only criticism which is perhaps valid is that the baryon density inferred from CMB observations is about twice as high as that indicated by Big Bang nucleosynthesis (BBN). However, instead of viewing that as two conflicting observations, Merritt takes the latter value as gospel and criticizes the standard model for the heresy of departing from it, instead of noting that the jury is still out. Two consequences of the higher value are the lithium problem and the missing-baryons problem; the standard model predicts both more lithium and more baryons than are observed. (Note that the reverse would be much worse.) It is at least not inconceivable that primordial lithium is destroyed, and it would be surprising if we knew where all baryons are as soon as the BBN prediction had been made. Interestingly, there have been recent claims that the missing-baryons problem has been solved — by finding them[4,5].

Probably the strongest claim is that MOND correctly predicted the ratio between the first two peaks in the CMB power spectrum while ΛCDM failed to do so. Such a prediction was indeed made by noted MOND proponent McGaugh[6], but it is not really a MOND prediction. McGaugh merely calculated the CMB power spectrum assuming the then current value for the baryon density and no dark matter. In other words, there is no MOND physics at all in McGaugh's calculation, which used CMBFAST[7], a standard software package based on standard cosmology. While that prediction does get the ratio between the first two peaks correct, it fails for the third peak, which McGaugh himself later acknowledged. Needless to say, ΛCDM can explain the CMB power spectrum in detail; seven peaks have now been detected. After criticizing ΛCDM because it merely 'fits' whereas MOND 'predicts', he then asks whether the MOND prediction can be modified in order to get the height of the third peak correct, and finds that it can — by introducing dark matter (!) in the form of a sterile neutrino, justifying it because "it has long been considered by physicists to be a natural addition to the known list of particles in the standard model". Such a particle has not been detected in the laboratory and its mass is a free parameter, two criteria which Merritt criticizes in the context of particle dark matter in connection with ΛCDM.

His discussion of combining various cosmological tests in order to determine parameters better than *via* individual tests is confused. Yes, there are degeneracies in the (CMB) power spectrum, but the whole point of using other cosmological tests is to break those degeneracies. Rather bizarre is his claim that $\Omega + \lambda = 1$, *i.e.*, a flat Universe, is assumed "whether or not such a value is required by the data". It might not be required by one set of data (the m–z relation for type-Ia supernovae, say) but strongly required by another (such

*'Dark energy' is usually understood to mean (something which behaves like) some sort of substance which has the sign of its pressure opposite that of its energy density and a ratio of the two other than −1, possibly changing with time. The case $p = -\rho$ for all times corresponds to the cosmological constant, though, depending on context, sometimes that is seen as a trivial example of dark energy. The important point is that the evidence for the cosmological constant is very strong, while there is no evidence for any more complicated form of dark energy.

as the CMB). In such cases, assuming a flat Universe is not some arbitrary auxiliary hypotheses, but merely a way of combining the data. It is also not true that "few if any of the fitted parameters can be independently derived from different data sets". The fact that that is possible is the reason for the term 'concordance model'. Combining different data sets gives tighter constraints and is a standard statistical procedure. Merritt also overlooks the fact that if something were seriously wrong with ΛCDM, then one should be puzzled that the constraints from different individual data sets overlap in the first place.

The most famous relativistic extension to MOND is TeVeS (Tensor Vector Scalar)[8]. Merritt correctly notes that that theory predicts different arrival times for simultaneously produced gravitational and electromagnetic radiation and hence such observations, and in particular a recent one he mentions, would rule out TeVeS if it "withstands critical scrutiny" (a caveat he doesn't apply to observations which he claims rule out ΛCDM). An interesting omission is not only that is it clear that TeVeS has been ruled out by such observations, but also that such a claim was made by none other than Sanders[9], one of the main proponents of MOND. (Sanders is also much less critical of ΛCDM than is Merritt[10].)

Chapter 7 was a surprise, casting the idea of superfluid dark matter due to Berezhiani & Khoury[11] as an extension of MOND, though a modification of its 'hard core'. (Why that is considered to be legitimate, while the cosmological constant or dark matter in the standard model is not, is not explained. Moreover, superfluid dark matter is postulated to have exactly the properties necessary to reproduce observations, which Merritt criticizes in the context of the standard model.) In discussing more-conventional alternative explanations for phenomena such as the lack of dynamical friction experienced by globular clusters in the Fornax galaxy, Merritt dismisses dark matter as globular-cluster-mass black holes without any justification, even though they are a viable dark-matter candidate[12]. While I think that both primordial black holes and superfluid dark matter are better dark-matter candidates than a single non-interacting elementary particle, both are somewhat non-mainstream, and Merritt seems to embrace one because it has a tenuous connection to MOND and to dismiss the other without reason.

Chapter 8 on convergence is good; what makes MOND worth considering at all is the fact that the acceleration constant a_0 appears in a variety of situations which are not obviously closely related. Such convergence is one of the best arguments in favour of MOND, or at least in favour of the argument that there is something non-trivial behind MOND phenomenology. The rest of the chapter contains some puzzling elements. While MOND, or something like it, might alleviate the need for dark matter, at least in some cases, the evidence for the cosmological constant is quite different, and in most cases quite independent, so it is unclear why "[o]ne can only speculate what would be the consequences for dark energy" should MOND turn out to be right. That is mentioned in relation to the fact that a_0 is approximately equal to $cH_0/(2\pi)$. (The factor 2π has no justification other than to make the approximation better.) Since H_0 was larger in the past, that would imply that a_0 was also larger in the past, unless the current near equality is a coincidence, though a decreasing value of a_0 would imply that MOND effects were larger in the early Universe, somewhat in contradiction to the assumptions of Chapter 6, where much is made of the fact that MOND should predict the same CMB spectrum as the standard cosmological model without dark matter.

Chapter 9, 'Summary/Final Thoughts', is a bit unfair in that it lists many (perceived) failures of ΛCDM but not of MOND. While complaining that ΛCDM has some wiggle room, Merritt notes that "[t]he lack of a unique relativistic theory complicates the generation of testable predictions" in MOND and grasps at the straw of the ratio of the first and second CMB peaks, calling McGaugh's prediction[6] "the *only* successful, quantitative prediction that anyone has made about the CMB spectrum" [Merritt's emphasis]; I doubt that even most MOND enthusiasts would count it as "a major success of Milgromian theory". Merritt finally admits that "no relativistic version of Milgrom's theory has yet been found that successfully reproduces the full CMB spectrum". By the criteria he applies to ΛCDM, that should rule out MOND. Indeed, the lack of a believable relativistic theory is one of the main reasons people remain sceptical of MOND, even if they allow for the fact that MOND is only an approximation to a relativistic theory, like Newtonian gravitation is an approximation to General Relativity (GR). However, in the absence of a viable relativistic extension to MOND, and considering that there is no known observation which is in contradiction to GR, it is perhaps asking too much to believe in a hypothetical extension to MOND as opposed to GR. He concludes the book with the claim that (MOND or some extension of it) is "a theory of cosmology that is both testable *and* viable" [his emphasis].

Despite my many complaints mentioned in this review, and keeping in mind that many more (with many references) are mentioned in my rebuttal of his article[3], the book is well written and many references are provided for statements about the philosophy of science. A greater portion of the book than of the article is concerned with the philosophy of science, and together with the greater length it means that the book contains much material on that. It is good, well researched, and I agree with it. It is thus even more puzzling that Merritt's application of that to the MOND *vs.* ΛCDM debate is so unbalanced.

While his criticism of the mainstream cosmological community is clear, I also think that it is unfair to the MOND community, as it could create the impression that that community has to resort to exaggerated claims in order to defend itself, which is essentially an admission of defeat. That is particularly sad because my impression is that there is something non-trivial about MOND phenomenology which deserves much more attention, whatever its explanation ultimately turns out to be. There is a need for a book like this, but Merritt's book sheds too much heat and not enough light on the debate. — Phillip Helbig.

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Hippolyte Fizeau, Physicist of the Light, by James Lequeux (EDP Sciences, Paris) 2020. Pp. 142, 24 × 16 cm. Price €29 (about £26) (paperback; ISBN 978 2 7598 2045 0).

The 19th Century saw physicists join in the fun of investigating the cosmos. Instead of stars being just mysterious pin-points of light, some started to have known luminosities, masses, surface temperatures, compositions, and radial velocities.

The Parisian, Armand-Hippolyte-Louis Fizeau (1819–1896), was an ingenious, intelligent, wealthy, bourgeois 'amateur' physicist, and his personal fortune enabled him to conduct his research as he saw fit. He is mainly remembered for both his work on the optical Doppler Effect (which in France is known as the Doppler–Fizeau Effect), and for his accurate measurement of the velocity of light using an 8·6-km light-path across Paris and a rotating toothed wheel. This later work led to much debate about the wave–particle dualism of photons and the search for æther drag. Fizeau was also a pioneer photographer, and with Léon Foucault obtained a superb daguerreotype of solar limb-darkening in 1845. He also played a significant role in the French 'movie' photographic investigation of the transit of Venus in 1874. Today he is also remembered for his pioneering attempts to measure the diameter of stars using interferometry.

Lequeux, an emeritus historian of astronomy at the Paris Observatory, has provided us with a highly readable, well-illustrated, and thoroughly researched biography of the scientific work of Fizeau. The book is greatly enlivened by the many reproductions of Fizeau's hand-written notes and diagrams. I was slightly disappointed by the lack of detail concerning Fizeau's home life. We were told in great detail *what* he did, but not *why* he did it, and certainly not why he did it when he did it. I would have also liked more information about Fizeau's relationship with François Arago and Léon Foucault.

The translation from the original French language also needed a slight polish. The book notes that Fizeau married Thérèse Valentine de Jussieu and moved in to the family 'castle'. I had imaginings of battlements, moats and portcullises and it was only on page 117 that a photograph informed me that this 'castle' was the beautiful Chateau Venteuil in Jouarre, Seine et Marne.

But these are very minor points. Lequeux has done a marvellous job in detailing the scientific efforts and successes of this influential and talented Frenchman. This is a very worthy book, and is a perfect basis for more detailed investigation, and I recommend it highly. — David W. Hughes.

Kazimierz Kordylewski as a Man and an Astronomer, edited by Bogdan Wszołek & Agnieszka Kuźmicz (Wydawnictwo Astronomia Nova), 2020. Pp. 200, 24 × 16·5 cm. Price 70 zł (about £14) (hardbound; ISBN 978 83 957016 1 0).

The five Lagrange points in a two-body Newtonian system of unequal masses are called so because they were discovered mathematically by Euler in 1765 (L_1, L_2, and L_3) and by Lagrange in 1772 (L_4 and L_5). The Trojan asteroids occupy the L_4 and L_5 positions of the Sun–Jupiter system. A very few have turned up at the L_4 and L_5 points of the Sun–Earth, Sun–Mars, and Sun–Neptune system. But what, if anything, lives at L_4 and L_5 of the Earth–Moon system? Kazimierz Kordylewski (1903 October 11 – 1981 March 11) started looking telescopically in the 1950s for small rocks, and by naked eye for dust clouds. He concluded that he had photographed the L_5 cloud in spring, 1961, and reported it in IAU Circular 1760, under the editorship of N. Stoyko (a Russian refugee in Copenhagen).

A conference in honor of Kordylewski and his clouds was held on 2019 October 12 in Rzepiennik Biskupi, Poland. This volume represents the proceedings of that gathering. The long-standing question has been, are the clouds real? Mathematically, L_4 and L_5 are stable if Earth and Moon are the entire Universe. Add the Sun, and this is no longer entirely true. Observationally, quite a few astronomers have seen faint patches of reflected light there, and even measured its polarization. Others have not. In the 'yes' camp was astronaut Alfred Merrill Worden (1932 Jackson, Mississippi — 2020 Houston, Texas) photographing L_4 from *Apollo 15* in 1971. He appears as the last of four authors of the *Apollo 15* Preliminary Science Report (NASA Special Publication 289 in 1972). 'Just for fun' the first author (also of the *Apollo 16* Preliminary Science Report) was the late Lawrence (Larry) Dunkleman, a boyhood friend of my late husband, Joseph Weber.

The original ground-based search was proposed by the then-director of Cracow Observatory (where Kordylewski spent most of his career), Tadeusz Banachewicz (Vice President of the IAU 1932–1938), who died in 1954, before the results were in. A photograph of his sarcophagus appears in the proceedings, under the rubric '*Credo quam redemptor meus vivit*' (I know that my redeemer liveth). Kordylewski had been his student at the Jagiellonian University in Krakow. This must have been about the last conference Al Worden attended, since he died less than a year later.

My favourite image in the proceedings appears on page 64. It shows Kordylewski's camera (a distinct resemblance to my father's 1921 Leica 35-mm) and his typewriter. Close examination shows that the Y and Z are in the eastern position, not the western position (Y next to X, and Z between T and U). Thus it should not surprise you to hear that, although the subtitle of the book is said to be *As a Man and an Astronomer*, it appears on the front cover as *jako czlowiek i astronom* and many of the less technical papers are in Polish. — VIRGINIA TRIMBLE.

Chelyabinsk Superbolide, edited by Nick Gorkavyi, Alexander Dudorov & Sergey Taskaev (Springer), 2019. Pp. 304, 24 × 17 cm. Price £22·99/$29·99 (paperback; ISBN 978 3 030 22985 6).

My initial interest in this work — although all astronomers must be interested in the event — centred on wondering about the quality of the translation of these various Russian-language contributions. The title page credits the Chelyabinsk University Publishing House, but in their acknowledgements the authors credit Alexey Lebedev. Although there are some problems (a few are mentioned later), in general the translation is excellent. A footnote on the very first page contained an English word *chatushkas* I had never encountered before, which sent me to my dictionaries. (*Chatushkas* are typically humorous, traditional Russian, four-line folk poems.) So I learned something straight away. And I certainly learned a lot from the rest of the book, which consists of fifteen chapters, detailing various aspects of the event: the trajectory of the bolide, collection of meteoritic fragments, recovery of dust from the snow, meteorological consequences, *etc.* There is no general bibliography, but each individual chapter has extensive notes. There is also an appendix in which the lead author, N. Gorkavyi, and

T. A. Taidakova, present arguments against the impact of Theia, a Mars-sized object, as the origin of the Moon, in favour of multiple, smaller impacts where the mechanism appears also to account for binary asteroids and the orbits of the satellites of the planets.

According to the lead author, the book "will be of interest to scientists, and also to those who are not quite so heavily involved with this event". It is, indeed, suitable for most non-specialists and contains many colour photographs not seen elsewhere. Only occasionally do the authors adopt complex scientific arguments, such as in describing solving polynomial equations to determine atmospheric drag on the major fragment that created the hole in the ice of Lake Cherbakul, and in the discussion of the way in which the dust trail from the bolide was detected from satellite measurements. A convoluted description of why the bolide's track appears curved is attributed to imperfections in the optics, whereas, as any photographer knows, straight objects, such as jet-stream cirrus and the Milky Way (or a bolide's trajectory) will appear curved, convex upwards, in photographs.

There are some oddities in the translation, notably the frequent omission of the articles 'a', 'an', or 'the' — typical of Russian — and the spelling of certain words ('chalcophylic' for 'calcophilic', for example). There are also some elementary errors in spelling ('principle' for 'principal'), but these are generally obvious and will cause little difficulty. It may be noted that the general spelling is American. Care also needs to be taken with masses, which are normally given in grams or kilograms, but where occasionally they are expressed in 'tons'. The same caution applies to certain dates, which are sometimes given in the American, non-scientific order of month (in figures, not letters), day and year.

These are signs, unfortunately, that the editorial process has not been rigorous. There are bound to be problems with any book written by numerous (in this case, twelve) authors, but some could have been avoided with a little more editorial care. The text in Chapter 1 describes how the illustrations show different colours, indicating different (high) temperatures. Certainly, to this reader, there is no blue apparent, supposedly showing temperatures higher than the surface of the Sun — and incidentally, the source of UV radiation that caused skin burns on some individuals. Problems occur, too, with some of the diagrams, particularly the maps. In Fig. 1.5, for example, it is impossible to determine which points are red and those that are orange (supposedly different), and in Fig. 4.1 although the caption notes the occurrence of red and green markers, there is no indication of the significance of those colours. There are problems too with the rendering of the Russian names of locations. For example, in the text we have 'Yemanzhelinka' and on the map (Fig. 4.1) 'Emanzhelinka', while Fig. 3.2, another map, uses Cyrillic letters. Anyone unfamiliar with Russian might well wonder if they were separate locations.

Yes, there are problems with the translation, occasionally because the poor translator has been uncertain of the correct terminology. There are mentions and illustrations of 'solar shadows', which are better known — certainly to meteorologists — as 'crepuscular rays'. In Chapter 1, Antarctic meteorites are described with "where glaciers bring the accumulated sky stones to the shore", whereas, of course, it is flow within the ice cap itself that brings concentrations of meteorites to (or close to) the surface in certain areas, hundreds of kilometres from any shore.

Some of the findings are particularly notable. Apparently no less than 99·5 per cent of the mass of the original meteoroid was lost to ablation in the atmosphere. The intense heat from the bolide created a convective cloud in the stratosphere, where convection is normally suppressed by the increase in temperature with height. This raised ablated dust particles to extreme heights in the atmosphere — heights that are normally not even attained by the most violent volcanic ejections.

Two of the later chapters deal with the consequences of studies undertaken of this superbolide, the only major impact in modern times. Most significant are the changes to ideas of the frequency and severity of major meteoroid impacts, with a downward revision of the size of dangerous objects. (Previously the angle of impact was considered to be particularly significant, but now it appears that the initial mass of the meteoroid and how much survives to impact the surface are the dominant factors in the destructive effects.) There is a discussion of ways in which dangerous asteroids could be deflected. Another finding is the immense importance of the amount of material deposited into the upper atmosphere by such events.

One rather disconcerting finding is that although about one tonne of material has been available for scientific examination, it is estimated that at least ten times that amount was recovered, but has been retained in private hands or sold commercially. Not only would certain witnesses not speak to researchers, there are still individuals who deny that it was a meteoroid, preferring to believe that the event was caused by an aircraft or missile crash. The authors stress that, scientifically, the recovery of the dust was more significant than obtaining fragments of the meteoroid itself.

All in all, a very useful summary of the effects of the superbolide, and a book to be recommended. — Storm Dunlop.

Origin and Evolution of the Universe: From Big Bang to ExoBiology, 2nd Edition, edited by Matthew A. Malkan & Ben Zuckerman (World Scientific), 2020. Pp. 232, 23 × 15 cm. Price £40/$48 (paperback; ISBN 978 981 120 772 3).

As an Editor kindly reminded me, it is 24 years since I — positively — reviewed the first edition of this book (**116**, 414, 1996). So how does the new version compare? First the trivial. The new edition has lost its leading definite article, gained a subtitle, and switched the order of its editors. It also has a significantly smaller page size. And the authors of the six chapters are, of course, 24 years more senior.

As to its tone, the Preface no longer asserts that the book is intended to be "accessible to anyone with an appreciation of science", but is even keener than its predecessor to note that "Scientific research is now depending on public support for even larger amounts of funding than ever before." (The Preface also takes a rather more 2020s angsty stance on the future, questioning whether the human race, formerly the unquestioned pinnacle of the evolutionary process, is actually "intelligent" or merely "technological".) We are therefore left with the question of who the book is aimed at.

While the level of articles is probably roughly *Scientific American*/*New Scientist* (depending on your position relative to the Atlantic Ocean), the chapters themselves seem to be unsure of where to go. References (in two cases called "Further Reading") range from actual *Scientific American* articles, through *Astrophysical Journal*/*Monthly Notices* papers, to *Phys. Rev* (*D*) and *JETP Letters*, as well as books, both popular and undergraduate level. One chapter lists half a page of books, another six pages of professional papers.

The individual chapters are generally a good read, though the level of updating is variable and the dates when chapters appear to have been updated seem to vary, too. For instance, the cosmology chapter has basically just had one paragraph on an accelerating universe and dark energy inserted in the main text and one tacked on the end in 'Current Research'. The rest of it reads exactly as it would have done when a critical density, zero-cosmological-constant model was the best buy. The most recent reference is a 2015 APS meeting report on BOSS. The lengthy reference list in the chapter on stars and planets has nothing since 2016, but that on 'Stellar Explosions, Neutron Stars and Black Holes' — which I particularly enjoyed — discusses *LIGO* results and references a book from 2019. The chapter on galaxies has been updated to include *ALMA* and looks forward to *JWST*.

Unfortunately, I cannot repeat my 1996 congratulations on the absence of typos (maybe after 24 more years reading student projects I'm just better at spotting them). In other circumstances, one of the book's authors (a regular reviewer in these pages) would no doubt have leapt upon a classic in the referencing of the famous B^2FH nucleosynthesis paper, which is stated to be from *Reviews of Modem Physics*; unfortunately it is in her chapter!

So do I recommend this new version? Sadly, no, not really. In this more internet-savvy age, most interested readers of a book at this level are now quite capable of finding up-to-date articles in the relevant areas for themselves, so the point of a general review in one book is reduced, particularly if some of it is only slightly updated from two decades ago. — Steve Phillipps.

The Cosmic Revolutionary's Handbook (Or: How to Beat the Big Bang), by Luke A. Barnes & Geraint F. Lewis (Cambridge University Press), 2020. Pp. 288, 14 × 22 cm. Price £ 17·99 (hardbound; ISBN 978 1 108 48670 5).

This book is a popular account of modern cosmology, with more emphasis than most similar books on two important aspects: how conclusions are arrived at and which conclusions depend on which observations. Both of those are intended as a challenge to would-be cosmic revolutionaries, *i.e.*, those who would like to replace the current standard model of cosmology with some other theory. The preface recounts some experiences, which many have had, with such armchair theorists, though in the rest of the book that aspect is limited to occasional comments at appropriate places in the text. I reviewed[1] another book[2] by the same authors (but in a different order) in these pages; there is little overlap between the two; the styles are similar, though the older book is somewhat more technical (but still popular science).

After the first chapter describing how science works, the next seven cover standard topics: the darkness of the night sky, redshifts of galaxies, cosmological time dilation and surface-brightness reduction (two consequences of the cosmological redshift which are difficult to explain by other means), the cosmic microwave background, the Lyman-α forest, cosmic elemental abundances, and inflation. Chapter 9 looks at some alternative cosmological theories (some familiar, others less so), and the final chapter deals with "some loose ends, untested predictions, observational puzzles, and missing pieces" such as dark matter, dark energy, satellite galaxies, the lithium problem, primordial neutrinos, matter–antimatter asymmetry, primordial gravitational waves, and the birth of the Universe. The last chapter is particularly interesting, not only because there is still work to do on the topics it covers, but because they are presented in a balanced way; there is no shortage of literature, at all levels, on such topics, but many or most people working on them have an axe to grind and it is thus difficult for the non-expert to gauge the importance of the topic and how it fits in with the rest of cosmology.

The book is well written and includes a bit more 'how' (do we know) in addition to the 'what' of the standard model of cosmology. That model is also known as the concordance model because the same basic parameters are consistent with a wide variety of independent observations. A challenge to any alternative theory is to explain all current data; so far, no such theory has achieved that goal. Of course, to be accepted, such a theory must also offer some advantages over the standard model, such as being more elegant or having confirmed predictions which differ from those of the concordance model. It is also important to concentrate on what is actually being tested; for example, Hubble's law stating that the cosmological recession velocity of galaxies is proportional to distance (which is a consequence of an expanding homogeneous and isotropic universe, whatever the underlying physics) is extremely well established, and thus holds up even if one has doubts about the data used by Hubble or even if quasars actually had non-cosmological redshifts. Similarly, our understanding of the Universe from just shortly after the Big Bang is very secure; it is important to distinguish that from more-speculative ideas about earlier events such as inflation, the origin of the Universe, and so on (a point also stressed by the Astronomer Royal[3]). Most books at this level don't mention redshift drift, *i.e.*, a predicted change with time of the redshifts of objects at cosmological distances, due to the expansion of the Universe during the time covering at least two measurements of such redshifts. Amazingly, current technology is almost capable of that feat. It is also an effect difficult to account for in alternative cosmological theories. Not only is it a rather direct measure of the expansion of the Universe, but it is also an independent method of determining cosmological parameters.

Although I would have liked even a bit more scepticism, their take on the monopole, horizon, and flatness problems (all often touted as motivation — if not evidence — for inflation) is more balanced than in most other cases. After presenting the standard arguments, they 'hit the brakes', back up, and examine the assumptions, not all of which are straightforward, occasionally citing a reference for further reading. I noticed no factual mistakes and only a few typos and passages which might confuse some readers though the intent was clear to me. There are a few black-and-white figures scattered throughout the book. Endnotes provide both additional information and (sometimes commented) references. Those are followed by two lists for further reading, both popular-level introductions and undergraduate (and higher-level) textbooks on cosmology (and one on astrophysics). This otherwise traditional book ends with a two-page small-print index; in a nod to the modern world, the dust-jacket notes mention the authors' individual Twitter handles as well as one for the book along with their YouTube channel.

I enjoyed reading this book; it's a breezy but careful introduction to where we are in our understanding of the Universe and how we got there. — Phillip Helbig.

References

(1) P. Helbig, *The Observatory*, **137**, 243, 2017.
(2) G. F. Lewis & L. A. Barnes, *A Fortunate Universe: Life in a Finely Tuned Cosmos* (Cambridge University Press), 2017.
(3) M. J. Rees, *QJRAS*, **34**, 279, 1993.

Essentials of Nucleosynthesis and Theoretical Nuclear Astrophysics, by Thomas Rauscher (IoP Publishing), 2020. Pp. 416, 26 × 18·5 cm. Price £120 (hardbound; ISBN 978 0 7503 1150 2).

My interest in nucleosynthesis and nuclear astrophysics received its initial stimulus when I chose Fred Hoyle's *Frontiers of Astronomy* in 1956 as a school prize. This interest was boosted in 1960 through delightful tutorials at Oxford given by Professor M. W. Johns, a visitor from McMaster University. Through my research into stellar compositions and a requirement to teach graduate courses over many years, I developed a deep interest in nucleosynthesis and, thus, a curiosity about monographs and textbooks on nuclear astrophysics. In particular, I was challenged on several occasions over 40 years in developing a reading list for a graduate course on observational and theoretical nucleosynthesis. With this background, I welcomed the opportunity to consider Rauscher's new book.

In his preface, Rauscher discusses the challenge of writing a text on an interdisciplinary topic such as nuclear astrophysics. He tells the reader that his goal was to present "essential definitions and approaches" and so to enable "the reader to enter the research field" and to follow "current open questions in the understanding the origin of the elements". The book is divided into two main parts: Part I, covering fundamental physics including relevant equations and definitions, is offered as a text which may stand the test of time; a slightly shorter Part II covering the contemporary state of nucleosynthesis is suggested to be "prone to change when our understanding of astrophysical objects and the evolution of the Universe changes". Part I — 'Essentials' — includes four chapters covering 'Basic Properties of Stars and Stellar Plasmas', 'Stellar Models', 'Nuclear Physics for Astrophysics', and 'Abundance Changes in Astrophysical Plasmas'. Part II — 'Stellar Evolution and Nucleosynthesis' — after a brief 'Introduction' provides six chapters covering 'Stellar Evolution', 'Hydrostatic Burning Phases', 'Origin of the Elements Beyond Fe', 'Explosive Nucleosynthesis', 'Primordial Nucleosynthesis', and 'Galactic Origin of the Elements'. I consider that the author met his goal and the book will prove useful to the graduate student, the active professional, and even to this and other retirees (!).

Although the book is devoted to the theoretical side of the ledger, near-total exclusion of experimental aspects of nuclear astrophysics detracts from the beauty of the story and appreciation of the alignment between theoretical and observational astrophysics. Such exclusion may irritate some readers. One example relating to the story's reach across disciplines: the drive to understand the *r*-process is proving a remarkable incentive to the measurement of properties (mass, *etc.*) of neutron-rich nuclei off the valley of stability. Acknowledgment — even brief — of the diverse experimental activities accompanied by a note on a comparison of theoretical and experimental approaches would better reflect the current understanding of nucleosynthesis in this frontier field, with expansion fed by detection of gravitational waves from coalescing massive binaries, abundance studies of metal-poor stars, and experimental and theoretical nuclear physics of massive neutron-rich nuclei. In a less exciting vein, I take a different example from Rauscher's discussion of the CNO-cycles, which includes a clear diagram of the cycles and discussion of the reaction sequence around the cycles, but little is said about equilibrium abundances between the cycle's participants. For example, one signature of the CNO cycles exploited by stellar spectroscopists is the prediction of carbon isotopes $^{12}C/^{13}C$ at about 3 at equilibrium, a quantitative signature not noted in the book and which cannot be estimated from the book's discussion for lack of information given on the reaction rates around the CN cycle. Such exclusions and omissions do not seriously mar the quality of Rauscher's book. But may I conclude this paragraph with a personal quibble? Rauscher provides a clear discussion of He-burning including the role of the ^{12}C 7·65-MeV zero-spin and positive-parity state. Surely, Fred Hoyle's bold 1953 prediction that this state must exist ranks as a signal triumph for theoretical astrophysics. A wish that the 7·65-MeV ^{12}C state be cited always as 'the Hoyle state' is surely not unreasonable!

Were I again to return to the classroom (but certainly not virtually!) to inform and entertain graduate students about theoretical and observational nucleosynthesis, Rauscher's book would be on my reading list to cover theoretical aspects of nucleosynthesis and nuclear astrophysics. — David L. Lambert.

Compact Star Physics, by Jürgen Schaffner-Bielich (Cambridge University Press), 2020. Pp. 311, 25 × 17·5 cm. Price £54·99/$69·99 (hardbound; ISBN 978 1 107 18089 5).

Author Jürgen Schaffner-Bielich describes the present volume as a textbook based on courses given at the Goethe University, Frankfurt, and Ruprecht Karl University, Heidelberg, and several lectures at summer and winter schools. It is intended for advanced undergraduate and graduate students with basic knowledge of mechanics, electrodynamics, quantum mechanics, and statistical mechanics. As much General Relativity as is needed is developed in place, also "basis of dense matter" and quantum statistics.

Every chapter has exercises ("tested" according to the back cover), even the first, Introduction. Those four require only the usual four operations of arithmetic, and those I could do at sight. Some of the later chapters, not so much. In fact in the later chapters (2–10), a large fraction of the exercises are 'show that's' and 'derive this', for which the enterprising student (as in secondary-school geometry) starts at both ends and works toward the middle. If matching occurs, one then rewrites and turns in the version that goes from beginning to end. If there is a solution set or an instructor's manual available, it is not mentioned.

The underlying physics is developed first (General Relativity, dense matter and compact stars leading to a Landau mass and radius) without reference to observed entities. Then come white dwarfs, pulsars, neutron stars, quark stars, hybrid stars, and gravitational waves. Omitted are rotation, cooling of neutron stars, proto-neutron stars, and core-collapse supernovae (also thermonuclear supernovae and anything to do with binary stars until they are ready to be gravitational-wave sources).

Is the volume expensive? Well, the price per equation is a bit less than six pence, about like peanuts, I suppose. Every equation is numbered, a blessing when one is trying to teach remotely. The index is a bit less happy. There is, for instance, a section called "dispersion measure", but the concept is not indexed, requiring one to remember that it is section 6.9; rotation measures are not mentioned. The author has dubbed a certain hypothetical class "twin stars", but again you must hunt.

I feel somehow that the author does not really love white dwarfs the way he should. We are told "typical magnetic fields are in the range of a few × 10^7 G to several × 10^8 G". Well, those are the ones we can measure, but most must be considerably smaller, and the distribution is bimodal (for reasons that are not terribly well understood). The same page (111) opines that no helium (core helium) white dwarf can have formed yet, but Schaffner-Bielich has forgotten about mass transfer in close binaries. And indeed a later chapter has a pulsar with a 0·17 $M_\odot$ white-dwarf companion.

Humour is undoubtedly in the ear of the beholder. The author notes that the surface gravity for a Schwarzschild black hole coincides "amusingly" with the Newtonian definition, and goes on to explain that "the surface gravity of a black hole is the local acceleration experienced by an observer hoovering at the black hole horizon".*

My strongest beef concerns units. Some equations have both c and G explicitly, some take $c = 1$, and others $c = G = 1$, without really saying which is which. Schaffner-Bielich uses the phrase "natural units", not indexed, and all I can tell you about them is that his Stefan–Boltzmann constant is $\sigma = (\pi)^2 / 60$. My Stefan–Boltzmann constant is $\sigma = 5{\cdot}67 \times 10^{-5}$ in cgs units. G is given to six figures, which is probably too many.

And now answers to questions you didn't know you had. All the compact stars are made of fermions. Why are there no boson stars? Because there are no stable bosons with non-zero rest mass to make them out of. Back in 1955, John A. Wheeler postulated bound spheres of photons (called geons) but they turned out to be unstable.

Finally (and high time) what are "twin stars"? Well, a first-order phase transition from stuff with pressure provided by degenerate electrons to stuff with pressure provided by neutrons allows white dwarfs and neutron stars to exist as separate families, each with its own mass–radius relation and similar masses, but with a large gap in possible radii. If there is another first-order phase transition to stuff whose pressure is dominated by, well, maybe pions or deconfined quarks at still higher densities, then you get a third family of solutions with, again, rather similar masses, but still smaller radii, not yet quite inside their Schwarzschild radii. These are the author's "twin stars". If, as is more likely, the actual objects would have pion condensate or quarks at the centre, surrounded by neutron stuff surrounded by degenerate electron stuff, surrounded by a crust of crystalline iron, then they are hybrid stars.

The crust could, of course, still support a thin layer of remaindered books, but I see no reason *Compact Star Physics* should be among them, if you are prepared to work reasonably hard for enlightenment. — VIRGINIA TRIMBLE.

The Evolution of Stars: From Birth to Death, by Graham Hill (Cambridge Scholars Publishing, Newcastle-upon-Tyne), 2020. Pp. 439, 21·5 × 15 cm. Price £75 (hardbound; ISBN 978 1 5275 5052 0).

I first met the author of this book, Graham Hill, some 50 years ago at the Dominion Astrophysical Observatory (DAO), Victoria, Canada, when I had

*If seven maids with seven mops swept for seven years? Or, an explanation for American readers: In my very first search for lodgings in Cambridge, I was graciously told by a potential landlady that I could have a particular bed-sitter for a particular price (seven guineas a week) if I would "do my own hoovering". Quite unenlightened, I agreed (also to take only 2–3 baths per week, not to use the garden, and to use only a particular corner of the refrigerator for my "butter and cream" neither of which I've ever actually liked). As for the garden, she soon decided better I should use it than do my sunbathing on a towel on her driveway opening directly on to Grange Road. But she ironed my dress for me when she heard I had been invited to a May Ball that summer of 1968. God bless you, Mrs. Clark-Kennedy, wherever you are, and I hope you never knew that your home has been turned into a language school. Oh, and 'hoover' is a trade name that has become generic in the UK but not in the USA for vacuum cleaner, like nescafe for instant coffee, kleenex for boxed tissues, xerox for copier, and so forth. Hovering was presumably intended.

just started my first postdoctoral position, and he was already an established professional astronomer. We became research colleagues and friends, despite only working at the same institute for two years, a research collaboration that extended for over 30 years. With only occasional contacts since then I was pleasantly surprised to learn that Graham Hill had completed this book, not a task that many people contemplate doing in their 80s! Readers will have to judge for themselves whether this review is necessarily biassed in favour of the author because of this connection.

This veteran observational astronomer and innovator of many techniques of analyses of data on stars (synthesis of eclipsing binary light-curves, cross-correlation and tomography techniques for separating the blended spectra of close binary stars, abundance analyses of stellar atmospheres from high-resolution spectra) has written a book about his favourite subject, the *Evolution of Stars: From Birth to Death*. It is not written in a traditional formal academic style, with references justifying every statement, and a long bibliography for further reading. It is written in what I would call a conversational style, as though the author were talking informally to you the reader, with coffee and tea to hand, and talking in his own colloquial manner. The subject matter is arranged into 15 chapters over 382 pages, with a further 33 pages for a glossary of astronomical terms used in the text. There are 148 monochrome images and figures distributed through those chapters helpfully at the locations where they are discussed, and some 35 of those images are presented in full colour plates collected into a set in the middle of the book. The captions to these images and figures provide references to the original research papers where relevant, the only references in the book. Clearly, the text is aimed at being accessible to the general-interest reader, the amateur astronomer, the non-science student who wishes to learn about how the science of astronomy has developed over the centuries, and how the subject of astronomy can be confident about describing stellar ages in millions and billions of years, when we the readers manage typically less than 100 annual orbits of our Sun.

The emphasis throughout the text lies with how observations of stars are conducted and recorded, from visual observations of the day and night sky, to telescopes with eyepieces, to photographic plates and spectrographs and measuring engines, photomultiplier tubes and pen recorders and punched cards, and ultimately the modern digital detectors based around charge-coupled devices. The author has experienced them all first hand from the late 1950s onwards, and his conversations provide some lovely and amusing anecdotes about those experiences without labouring them. There is sufficient description to allow the reader to reach an understanding of the work involved, and how much easier modern observing at night-time has become thanks to computer-controlled telescopes and digital detectors. I believe it would also be instructive for undergraduates in astronomy to read this book even if they think they know the subject matter quite well because of the alternative perspective presented compared to that published in more formal academic texts.

The subject matter is presented as an historical development, for example, indicating that white dwarfs were recognized by 1930 as being most unusual stars, even although there was no viable theory of stellar evolution at that time. The text is factually correct and I found myself quibbling here and there about relatively minor details, or even topics that are tangential to the main subject. For example, the Maunder Minimum and the Little Ice Age are mentioned, and I wished the author had seen the article in *A&G* (**58**, 17, 2017) by Lockwood *et al.* that cleared up the confusions that I had about that topic. Another example is his statement that there is still a "missing mass" problem in the Local Neighbourhood of the Galaxy. That result is what Graham and I found in 1979 from our attempts to match a *mathematical* model to *all* of our data on stellar density and velocity distributions of A-type and F-type stars to determine the local mass density. Ten years later, fellow New Zealander Gerard Gilmore and his Dutch colleague Konrad Kuijken used *our data* but recognized the necessary *astrophysics* to rule out the use of the A-type stars and early F-type stars in that analysis because they were not old enough to have relaxed their motions around the Galaxy. Only the late F-type stars were old enough, and they showed readily that the missing-mass problem had been resolved. Graham knew this in 1989, and was as upset as me for our mistake, but he seems to have forgotten — I have not! It was an objective lesson learned the hard way in recognizing when to step back from a science problem to gain a different perspective, an issue I remember emphasizing to many of my final-year undergraduate students over many years of teaching at St Andrews. I found a number of minor typographical errors, but only two stood out as 'howlers'. Evidently, a friendly spell-checker changed 'Synoptic' to 'Synodic' in every mention of the *LSST*, and the luminosity of a star is expressed in Watts, not Watts/second.

The last few chapters introduce some very recent results of observations conducted with the latest equipment such as the high-resolution observations of white dwarfs in globular clusters obtained with the *Hubble Space Telescope*, the resolved surfaces of nearby stars obtained by the *Very Large Telescope Interferometer*, and the gravitational-wave detections of merging black holes and neutron stars and how different those two merger scenarios are. The presentations here are at a more advanced level than earlier, but they are still descriptive, and answer points that the more enquiring reader may have recognized. The last chapter, entitled 'Where is astronomy heading?', provides a brief review of the latest enormous telescopes under construction, the on-going success of the satellite *Gaia*, as well as mentioning the 'Big Data' problems that are being addressed for *Gaia* and other major surveys. The author and this reviewer are in awe at the present-day achievements of those enormous projects. I found the book to be interesting, different from the usual rigour of academic texts, and more engaged with the practice of securing observations of faint sources than can be achieved by professional writers of introductory texts on astronomy. — Ron Hilditch.

Life With Hubble: An Insider's View of the World's Most Famous Telescope, by David S. Leckrone (IoP Publishing), 2020. Pp. 288, 26 × 18·5 cm. Price £30 (hardbound; ISBN 978 0 7503 2036 8).

First, I have a confession to make … I am one of the 'Hubble Huggers' described in Dave Leckrone's book. I have been involved with the *Hubble Space Telescope* mission since 1988, when I became part of a team making a successful proposal to use the facility to study white dwarfs. Since then, I have written and contributed to many proposals, besides sitting on a number of time-allocation and advisory committees. During my tenure on the Space Telescope Users' Committee (STUC), I came to know Dave Leckrone, at that time the Senior Project Scientist, the author of this wonderful book. Dave was involved in the project for 33 years, from 1977 until his retirement in 2010. His detailed knowledge of the project, along with his warmth, friendliness, and absolute dedication to the cause shines through in what he has written. It is hard to imagine someone better able to tell the definitive story of the trials and tribulations of this 'most famous' and, dare I add, 'best loved' telescope.

There have been many publications during the last 30 years filled with gorgeous *Hubble* images, illustrating the scope and excitement of the science produced by the Observatory. This is not a volume that competes with those, although there is a good collection of images to illustrate the story. However, it is the book that should be read alongside each and every one of those past volumes. It is the warts-and-all story of how *Hubble* came to be: the delays; the trauma of the now infamous spherical aberration; the recovery in the first servicing mission; subsequent hardware failures followed by replacements; and a final servicing mission in 2009. Importantly, the story is also about the people: the many engineers, technicians, scientists, administrators, and astronauts who delivered outstanding support for the mission, often above and beyond normal expectations.

I thought that I already knew this history, through my own journey with the mission and the extensive media coverage that has always followed it. However, Dave reveals details and insights that few others will have known and weaves it into a fascinating narrative that often surprises. Indeed, even though the problems and successes are public and very well known, the story told is often gripping and the uncertainty surrounding the outcomes at the time comes across very clearly. The effect is not just historical record, but part science-history thriller. There should be a movie!

The technical story culminates with the final servicing mission (SM4) in 2009, to which I made a modest contribution through the development of the science priorities for the planned EVAs. SM4 left *Hubble* in excellent health and more scientifically capable than it had ever been. Now, 11 years after that mission, *Hubble* is still going strong and will likely continue well into another decade. As NASA reinvigorates its human space-flight programme, who would rule out plans for another servicing mission? Dave's book will be the definitive record of the *Hubble Space Telescope* story, at least up to that point. It is a triumph and a fitting celebration of the 30th anniversary of *Hubble*'s launch. — MARTIN BARSTOW.

The NASA Kepler Mission, edited by Steve B. Howell (IoP Publishing), 2020. Pp. 250, 26 × 18·5 cm, Price £120 (hardbound; ISBN 978 0 7503 2294 2).

By the time the *Kepler* Mission (launch 2009 March 6; final commands 2018 November 15) had collected its last photons, hundreds of people had been involved, but the idea had come from one man, William J. Borucki, who, starting in 1983, had designed, tested, improved multiple technologies, convened workshops (1984, 1988, 2000) to study them, and finally got *Kepler* into the NASA queue as a Discovery Mission in 2000, it being then regarded as a pathfinder for the *Terrestrial Planet Finder* (not now in anybody's queue). The data stream yielded more than 4600 exoplanet candidates that had revealed themselves as dips in the light coming from their host stars as they transited across the stellar discs. Major contributions to asteroseismology, asteroid tracking, and studies of variability of AGNs, supernovae, variable stars, and ordinary binary stars also came over the years. The present volume, edited by Steve Howell (who was the *Kepler* PI through many of the operational years) has chapters devoted to each of these areas, written by astronomers who were involved in collecting, analyzing, and interpreting the data.

What is missing? Borucki himself! There is not even a picture of him, though he contributed a three-page preface to the volume. He has told portions of his own view of the story in *Reports on Progress in Physics* (2016, 79 and the 48 following pages). He also has a fairly informative Wikipedia entry, with birth (1939), degrees, not including a PhD, early work on the Apollo heat shield and later on the production of biomolecule precursors by lightning. Nearly all his career has been spent at NASA Ames, in middle California. When it became clear to all that the *Kepler* Mission was finding not only enormous numbers of exoplanets but also combinations of planet masses, orbit periods, and host-star types not previously recognized, prizes began to trickle in. I had the good fortune to be in the part of Poland from which his family had come, just days after one of the prizes had been announced, having been one of the nominators. How do you nominate someone you have never even met for a prize? Easy: send an email saying, "Please send me a copy of your CV and don't ask why!" How do you find out how to pronounce a name under similar circumstances? Also simple: just phone the office number from some directory at a time when the person will surely not be there, since nearly all voice mail systems begin with a voice saying "This is person-you-called. Please leave a message."

Let's have one highlight from each of the four result-laden chapters. First, on exoplanets, it became clear that multi-planet systems are common, though, so far, none like ours (if only because many of our periods are too long). But analysis of the spacing in systems found shows that the typical gap between planet orbits is about 20 mutual Hill radii, and that the period ratios tend to pile up just wide of the mean-motion resonances. Most of those planets know about each other more intimately than Earth knows about even Jupiter.

Second, from the stellar astrophysics chapter we learn about the interior stratification of oxygen, carbon, and helium in the helium-atmosphere white dwarf KIC 862021 (in the *Kepler Input Catalogue*). Helium makes up only about 10^{-4} of the star, alone at the top, sharing 40:60 with carbon down to 10^{-4} of the mass. The very centre is dominated by oxygen (85:15 with carbon), and the star as a whole is 79% oxygen, with the transition between the zones very sharp. Oxygen also outweighs carbon in the Solar System, but not by that much.

Third, the K2 mission (after two of the reaction wheels failed) necessarily looked at the ecliptic plane and so saw main-belt asteroids. The average rotation period turned out to be 9·45 hours, *versus* 7 hours for asteroids observed from the ground. We need, in other words, more space-based photometry, say the authors (or more global telescope networks like Las Cumbres Observatory, says your reviewer).

Fourth, in the extragalactic regime, "high cadence light curves with exquisite photometric accuracy for every class of supernova" were collected along with the fastest-to-date of the "Fast-evolving Luminous Transients", with a rise time of only 2·2 days and a time above half-maximum brightness of only 6·8 days. It is called KSN2015K (a year, not a location). About 18 possible models are cited. And one galaxy with a quiescent nucleus became a bit of an AGN in real time, due, plausibly, to a tidal disruption event yielding a 20% brightening over about 30 days.

Altogether, the book is full of fascinating results from a fascinating Discovery Mission, but I still wish they had included at least a photograph and a brief biography of the creator, along with the biography of the editor, and photos of all those men in bunny suits at Ball Aerospace. — Virginia Trimble.

Thinking About Space and Time: 100 Years of Applying and Interpreting General Relativity, edited by Claus Beisbart, Tilman Sauer & Christian Wüthrich (Birkhäuser), 2020. Pp. 285, 24 × 6 cm. Price £89·99/$119·99 (hardbound; ISBN 978 3 030 47781 3).

I'm writing this during the corona-virus pandemic, during which many, especially those in quarantine, are thinking about space and time, but of course in a completely different sense. This book, volume 15 of the *Einstein Studies* series, is the proceedings of a conference held in Berne in 2017 consisting of historical and/or philosophical (which should not be taken to exclude physics) accounts of various topics in General Relativity (GR), such as the heuristics Einstein used in deriving GR and various mathematical details, though, except for cosmology, few applications; rather, the emphasis is on the structure of the theory, its interpretation, and relation to other theories (the "theory of theories", meaning not the best theory of all but rather the theory about how theories work, also gets a mention). The title of the chapter 'The Metaphysics of Machian Frame-Dragging' gives a flavour (apart from nice introductions to various levels of Machianism, it also makes use of techniques developed for psychology and social sciences as well as mentioning Leonardo and Monika, stones breaking windows, and Socrates!).

The first chapter is a look back at another conference in Berne, in 1955, celebrating 50 years of the special theory of relativity, the first international conference on relativity and later known as the GR0 conference. (Such conferences take place every 2–4 years, the most recent, GR22, in 2019.) The next three chapters are mainly historical (the remaining eight are concerned with more philosophical and/or mathematical topics), Chapter 2 examining various heuristics used by Einstein during his development of General Relativity. Chapter 3 on 'Historical and Philosophical Aspects of the Einstein World' looks at lesser known aspects of a well-known (or at least highly cited) paper, usually taken to mark the beginning of modern cosmology. Apart from the first chapter, this is probably the least technical chapter, though still worth reading for a fresh look at an old friend.

I had noticed this book before it was published because of a preprint of Chapter 4, which is concerned with stability in cosmology, a topic which I have investigated in relation to the flatness problem[1–3]. At first I was somewhat disappointed that much relatively recent work (*e.g.*, refs. 4–8) on the flatness problem was not cited, but now think that that is actually a good thing, because it demonstrates that similar conclusions have been arrived at independently.* The author sees himself more as a philosopher than as a physicist (Casey McCoy, personal communication) (though he has a background as both, and also in electrical engineering, and in addition spent time in the air force). After contrasting the reactions to the instability[10] of Einstein's static model of the Universe[11] (which led to rejection of the model, in particular by Einstein himself†) to those of the Einstein–de Sitter universe (rather the opposite, as

*A good parallel is the determination of Avogadro's number: the community was not convinced by a single, definitive measurement, but rather by the fact that very different lines of investigation all led to the same value; one of those lines was pursued by Einstein in his doctoral thesis[9].

†To be sure, the observation of the expanding Universe ruled out Einstein's static model, while it took several more decades until observations definitively ruled out the Einstein–de Sitter model. However, Einstein himself stated that the instability argument alone would have been enough for him to abandon his original model, even without "Hubbel's" [*sic*] observations[12,13] (the misspelling perhaps demonstrating his lack of familiarity with the astronomical literature, a fact also noted by Lemaître[13–15]).

the instability suggested to many that our Universe must be almost exactly described by the Einstein–de Sitter model), McCoy introduces an additional point which, at least to me, is new in the discussion of the flatness problem: in the past, there was often an assumption that any idealized model must be stable, if only because that allowed the real system to be seen as a perturbation of the model ("just one perturbation away"), without which the model would not be very useful. However, today it is known that many physical systems are chaotic, and thus cannot be usefully studied *via* a stable model. (As McCoy points out, there is of course a range of fragility from stability to chaos.) All the same, that in itself is not enough to counter all concerns with respect to the instability of the Einstein–de Sitter universe, since it is not only the instability *per se* but the instability with respect to the only stable value, the 'special' value corresponding to a flat universe, which is (perceived to be) problematic. Having thought a lot about that 'problem', it is enlightening to see someone come up with a new perspective on it.

I won't discuss the rest of the chapters in detail since they have little or no astronomical content. (The Friedman who appears in the title of one is not cosmologist Alexander Friedmann, whose name has appeared in various spellings in the literature.) Like the ones mentioned above, they are all well written. In contrast to discussions of quantum mechanics, where various interpretations disagree about what 'really' happens, there is little disagreement about what GR really describes; the emphasis is on how best to understand that and, perhaps, relate it to other fields. An example: "One might wonder whether satisfaction of the [strong equivalence principle] should be regarded as being a *necessary* condition for the metric field to have its chronogeometric significance, or rather as being a *sufficient* condition, or rather something else." [Emphases in the original.]

My only real complaints are that some chapters are more technical than others (those happen to be the non-astronomical ones about topics with which I am less familiar, though that is, to paraphrase my late history teacher, just an observation, not a complaint) and that the style could have been made a bit more uniform, though many other collections are much worse in both respects. References (at the end of each chapter) include titles, which is especially useful for those unfamiliar with the literature; with such a broad range, probably no-one is familiar with all of it. There are only six figures in the book, four of those in the first chapter. There are many footnotes but, thankfully, no end notes. Neither is there an index, but one is not really needed for a book like this.

This book should prove interesting for those looking for a survey of current work on a theory which is over a century old but still a topic of current research, not just on its applications but, as emphasized here, on its foundations as well. — PHILLIP HELBIG.

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Mars, by Stephen James O'Meara (Reaktion), 2020. Pp. 232, 23 × 18 cm. Price £25 (hardbound; ISBN 978 1 78914 220 4).

This topical general and up-to-date book has arrived on the scene in time for the 2020 perihelic Mars opposition, and is to be warmly welcomed. It is the sort of all-round descriptive book one would have liked to have written oneself. O'Meara's approach is largely historical but never stuffy. He weaves a compelling tale from the ancient puzzle of the naked-eye motions of Mars to the exploits of the 20th- and 21st-Century surface rovers, the search for life, and the chances of humankind eventually living there. He is uncritical about the reported detections of Martian methane. The book includes many highly unusual and well-chosen illustrations among the more predictable.

The book contains some fascinating new insights, from aspects of African star legends to pointing out that Schiaparelli at the Brera Observatory was viewing Mars within sight of the medieval artificial canal system (*navigli*) of the city of Milan.

O'Meara has produced an engaging text, and the format of the book is pleasing. The standard of editing, printing, and colour reproduction is very high, and the book takes its rightful place in the now well-established Solar System series by this publisher. (And as the publisher writes on the flyleaf, Mars is a small world with a big reputation!) Useful data appendices conclude the book, including the now almost obligatory but detailed listings of spacecraft launched towards Mars. There are many useful references.

I must take issue with the author about changes in the naked-eye colour of Mars (page 179). The change of colour from reddish to a more yellow tone near the time of the 2018 opposition was due to the incidence of a global dust storm. During several previous such events the planet's colour has been seen to change in a like manner: lack of redness is not, as implied, related to the distance of the planet and its changing contrast and the night sky. It is a pity the author did not offer any telescopic drawings (perhaps his own?), or more telescopic images, or a more useful reference map, to illustrate his enticing final chapter about the practical details of observing Mars.

In summary, an excellent publication that is to be recommended. — Richard McKim.

The Moon. A Translation of Der Mond, by Johann Friedrich Julius Schmidt; trans. Stephen Harvey (Springer), 2020. Pp. 153, 24 × 16 cm. Price £99·99/$139·99 (hardbound; ISBN 978 3 030 37268 2).

The middle part of the 19th Century was a time when serious measurements and scientific rigour were being brought to astronomical observations. This book is a translation of a book, *Der Mond*, originally published in German by Julius Schmidt, one of the leading lunar scientists of the time. Here we read what the current state of knowledge about the Moon was in the Victorian era, a time when craters were still believed to be endogenic in origin, and yet we see Schmidt highlighting significant differences in topographic cross-sections between terrestrial volcanic calderas and lunar craters — which, with hindsight, should have set some alarm bells ringing. It is pleasing to see good agreement with modern-era heights for some features, *e.g.*, Mons Pico according to NASA's *LOLA* data is 2·3 km above the surrounding terrain and Schmidt gives 2·4 km. Though due to limitations of the shadow method for determining heights, this is more problematic for crater depths, but nevertheless it was interesting to see efforts at crater depth-to-diameter ratio estimation, which are used extensively in modern lunar science. He also never shies away from criticism of the fancier lunar theories at the time or dubious observations made by other well-known astronomers. Ever wondered what a 'Toise' was? In a rather valuable 'Translator's Note' chapter, Stephen Harvey describes this unit of measurement that was utilized by Schmidt throughout the book. The introductory chapter of the translation puts everything in context with a biography of Schmidt and a history of Athens observatory of which he became the director. Stephen Harvey has done an excellent job at translating Schmidt's most famous publication, and so the book should be of great value to astronomical historians and amateur astronomers interested in the Moon who wish to own this work, but cannot decipher the original in German. It is a shame, though, that the publisher has priced the book beyond the reach of most individuals. — Anthony Cook.

OBITUARY

John David Barrow (1952–2020)

Professor John David Barrow, distinguished cosmologist, physicist, mathematician, polymath, and renowned popularizer of science died on 2020 September 26, at the age of 67. With his passing, one of cosmology's brightest lights has gone out.

Throughout his extremely distinguished career John Barrow's research involved the application of sophisticated mathematical methods and deep physical insight to the problems of understanding the very early Universe. Among many other achievements, he brought new ideas and models to the theory of cosmic inflation, during which a very high vacuum energy density causes the Universe to undergo a phase of accelerated expansion. In particular he examined the behaviour of inflationary models in the presence of departures from Einstein's General Theory of Relativity and in models in which large-scale isotropy is violated. He more recently became interested in theories in which the physical constants — especially the fine-structure constant — could vary with time. Indeed, John was part of a team that claimed to detect such a variation using astronomical spectra, although this claim remains controversial.

Alongside his prolific output of academic papers he was a noted popularizer of science with more than twenty books on various subjects in astronomy, mathematics, and physics, never shying away from tackling the philosophical and theological implications where he felt them relevant. His superb books, including *The Left Hand of Creation* (with Joe Silk), *The Book of Nothing*, *The Artful Universe*, *Pi in the Sky*, and *Impossibility*, were always beautifully written in characteristically direct and uncluttered prose. He always seemed to find writing very easy, but I know that behind this apparent facility lay a great deal of hard work and research. He immersed himself in whatever topic he was writing about and wrote very little until he knew exactly what he wanted to say.

Perhaps his most famous book was *The Anthropic Cosmological Principle*, written with Frank Tipler, which explores various ways of thinking about the relationship between the observed fact that intelligent life exists in the Universe with the nature of the physical laws that describe the behaviour of the Universe.

He was awarded the 2006 Templeton Prize for "his writings about the relationship between life and the universe, and the nature of human understanding, which have created new perspectives on questions of ultimate concern to science and religion". John never made any secret of his religious beliefs. A committed Christian, he was a member of the United Reform Church and a regular church-goer. In January of 2020 he was elected to the Pontifical Academy of Sciences.

John David Barrow was born in Wembley, in North London, in 1952. He attended Ealing Grammar School for Boys and obtained his degree in mathematics and physics from the University of Durham in 1974. He then studied for a doctorate in astrophysics, on 'Non-uniform Cosmological Models', with Dennis Sciama at Magdalen College, Oxford, completing his thesis in 1977. After spells as a Junior Research Lecturer at Christ Church, Oxford, and as a postdoctoral fellow at the University of California, Berkeley, John joined the Astronomy Centre of the University of Sussex as a lecturer in 1981, becoming a Reader in 1989 and Professor in the same year. It was during this time at Sussex (in 1985) that he became the supervisor of my own graduate studies. From 1995–99 he was Director of the Astronomy Centre at Sussex University. He then moved to Cambridge, becoming Professor of Mathematical Sciences in the Department of Applied Mathematics and Theoretical Physics, and Director of the Millennium Mathematics Project, which was awarded the Queen's Anniversary Prize for Educational Achievement in 2006. He was Gresham Professor of Astronomy in 2003–7 and of Geometry in 2008–12, the only person since 1642 to be elected to two different Gresham Professorships. He was made a Fellow of the Royal Society in 2003, and was awarded the Faraday Prize of the Royal Society in 2008, the Kelvin Medal in 2009, the Dirac Prize and Gold Medal of the Institute of Physics in 2015, and the Gold Medal of the Royal Astronomical Society in 2016.

John was an excellent all-round sportsman in his youth. He was not only a very good runner — there is a famous photograph of him beating the young Steve Ovett in a junior race — but also a talented footballer who had a trial for Chelsea Juniors. It was typical of him that he was able to perform at very high levels at whatever he turned his hand to.

I will never be able to find adequate words to express how much I owe him for his advice and encouragement not only during my graduate studies but also throughout the 35 years that have elapsed since I started my career at Sussex University under his supervision. I would like to give a couple of examples explaining why John Barrow was such a good supervisor. I was a bit stuck with the first project that John had assigned me and eventually admitted to him that I was having problems getting anywhere. I thought he'd assume I was useless and suggest that someone else should supervise me. But no. He said he realized it was a hard problem and sometimes it's good to think about something else when you're stuck. So he asked me to look for a while at a different problem, about the clustering of rich galaxy clusters, a subject which had become topical all of a sudden. At our next meeting I told him something I had I found and he said I should write this up as a paper, which I did. Most importantly, however, the trick I used in simplifying the calculations in the clustering paper turned out to be applicable to the first problem, about hotspots in the cosmic microwave background. That led to a success in the first project and to my second paper. We were both delighted that everything turned out well with that original project. My original draft of the first paper had John Barrow's name on it, but he removed his name from the draft (as well as making a huge number of suggestions to improve the text). At the time I assumed that he took his name off because he didn't want to be associated with such an insignificant paper, but I later realized he was just being generous. It was very good for me to have a sole-author paper very early on in my career. John was co-author of the second paper. I've taken that lesson to heart and have never insisted — unlike some supervisors — in putting my name on my students' work.

John had an extraordinary mind that combined immense mathematical gifts with an encyclopaedic knowledge of all kinds of literature and a wonderful flair for expressing ideas in writing or using the spoken word. Whether they were intended for students or the general public his talks were always a model of clarity. He was a whirlwind of ideas who had an uncanny knack of finding clever ways to crack previously unsolved problems. That he was happy to share these ideas with his students is a credit to his intellectual generosity. He inspired dozens of researchers early in their careers and continued to inspire them when they became not so young.

Another point worth making is about work-life balance. People have often asked me how he managed to be so productive. Did he work very long hours? Did he push his students hard? Well, John did work hard but he knew how to manage his time. A devoted family man, he was never in the Department late at night or at weekends, preferring to spend those times with his wife Elisabeth and their three children. He certainly made it clear that he expected his students to work, but he left us space to decide for ourselves how best to organize our time. I had to take some time out during my graduate studies for personal reasons, and he was very kind and understanding about that.

On a personal level, I always found John to be rather reserved and, despite his being a talented and confident public speaker, I always felt he was quite a shy person. It is also interesting that, despite writing so many superb popular books, giving wonderful public lectures, and being a regular guest on radio programmes, he steadfastly refused to appear on television. He just didn't want to become a TV celebrity, though I suspect that if he did he would have been rather good at it. I was quite intimidated by him when I started as a graduate student, but I soon realized he was really very friendly and supportive behind the reserve.

Although I didn't see as much of John in recent years as I would have liked, I did get the chance to see and talk to him at the RAS Club fairly regularly. I always found him a very agreeable dining companion on such occasions. He had a very dry and sometimes lugubrious sense of humour. I remember sending him a congratulatory email in 2003 when I found out he had been made a Fellow of the Royal Society. He replied thanking me, but pointing out his joy at having been elected was tempered by the fact that the first official communications he got from Carlton House was a rather substantial bill for the subscription and a form on which to enter details to be used in an obituary.

During my time as his student at Sussex we found a mutual interest in football, which we often talked about at coffee breaks. We even played together a number of times, often on a horrendous all-weather pitch on the Sussex campus. Despite not playing very regularly, he was energetic, skillful, and industrious, with very good tactical sense, though he wasn't a natural goal-scorer. In later years when we had the chance to chat, such as those occasions at the RAS Club, it was more often than not football that we talked about rather than science.

It was through the RAS Club that I first heard that John was suffering from cancer. For a time he responded well to treatment then his condition deteriorated to the extent that only palliative care was possible. That news came as a shock as he always seemed so healthy and ageless that one imagined him to be indestructible. The end came more quickly than we had imagined but at least he was at home among his loved ones when he passed away peacefully. Rest in peace, John. — Peter Coles.

OBITUARY NOTICE

Roger Francis Griffin (1935–2021)

The Editors of *The Observatory* have been deeply saddened to learn of the death of Roger Griffin on 2021 February 12. We are sure that these feelings will be echoed by many readers of this *Magazine* given Roger's long association with it, as both an Editor and an amazingly productive contributor, with his astounding series of 265 papers on spectroscopic binaries. It is intended that a full obituary will appear in a forthcoming issue.

Here and There

THAT DEPENDS ON HOW HARD YOU THROW THEM.

Advanced *LIGO*, housed in tunnels in Louisiana and Washington state, works by measuring how long it takes lasers to travel to a distant mirror. — *Discover Magazine*, January/February, 2021, p 66.