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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2017 May 12 at $17^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

J. C. Zarnecki, *President*
in the Chair

The President. We have some announcements and regular business. I would like to start with the 2016 thesis prizes. I am pleased to announce that the Michael Penston Prize has been awarded to Dr. Justin Alsing of Imperial College London, for a thesis entitled 'Bayesian analysis of weak lensing'. We have, this year, two runners up. The awards panel could not separate the two potential runners up: they are Dr. Antonia Bevan of University College London and Dr. Tom Louden of the University of Warwick. The Keith Runcorn Prize has been awarded to Dr. Rishi Mistry of Imperial College London, with a thesis entitled 'Magnetic reconnection exhausts in the solar wind'. The runner up is Dr. Robert Green from the University of Cambridge. We hope that we will hear from some of these prize winners, who will give talks at future RAS Ordinary Meetings. We now move to the programme, and I call on Professor Steve Miller to announce the second tranche of RAS200 awards.

Professor S. Miller. I am announcing today the second tranche of winners of our outreach-and-engagement scheme, called RAS200. This is the one-million-pound fund that we put in place out of our reserves as part of our activities towards our 200th anniversary, and as part of our requirements as a charity. There are already five projects plus an auxiliary project up and running, and they are being monitored closely. Every single one of them is doing well.

We made the announcement at the last AGM that we were opening up for the second tranche of funding, and we held a lot of meetings to alert the community around the country about it. Proposals had to be in by December 9, and we had 62 outline proposals. That was less than for the first tranche, but the proposals that we got in were much better focussed than some of the proposals for the first round, so I do not think we lost anything at all the second time. Indeed, we probably gained in terms of proposals that really were fitted to what the RAS 200 project is all about.

In the first grants panel, we whittled those 62 down to just 17 full proposals;

an attrition rate of about 75% there already. We then had to look at the 17 full proposals. I have to say that they were fantastic. There was not a single one of them that was not worth funding. We could have spent our budget four or five times over and I would have been able to get up here and say, "We have not wasted a single penny of the RAS's precious funds", but we only had £400 000 this year to play with. As a result we were able to fund fully four projects, and one was only partially funded.

This is the bit I like best because I feel like someone at the Oscars... [laughter]. And the winner is — 'Beyond Prison Walls' — working with offenders and ex-offenders who are going to get astronomy, and they are going to make products that will help bring in funding that will help the scheme even better. Is somebody here from 'Beyond Prison Walls'? Please stand! [Applause.]

'Making Space': these are our colleagues in Galway (National University of Ireland, Galway) who are going to go right up and down the western seaboard of Ireland with projects that engage with cultural festivals, bringing astronomy and geophysics to a very large number of people in quite a widespread area. So if there is anybody here from Galway please stand. [Applause.]

'Reaching for the Stars': we are teaming up with the Girlguiding organization in a number of activities. One of them I am not really supposed to announce, so I will not, but they are going to be having a press launch of their own very shortly. If somebody is here from Girlguiding, please stand. [Applause.]

'Touch the Sky': here we will be working with the Royal National Institute of Blind People and Glasgow Science Centre to bring astronomy to people who are visually impaired, in such a way that they can feel the sky. This is going to be an extremely exciting project. It has been the subject of a small grant to get it going initially, and now it's going to be rolled out nationwide. Is somebody here from RNIB or Glasgow Science Centre? [Applause.]

'Cornwall — Sea to Stars': I went down to a community meeting in Cornwall; I stayed near Lostwithiel, then went down to Goonhilly, and I had no idea just how long it takes to get there! [Laughter.] We are going to be working with the team around Truro, Goonhilly, and lots of organizations along the length of Cornwall to bring astronomy and geophysics to a region where it is difficult to reach audiences. The Cornwall team, please stand! [Applause.]

And that is it, unless someone says we should have another round of RAS200.

The President. We now proceed to the Presidential Address, and, as I thought it was inappropriate to chair myself, I asked Don Kurtz to keep time for me.

Professor D. Kurtz. I will do more than that — I will do a little bit of an introduction. Besides serving as our President for the last year, and for the coming year, I would like to remind you all that the most prestigious award that this Society gives, the Gold Medal, which has been given since 1824, was given to John in Geophysics in 2014. This is very illustrious. We look forward to a talk today on a most amazing and unique moon, and exo-planet of sorts, an 'exo-moon' — Saturn's moon Titan.

The President. [A summary of this talk has appeared in *A&G*, **58**, 4·31, 2017.]

Professor Kurtz. That was a fascinating address, John, outstandingly presented. You have brought to life in great detail something that a few years ago would have been science fiction, with a grand picture of a most amazing moon. I was captivated throughout and I think I probably speak for all of us in the room. I ask you to thank John once again. But, before you do that I also need to hand back over to him to close the meeting. Let us thank John for his Presidential Address. [Applause.]

The President. Thank you very much indeed. I have lost my crib sheet, but I think it is just down to me to announce the closing of the meeting and the next time we meet is at NAM, whenever that is. [Laughter.] I am sure it is in your diaries so I shall see you there. Drinks across the courtyard, and it would be great to welcome our visitors.

COLOGNE–PRAGUE–KIEL MEETINGS 2013–2017: FROM ACCRETION TO STAR FORMATION IN GALACTIC NUCLEI

By Michal Zajaček
University of Cologne

An intensive and fruitful trans-regional cooperation between Cologne, Prague, and Kiel research institutes (CPK) has taken place for more than ten years now. The collaboration has already resulted in several breakthrough studies of the Galactic-centre region and galactic nuclei in general. The studies included the observations and modelling of total and polarized intensity of Galactic-centre flares[1,2], resulting in the constraints on the orientation and the spin of the Sgr A* system[3,4]. A crucial project was also observing simultaneous sub-mm/near-infrared flare emission of Sgr A*, which was successfully modelled by an expanding adiabatic blob[5]. A unique factor of the collaboration from its beginning up to the present time has been the combination of cutting-edge near-infrared (NIR) observations with the state-of-the-art General Relativistic (GR) modelling tools. In particular, variations of KYSPOT code[6] have been used to fit the NIR light curves of the flares associated with Sgr A*. In Figs. 1, 2, and 3, we show example calculations of the light-curve and polarization signal associated with a bright spot in the accretion flow that is falling in towards Sgr A*. The hot spot has an assumed intrinsic emissivity profile that fades away from its centre with Gaussian dependency. The versatile set-up of our code allows us to use it for model computations of GR effects in light-curves and spectra, as well as polarimetric features in the electromagnetic signal, going from radio cm/mm/sub-mm and NIR bands up to keV X-rays. Recently, the CPK collaboration shifted towards studying NIR-excess sources and star formation in the strong-gravity régime[7–9] and fundamental physics and philosophical problems of supermassive black holes[10].

The first collaborative Cologne–Prague–Kiel (CPK) meeting was organized by Professor Wolfgang Duschl in 2013 at the University of Kiel. Subsequently, the CPK meeting was hosted by Professor Vladimír Karas in Prague (2015) during the centenary of Einstein's General Theory of Relativity. Two consecutive times (2016 and 2017) the meeting was chaired by Prof. Andreas Eckart from the University of Cologne, and took place at Castle Wahn.

The last meeting, in 2017 May 8–10, which also took place at the picturesque Castle Wahn, enabled the participants to exchange ideas between observers and theoreticians on the one hand and junior and senior researchers on the other. That was especially important in providing an update on the on-going *GRAVITY* observations from the *Very Large Telescope Interferometer* (*VLTI*)

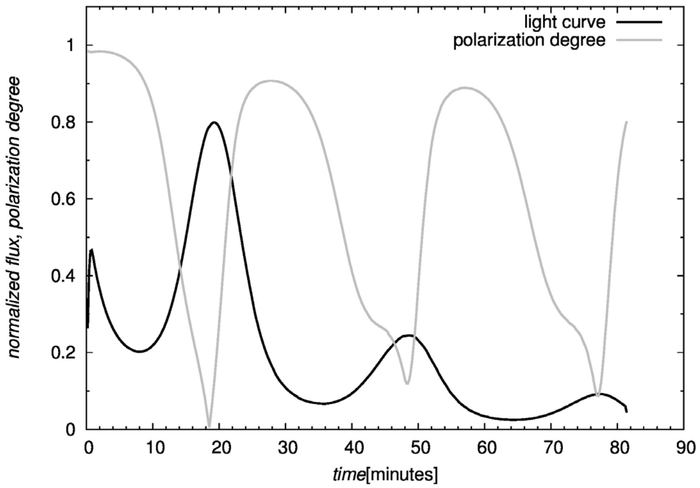

FIG. 1

Simulation of the shearing spot in-falling towards a non-rotating black hole with a mass of 4 million solar masses. An initial position of the spot corresponds to 90 degrees and starts moving away from the observer. The trajectory of the spot in the equatorial plane is depicted in Fig. 2. The black solid line represents the normalized flux density, the gray curve depicts the polarized signal. The viewing angle of a distant observer is 30 degrees. For an example calculation we used the KYSPOT code[6].

and the *Event Horizon Telescope* (*EHT*), with observations utilizing a very-long-baseline interferometry (VLBI) network, and up-coming NIR and MIR observations with the *James Webb Space Telescope* (*JWST*) and *Extremely Large Telescope* (*ELT*). Below we give an overview of highlight talks presented during three days in the Garden Hall of Castle Wahn.

Thanks to the *Chandra*, *XMM-Newton*, and *Swift* observations of the supermassive black hole at the centre of our Galaxy, Sgr A*, during the period 1999–2015, Enmanouelle Mossoux, currently at the University of Liège, tested the significance and persistence of the increase of 'bright and very bright' X-ray flaring rate proposed by Ponti *et al.*[11]. They detected the X-ray flares observed with *Swift*, *XMM-Newton*, and *Chandra*, and they determined the intrinsic distribution of the flare fluxes and durations. They then applied an algorithm on the flare arrival times corrected for the detection efficiency computed for each observation. They confirmed a constant overall flaring rate, a rise of the flaring rate for the faintest flares from 2014 August 31, and identified a decay of the flaring rate for the brightest flares from 2013 August and November. A mass transfer from the Dusty S-cluster Object/G2 to Sgr A* is not required to produce the rise of bright-flaring rate since the energy saved by the decay of the number of faint flares during a long time period may be later released by several bright flares during a shorter time period.

Abhijeet Borkar, currently at the Astronomical Institute in Prague, presented an historical overview of the compact radio source of Sgr A* as seen with radio telescopes. The supermassive black hole at the centre of the Milky Way, associated with the compact radio source Sgr A*, has been studied extensively,

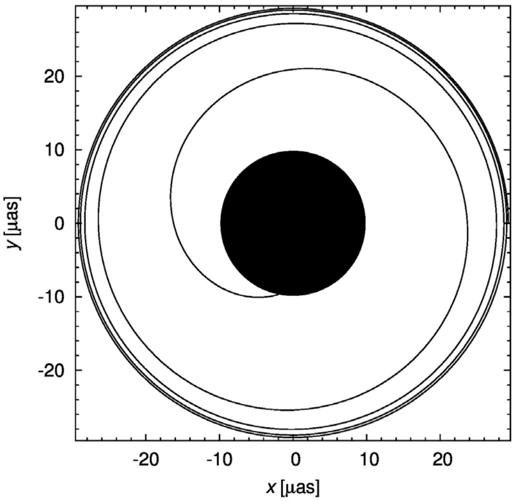

FIG. 2

Trajectory of an in-falling spot (in the equatorial plane) for a non-rotating black hole.

but the history of its discovery is not widely known. In his talk, Borkar discussed the observations of Sgr A*, from the first detection of radiation from the Galactic centre by Karl Jansky, the post-World War II advances in radio observations, in particular the discovery of the radio source Sgr A by Piddington and Minnett in 1951, to the discovery of the compact radio source Sgr A* in 1974 by Balick and Brown. He also discussed the role played by radio observations in the study of the physics of Sgr A*, the immediate SMBH environment, and the Galactic-centre region.

Electromagnetic fields play an important role in astrophysics. Near rotating compact bodies, such as neutron stars and black holes, the field lines are deformed by an interplay of rapidly moving plasma and strong gravitational fields. Vladimír Karas, currently the director at the Astronomical Institute in Prague, delivered an introductory lecture about relations that hold for test-field and exact electro-vacuum solutions in General Relativity. Given the subject of CPK meetings, electromagnetic fields near black holes were the main focus of the discussion. First, Karas concentrated on weak electromagnetic fields and he examined their structure by constructing the magnetic and electric lines of force. The gravitational field of a rotating (Kerr) black hole assumes axial symmetry, whereas the electromagnetic field may or may not share the same symmetry. With these solutions we can investigate the frame-dragging effects. The distorted field lines develop magnetic null points and current sheets, the structure of which suggests that magnetic reconnection takes place near the ergosphere[12,13]. The second part of the lecture was devoted to the transition from test-field solutions to exact solutions of coupled Einstein–Maxwell equations, such as magnetized black holes embedded in the Melvin universe. New effects emerge: the expulsion of the magnetic flux out of the black-hole horizon depends on the intensity of the imposed magnetic field.

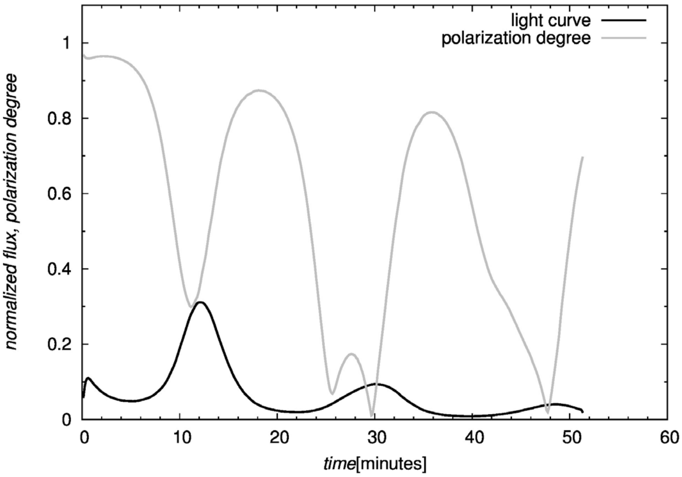

FIG. 3
The same as in Fig. 1 but for a rotating black hole with the rotation parameter $a = 0{\cdot}5$.

Bright active galactic nuclei (AGN) are powered by the accretion of the surrounding mass onto the supermassive black holes at the centres of their host galaxies. For fainter objects, star formation may significantly contribute to the luminosity. Andreas Eckart, professor at the University of Cologne, summarized experimental indicators of the accretion processes in AGN, *i.e.*, observable activity indicators that allow us to draw conclusions on the nature of accretion. The Galactic centre is the closest galactic nucleus, hence it can be studied with unprecedented angular resolution and sensitivity. Therefore, at the CPK meeting, he also included the presentation of recent observational results on Sgr A⋆ and the conditions for star formation in the central stellar cluster. The results across the whole electromagnetic spectrum were covered. He concluded that the Sgr A⋆ system is well-ordered with respect to its geometrical orientation and its emission processes, which we assume to reflect the accretion process onto the supermassive black hole. Also, in the first part Eckart highlighted the experimental requirements like VLBI in the radio and adaptive optics in the NIR.

Florian Peissker presented the results of 2014 and 2015 *SINFONI* observations of the Galactic centre. He and his colleagues followed the Dusty S-cluster Object (DSO) on its way around Sgr A⋆ before and after its pericentre passage in about 2014·39. Besides the clear detection as a point source before and after its fly-by, the discussion about its nature is still controversial. As already stated by A. Eckart *et al.*[14], it is highly unlikely that the activity of Sgr A⋆ increases because of the passage of the DSO. Until now, the Cologne Infrared Group and other Galactic-centre work-groups have not detected increased NIR or radio activity before or after its pericentre passage around Sgr A⋆, nor did they detect the proposed stretching of the emission associated with the Br-gamma recombination line in the time before, during, and after the periapse. Peissker furthermore showed that the interpretation of several other dusty sources as a 'tail' is wrong, and reflects a misleading picture about the nature of the DSO. To underline those statements, he presented a sample of isolated Br-gamma-line maps as well as low-pass-filtered continuum maps for different years between 2006 and 2015, where he clearly detected without any confusion the aforementioned dusty sources and the DSO. He presented the robustness of the applied tools and methods and compared the 'raw' data cube with the line maps, the low-pass-filtered continuum maps, and presented position–velocity diagrams where they clearly did not detect any signs of a tail feature that can be linked to the DSO.

Rusen Lu, from the Max Planck Institute for Radio Astronomy in Bonn (Germany), presented results from 1·3-mm Very Long Baseline Interferometry (VLBI) observations of the supermassive black hole at the centre of our Galaxy (Sgr A*). The observations were performed in 2013 with stations at four well-separated sites, including *CARMA*, *SMT*, Hawaii, and *APEX*. Lu showed that the *APEX* telescope greatly improved and extended the baseline coverage of the 1·3-mm VLBI array to the southern hemisphere. The observations have, for the first time, reached a spatial resolution of 3 Schwarzschild radii (3 R_s). He and his colleagues found that the event-horizon-scale structure of Sgr A* has been spatially resolved. They described the brightness distribution of the source in terms of multiple-Gaussian components and crescent-like models, and then discussed the results in the context of disc-dominated and jet-dominated accretion-flow models. Interestingly, a crescent-like model with a non-uniform brightness distribution, which resembles an asymmetric annulus with an outer diameter of ~50 μas (5 R_s) and an inner diameter of 25 μas (2·5 R_s) fits the data best. Such a structure is theoretically expected from GRMHD simulations. Near-future 1·3-mm VLBI observations with an even better coverage of the *u–v* plane (which represents the Fourier transform of an image in the sky) and sensitivity can confirm the reality of such a source morphology.

Decades of VLBI-studies of AGN jets have increased our knowledge about their kinematics. Recently, Britzen *et al.*[15] could show that AGN jets rotate. A detailed reanalysis of *MOJAVE VLBA* data for the quasar 1308+326 yielded evidence for changing apparent speeds with the time of ejection from the core region. The apparent speeds are correlated with the flux-densities and can be explained *via* Doppler-beaming and a changing viewing angle. Jet components seem to be the plasma structures following a helical magnetic field. These findings might be relevant for quasars in general but refer to the so-called 'blazar-zone' — at some distance from the jet-launching region close to the black hole. The question, how jets are launched, has been addressed by Britzen *et al.*[16] by a re-analysis of 15 GHz *MOJAVE VLBA* observations of M 87. Most likely turbulent mass loading into the jet explains the observed phenomena best. Most probably local, fast reconnection processes driven by turbulence of a tangled magnetic field, which is either generated in the accretion disc or the disc corona, load the jet. In addition, a global magnetic structure is required to channel the turbulent flow into what evolves into a large-scale jet. Large-scale jet instabilities may explain the curved pattern of the observed jet flow.

Marzieh Parsa (University of Cologne) presented her work on the analysis of relativistic stellar orbits near the supermassive black hole (SMBH) in the Galactic centre. An analysis of published and newly reduced data on the three short-period stars S2, S38, and S55 (alias S0-102) resulted in a new estimate of the Sgr A* SMBH mass and its distance[17]. A special weight was put on a novel method of analyzing relativistic orbits and the influences of relativity on orbital elements. Applied to the case of the star S2, this method indicates that the relativistic parameter defined as $Y = R_s/R_p$ (with R_s being the Schwarzschild radius and R_p the peribothron distance) has a value of $Y = 0{\cdot}00088 \pm 0{\cdot}00080$, which agrees well with the expected value of $Y = 0{\cdot}00065$. While the results will certainly be improved through upcoming interferometric measurements with *GRAVITY*, it is the first time that such a quantity could be derived from the observational data.

The CPK meeting was concluded with project planning for the near future. Researchers outside CPK institutes are always welcome to join both the collaboration and the upcoming meetings. Details and contacts may be found on the websites: www.astro.uni-koeln.de/cpk16 and www.astro.uni-koeln.de/cpk17.

Although the collaboration between Cologne, Prague, and Kiel research groups is rather small in terms of the number of people involved, it may serve as a paradigm for small-scale collaborations that are still important in the current era of big astronomical projects. In particular, it has provided a stimulating environment for the development of students and junior researchers thanks to the flexible exchange programme between the institutes that have an expertise and long-term experience in different areas. In addition, a particular importance has been the access to the modern instrumentation at the European Southern Observatory and the Max Planck Institute for Radio Astronomy.

Acknowledgements

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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 257: HR 212, HD 61994, HR 6286, AND HR 8972

By R. F. Griffin
Cambridge Observatories

Orbits are presented for four quite bright stars, whose identities appear in the title of this paper. Their periods are about 5, 1½, 6, and 8 years, respectively. The orbits of HR 212 and HR 8972 are distinguished by their very high eccentricities (well above 0·8).

Introduction

This paper, like some previous ones in this series, provides orbits for four late-type spectroscopic binaries. In this case, three of them (the exception is HD 61994) were not previously recognized as such. Two of them, HR 212 and HR 8972 (which despite the great difference in their numerical designations are only about 5° apart on the sky, being at high declinations and both being close to, though on opposite sides of, the equinoctial colure), have orbits of very high eccentricities. HD 61994 is also at high declination; and whereas the other three stars have orbital periods of several years, the period of HD 61994 is 'only' about 18 months.

HR 212

HR 212 (HD 4440) is an object slightly brighter than the sixth magnitude, to be found in the constellation Cassiopeia at a declination of some 72°; a little over 2° still further north is the interesting wide pair 21 (YZ) Cas and 23 Cas*. The V magnitude and $(B - V)$ colour index of HR 212 have been derived from *Tycho 2* photometry and listed by *Simbad* as $5^{m}\cdot855$ and $1^{m}\cdot02$, with uncertainties of about $0^{m}\cdot01$ and $0^{m}\cdot02$, respectively.

In 'field 59' of the main *Hipparcos Catalogue*[4], HR 212 (HIP 3750) is flagged with an 'X', meaning that the data could be fitted only by what the *Hipparcos* authors called a 'stochastic solution', that they described as follows: "… it was not possible to find an acceptable single or double star solution in reasonable agreement with the statistical uncertainties assigned to the individual measurements. These objects are probably astrometric binaries … ". Goldin & Makarov[5] subsequently (2006) tried to improve on the original *Hipparcos* reductions in the cases of 1561 stars with stochastic solutions, and obtained orbital fits for 65 of them. They found the orbital period of HR 212 to be about 1640 days, although the actual elements of the orbit were quite uncertain — the 1-σ range of uncertainty of the period was from about −1 year to +2 years from the central value, and the orbital eccentricity could range from about 0·5 to 0·99. The same authors took another bite[6] at the same cherry the following year, with much the same results in the case of HR 212.

The *Hipparcos* parallax of 16·33 ± 1·02 arc milliseconds inverts to a distance modulus of $3^{m}\cdot94 \pm 0^{m}\cdot14$ and thus implies an absolute magnitude of $1^{m}\cdot91$, with

*Both of those stars are spectroscopic binaries whose natures were recognized and whose orbits were first determined in Canada quite early in the last century and published from the Dominion Astrophysical Observatory (Victoria) and the Dominion Observatory (Toronto), respectively[1–3].

the same uncertainty. The astrometric data also show the orbit to be of high inclination, so if sin i is taken as unity the mass function can be approximated by $M_2{}^3/(M_1 + M_2)^2$. Then, if the mass M_1 of the primary star (a subgiant) is taken as $2M_\odot$, the secondary needs to be about $0{\cdot}85M_\odot$, corresponding to a late-G main-sequence star whose luminosity would be nearly four magnitudes fainter than the primary, making it unobservable in the spectrum, as indeed it is.

The present writer could claim to have been familiar with HR 212 for a long time: it features in a paper (written in collaboration with his then PhD supervisor and Director of the Cambridge Observatories, Prof. R. O. Redman) published[7] the 'best part' [marginally! — Ed.] of 100 years ago! That paper (which is the earliest one in the *Simbad* bibliography for the star) listed the measured intensities of the λ4215-Å CN band in several hundred late-type stars. At that time no two-dimensional MK classification had been made for HR 212, and the object was included in a small list of stars lacking such information, although the type quoted in the paper[7], 'sgK0', actually is equivalent to the presently accepted MK type of K0 IV. (The parallax-derived luminosity derived in the preceding paragraph is seen to be appreciably fainter than the norm for a giant star, although it might more properly be represented as luminosity class III–IV than the IV proposed from classification of the observed spectrum.)

Radial velocities and orbit of HR 212

The radial velocity of HR 212 was first measured at the David Dunlap Observatory, from which a mean of four measurements was published[8] under the name of the Director, Young, in 1945. The mean of +0·9 km s^{-1} is attributed a 'probable error' of 0·4 km s^{-1}, which in the context of that paper represents satisfactory agreement between the individual velocities and did not suggest real variability. Three velocities obtained with the Mount Wilson 60-inch reflector in 1936, 1942, and 1946 were long afterwards published individually by Abt[9]; they exhibit a range of 3·4 km s^{-1}, which again would be tolerable for a star of constant velocity, and they are reasonably close to the David Dunlap mean value. Four velocities dating from 1977/8, obtained with the Iowa spectrometer and spanning a range of 4·1 km s^{-1}, still in the vicinity of the previous ones, were published by Beavers & Eitter[10] in 1986. Famaey *et al.*[11] gave a mean of two velocities measured with the Haute-Provence *Coravel* in 1987 and 1988; they have kindly provided the individual details, and those velocities appear near the head of Table I, after the Mount Wilson and Iowa ones.

TABLE I

Radial-velocity observations of HR 212

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity km s^{-1}*	*Phase*	*(O–C) km s^{-1}*
1936 Sept. 8·43*	28419·43	+5·0	$\overline{14}$·212	+2·5
1942 Aug. 25·45*	30596·45	5·8	$\overline{13}$·388	+3·5
1946 Dec. 12·24*	32166·24	2·4	$\overline{12}$·236	−0·1
1977 Sept. 26·34†	43412·34	+2·7	$\overline{6}$·311	+0·4

TABLE I (*continued*)

Date (UT)			*MJD*	*Velocity* *km s^−1^*	*Phase*	*(O − C)* *km s^−1^*
1978	Aug.	5·42†	43725·42	+5·4	$\overline{6}$·480	+3·0
	Sept.	5·32†	756·32	3·9	·496	+1·5
	Nov.	3·22†	815·22	1·3	·528	−1·2
1987	Nov.	21·87‡	47120·87	2·3	$\overline{4}$·314	0·0
1988	Aug.	28·08‡	47401·08	2·2	$\overline{4}$·465	−0·2
2006	Nov.	26·00	54065·00	4·7	0·064	−0·2
	Dec.	16·96	085·96	4·0	·076	−0·4
2007	Jan.	31·77	54131·77	3·5	0·100	−0·1
2008	Feb.	26·77	54522·77	2·5	0·312	+0·2
	July	24·12	671·12	2·7	·392	+0·4
	Sept.	14·03	723·03	2·2	·420	−0·1
	Nov.	1·02	771·02	2·4	·446	0·0
2009	Jan.	2·89	54833·89	2·3	0·480	−0·1
	July	5·09	55017·09	2·4	·579	−0·2
	Aug.	12·11	055·11	2·9	·599	+0·2
	Sept.	10·04	084·04	2·9	·615	+0·2
	Oct.	13·01	117·01	2·7	·633	−0·1
	Nov.	9·01	144·01	2·9	·647	0·0
	Dec.	6·91	171·91	2·8	·662	−0·1
		20·86	185·86	3·3	·670	+0·3
2010	Jan.	26·77	55222·77	2·9	0·690	−0·2
	Mar.	4·80	259·80	3·3	·710	+0·1
	June	24·10	371·10	3·5	·770	−0·1
	Aug.	11·12	419·12	3·8	·796	0·0
	Sept.	3·08	442·08	4·0	·808	0·0
	Oct.	5·03	474·03	4·1	·825	−0·1
	Nov.	10·95	510·95	4·4	·845	−0·1
	Dec.	8·95	538·95	4·6	·860	−0·2
2011	Jan.	9·84	55570·84	5·3	0·878	+0·2
	June	8·10	720·10	9·9	·958	0·0
	Sept.	13·05	817·05	18·6	1·011	+0·1
		14·09	818·09	17·9	·011	0·0
		15·04	819·04	17·1	·012	−0·3
		16·06	820·06	16·8	·012	−0·1
		17·00	821·00	16·5	·013	+0·1
		24·04	828·04	13·7	·017	0·0
		28·01	832·01	12·6	·019	+0·1
		30·06	834·06	12·2	·020	+0·2
	Oct.	7·07	841·07	10·4	·024	−0·1
		16·05	850·05	9·0	·028	−0·1
		24·00	858·00	8·3	·033	+0·2
	Nov.	1·99	866·99	7·5	·038	+0·2
		27·93	892·93	6·1	·052	+0·4
	Dec.	28·87	923·87	4·8	·068	+0·1
2012	July	23·07	56131·07	2·5	1·180	−0·2
	Aug.	31·11	170·11	2·7	·201	+0·1
	Nov.	3·04	234·04	2·5	·236	0·0
2013	Jan.	31·75	56323·75	2·5	1·284	+0·1
	Mar.	2·80	353·80	2·3	·301	0·0
	July	10·10	483·10	+2·5	·370	+0·2

TABLE I (*concluded*)

Date (UT)		MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2014 Jan.	11·80	56668·80	+2·3	1·471	−0·1
Aug.	12·12	881·12	2·6	·585	0·0
Oct.	31·83	961·83	2·8	·629	0·0
2015 Aug.	27·16	57261·16	3·7	1·791	−0·1
Nov.	25·95	351·95	4·5	·840	+0·1
2016 Aug.	10·14	57610·14	15·3	1·979	0·0
	16·16	616·16	16·9	·982	−0·1
	20·10	620·10	18·4	·984	+0·1
Sept.	15·04	646·04	31·5	·999	0·0
Nov.	28·93	720·93	7·1	2·039	0·0
2017 Jan.	5·81	57758·81	+4·7	2·059	−0·5

* Mt. Wilson 60-inch; published by Abt[9]
† Observed at Ames by Beavers & Eitter[10]
‡ Reported by Famaey *et al.*[11] from the OHP *Coravel*

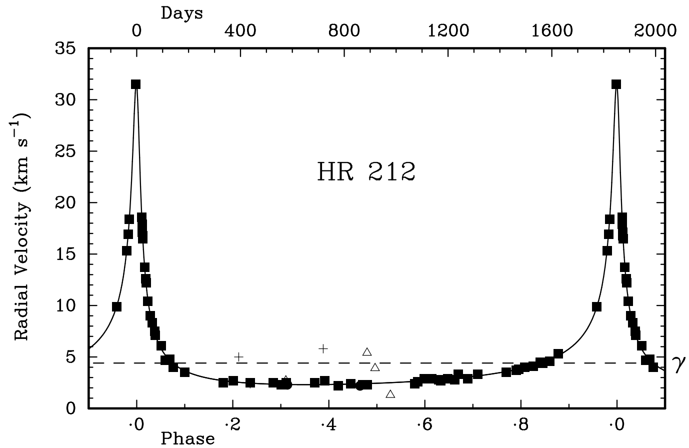

FIG. 1

The observed radial velocities of HR 212 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. Three early Mount Wilson observations[9] plotted as plusses (one hidden at phase ·236), and four Iowa velocities[10] plotted as open triangles, were not given any weight in the solution of the orbit, which depends on the 50 measurements made with the Cambridge *Coravel* (filled squares) and two provided by Famaey *et al.* (previously published as a mean value[11]) (filled circles) from Haute-Provence.

The rest of Table I records the 50 radial velocities obtained by the present writer with the Cambridge *Coravel*. Because the zero-point of those velocities has been found to differ from the normally accepted one by +0·8 km s^{-1}, the velocities in the three earlier minor series[9–11] have been increased by that amount before being entered in Table I. Except in the case of the Haute-Provence ones, the effect is merely cosmetic, because in the derivation of the orbital parameters the DDO and Mount Wilson velocities have been zero-weighted. The two Haute-Provence ones were given the same weight as the 50 Cambridge measurements. The ensemble readily yields a solution for the orbit of HR 212, which is plotted in Fig. 1 and whose elements are as follows:

$P = 1851{\cdot}4 \pm 0{\cdot}9$ days	$(T)_1 = \text{MJD } 55797{\cdot}40 \pm 0{\cdot}36$
$\gamma = +4{\cdot}40 \pm 0{\cdot}03$ km s^{-1}	$a_1 \sin i = 187{\cdot}2 \pm 1{\cdot}6$ Gm
$K = 14{\cdot}64 \pm 0{\cdot}11$ km s^{-1}	$f(m) = 0{\cdot}0764 \pm 0{\cdot}0020\ M_\odot$
$e = 0{\cdot}8648 \pm 0{\cdot}0012$	
$\omega = 7{\cdot}77 \pm 0{\cdot}27$ degrees	R.m.s. residual (wt. 1) $= 0{\cdot}17$ km s^{-1}

The very high eccentricity, which with $\omega \sim 0°$ manifests itself as a sharp maximum in the velocity curve, is no doubt responsible for the unusually agreeable precision of the period, which is determined to one part in 2000 after the observation of only two revolutions of the orbit. The high orbital inclination that has been determined astrometrically means that the masses of the component stars of the HR 212 binary system are only slightly above the minimum values, already mentioned above, implied by the orbital elements.

HD 61994

This is seen as a seventh-magnitude star at a declination just over 70° in Camelopardus. Its magnitude and colour index have been given by *Tycho 2* as $V = 7^{m}{\cdot}08$, $(B - V) = 1^{m}{\cdot}02$. The spectral type has been put at G6 V by White *et al.*[12]. The star could be said to be quite an 'old friend' of the present writer, by whom it was observed when he was a student. At that epoch he observed the intensity of the violet (λ4200-Å) CN band with a small photoelectric spectrometer in several hundred stars, one of which was the one of present interest. The results were presented[7] as 'CN ratios', defined in such a way that a featureless spectrum would give a value of 2·00. Increasing absorption in the relevant molecular band gave higher values, up to about 2·5 in the cases of supergiant stars around type K0, and exceptionally 2·79 in the case of the carbon star BL Ori. But HD 61994 gave a ratio of only 1·95, which could give the impression that the CN band is slightly in emission. The real situation is no doubt that the CN band *is* quite weak in G-type stars, and there is in fact slightly more absorption in the 'comparison bands' (wavelength regions on either side of the CN band and quite closely adjacent to it) measured by the spectrometer. (Many other main-sequence stars of similar types have given comparable ratios, so there is no suggestion that the low ratio indicates that HD 61994 is peculiar in any way. Analogous measurements were made on other absorption features in the same set of stars by subsequent research students at Cambridge, but nothing out of the ordinary was noted in the case of HD 61994.)

The spectrometer that measured CN ratios was replaced by one of much higher resolution, designed by the writer[13] while he was still a graduate student, and made at Cambridge. It was subsequently modified to serve as the prototype radial-velocity spectrometer, a device whose principle had long been mooted in Cambridge but which had never actually been implemented. Spectrometers

TABLE II

Radial-velocity observations of HD 61994

Except as noted, the observations were made with the Cambridge Coravel

Heliocentric Date	*HMJD*	*Velocity* Prim. km s⁻¹	*Velocity* Sec. km s⁻¹	*Phase*	*(O – C)* Prim. km s⁻¹	*(O – C)* Sec. km s⁻¹
1937 Jan. 26·31*	28559·31	−11·1	—	$\overline{48}$·301	+3·5	—
1945 Apr. 4·25*	31549·25	−23·1	—	$\overline{43}$·705	−0·5	—
30·21*	575·21	−26·2	—	·752	−1·7	—
1948 Mar. 23·27*	32633·27	−24·2	—	$\overline{41}$·665	−3·0	—
1980 Mar. 18·87†	44316·87	−25·8	—	$\overline{20}$·782	+0·1	—
Dec. 11·10†	584·10	−14·3	—	$\overline{19}$·265	+0·2	—
1983 Apr. 19·84†	45443·84	−28·4	−15·2	$\overline{18}$·819	−0·5	−2·2
1984 Jan. 14·04†	45713·04	−14·5	−32·2	$\overline{17}$·306	+0·1	−0·9
Nov. 24·17†	46028·17	−32·0	−8·3	·876	−0·5	−0·2
29·19†	033·19	−32·3	−7·0	·885	−0·2	+0·2
Dec. 5·12†	039·12	−33·0	−10·9	·895	−0·2	−4·7
1985 Feb. 26·03†	46122·03	−26·7	−12·8	$\overline{16}$·045	−0·4	+2·4
Apr. 1·83†	156·83	−19·4	—	·108	−0·5	—
Nov. 26·14†	395·14	−18·4	−33·4	·539	−0·6	−6·6
1986 Oct. 2·18†	46705·18	−19·9	—	$\overline{15}$·099	−0·2	—
Dec. 11·12†	775·12	−14·0	−32·4	·226	+0·7	−1·3
1987 Feb. 17·08†	46843·08	−14·7	−33·1	$\overline{15}$·348	+0·2	−2·2
2010 Jan. 18·06	55214·06	−16·9	—	0·479	−0·2	—
30·07	226·07	−17·4	—	·500	−0·3	—
Feb. 20·98	247·98	−18·0	—	·540	−0·1	—
Mar. 22·96	277·96	−19·5	—	·594	−0·3	—
Apr. 5·90	291·90	−19·7	—	·619	+0·1	—
May 3·87	319·87	−21·4	—	·670	0·0	—
Nov. 24·19	524·19	−26·9	—	1·039	+0·3	—
Dec. 9·19	539·19	−23·0	—	·066	+0·3	—
12·20	542·20	−22·4	—	·072	+0·2	—
19·16	549·16	−21·2	—	·084	−0·1	—
2011 Jan. 10·12	55571·12	−17·9	—	1·124	−0·1	—
Apr. 6·91	657·91	−14·3	—	·281	+0·2	—
Oct. 1·17	835·17	−19·6	—	·601	−0·3	—
Nov. 28·18	893·18	−22·5	—	·706	+0·1	—
Dec. 18·23	913·23	−24·0	—	·742	+0·1	—
2012 Jan. 4·12	55930·12	−25·1	—	1·773	+0·4	—
27·03	953·03	−27·2	—	·814	+0·4	—
Feb. 11·01	968·01	−29·2	—	·841	0·0	—
24·98	981·98	−30·7	—	·867	+0·2	—
Mar. 7·92	993·92	−32·5	—	·888	−0·2	—
Apr. 1·87	56018·87	−34·8	—	·933	+0·2	—
15·90	032·90	−35·3	—	·959	+0·2	—
May 14·88	061·88	−31·8	—	2·011	−0·3	—
22·88	069·88	−29·0	—	·026	+0·4	—
Sept. 7·18	177·18	−14·8	—	·220	0·0	—
19·18	189·18	−14·6	—	·241	0·0	—
Nov. 3·21	234·21	−14·4	—	·323	+0·3	—
Dec. 2·21	263·21	−15·0	—	·375	+0·1	—
26·12	287·12	−15·8	—	·418	−0·1	—

TABLE II (*concluded*)

Heliocentric Date		*HMJD*	*Velocity* Prim. km s⁻¹	Sec. km s⁻¹	*Phase*	*(O–C)* Prim. km s⁻¹	Sec. km s⁻¹
2013 May	2·85	56414·85	−20·5	—	2·649	+0·2	—
Oct.	29·24	594·24	−35·3	—	·973	−0·1	—
Nov.	9·22	605·22	−33·7	—	·993	0·0	—
2014 Jan.	5·15	56662·15	−20·4	—	3·096	−0·5	—
Mar.	1·92	717·92	−14·8	—	·197	+0·3	—
2015 Apr.	5·89	57117·89	−34·5	—	3·920	−0·2	—
	23·90	135·90	−35·6	—	·952	−0·1	—
2017 Jan.	11·02	57764·02	−21·0	—	5·088	−0·2	—

* Mt. Wilson 60-inch; published by Abt[9]
† Observed at OHP by Duquennoy & Mayor[14]

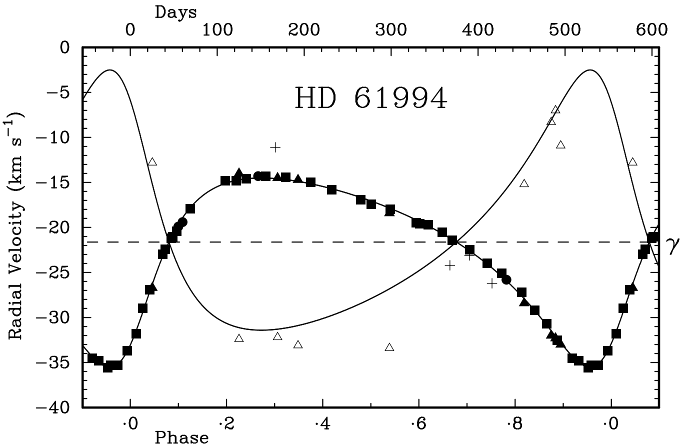

FIG. 2

The observed radial velocities of HD 61994 plotted as a function of phase, with the velocity curves corresponding to the adopted orbital elements drawn through them. The orbit of the primary star largely depends on the 37 Cambridge velocities, which are plotted as filled squares. They were reduced as if the system were single-lined; slight 'dragging' towards the γ-velocity, caused by blending with the weak secondary dip, can be discerned. Four plusses denote early Mount Wilson velocities published by Abt[9] and not utilized in the solution of the orbit. The 13 filled triangles represent velocities obtained with the Haute-Provence *Coravel*, published by Duquennoy & Mayor[14], and given weight ⅓ in the solution. Those authors sometimes recognized the weak secondary component as a separate entity, which they measured on nine occasions. The resulting velocities, which alone are responsible for the amplitude determined here for the secondary star, are plotted as open triangles and were attributed a weight of only 1/200 in the calculation of the orbit.

operating on the same principle were subsequently made at a few other observatories. One of them, at Haute-Provence, was used by Duquennoy & Mayor[14] (the latter of whom constructed it) to observe HD 61994; those authors' paper illustrates a trace of the star, obtained near a nodal passage, showing a very shallow secondary dip whose velocity looks somewhat indeterminate because the dip is blended with the primary one and is at (or even in part slightly beyond) the end of the velocity region that was scanned. As far as the Cambridge observations are concerned, in the present paper HD 61994 is regarded as single-lined, but velocities of the secondary were obtained by the Haute-Provence observers from some of their traces. Table II includes four early velocities found by Abt in the Mount Wilson plate files and published by him[9], and thirteen published by Duquennoy & Mayor[14] themselves from Haute-Provence. Nine of those thirteen were reported as double-lined, with two velocities given, and they are so listed in Table II. Their authors derived a double-lined orbit from the limited number of observations that they had at their disposal.

The rest of Table II presents the 37 Cambridge radial velocities, which were reduced as single-lined. In the solution of the orbit, they were regarded as measurements of the primary alone, and were attributed unit weight. A zero-point adjustment of –0·5 km s^{-1} was made to those velocities as initially reduced, an amount more or less in line with expectation from the colour index of HD 61994. To obtain approximately equal weighted variances, the velocities provided by Duquennoy & Mayor were given weight ⅓ in respect of the primary star, and only 1/200 in respect of the secondary; they were all adjusted by +0·8 km s^{-1} to account for the recognized offset (error, as it might unkindly be called!) of the zero-point of Cambridge velocities. The early Mount Wilson radial velocities were zero-weighted, although they still feature in Table II and in Fig. 2 where the orbit is plotted. The elements of the finally adopted orbit are given in Table III, together with the elements published long ago by Duquennoy & Mayor. It will be seen that the new elements for the primary star are in general agreement with those found by the previous authors, but their standard errors are smaller by factors typically of about four. It is accordingly admitted that the new solution does not offer information that is qualitatively new, but it does provide a considerable refinement of the original orbit.

TABLE III

Orbital elements for HD 61994

Element	*Duquennoy*[14]	*This paper*
P (days)	553·51 ± 0·31	553·26 ± 0·06
T (MJD)	56657·4 ± 3·0	54949·2 ± 0·8
γ (km s^{-1})	–22·58 ± 0·14	–21·62 ± 0·04
K_1 (km s^{-1})	10·69 ± 0·23	10·50 ± 0·06
K_2 (km s^{-1})	14·94 ± 0·51	14·5 ± 1·5
e	0·415 ± 0·021	0·426 ± 0·004
ω (degrees)	225·3 ± 3·1	220·7 ± 0·8
$a_1 \sin i$ (Gm)	74·0 ± 1·6	72·3 ± 0·4
$a_2 \sin i$ (Gm)	103·4 ± 3·6	99 ± 10
$m_1 \sin^3 i$ ($M_\odot$)	0·425 ± 0·070	0·38 ± 0·10
$m_2 \sin^3 i$ ($M_\odot$)	0·304 ± 0·046	0·28 ± 0·03
R.m.s. residual (wt.1) (km s^{-1})	0·61	0·23

HR 6286 (HD 152812)

HR 6286 is a late-type giant star of exactly the sixth magnitude; it is to be found near the northern boundary of Hercules, about 1½° north-following 52 Her, a visual triple system whose primary is an Ap star. The magnitudes of HR 6286 were measured more than 50 years ago by Argue[15], a former 'Assistant Observer' at the Cambridge Observatories, who was deputed by Redman (the then Director) to make a visit to KPNO on purpose to obtain *UBV* photometry for many of the stars (one of which was HR 6286) that were on the Cambridge programme of narrow-band photometry at that time; for HR 6286 he obtained $V = 6^{m}{\cdot}00$, $(B - V) = 1^{m}{\cdot}32$, $(U - B) = 1^{m}{\cdot}44$. The star features in a 1953 paper[16] by Keenan & Keller on 'high-velocity stars', in which its spectral type is given as K2 III and its space motion as 96 km s^{-1}. A radial velocity of –62·3 km s^{-1} that, by itself, would just about put the object in the 'high-velocity' category had long previously been published by Young[17] from the David Dunlap Observatory on the basis of four low-dispersion photographic spectrograms whose inter-agreement was not such as to suggest any real variation.

The Cambridge programme of narrow-band photometry that is mentioned in the section on HR 212 above began in 1958 with a programme on the violet CN band; the results were written up[7] jointly by Redman and the present writer, and in the case of HR 6286 showed the band to be slightly less strong than the mean for stars of its type. Some other features were later measured analogously by other (student) observers who used the improved higher-resolution spectrometer designed by the writer[13]. Brown *et al.*[18] subsequently observed some of the same stars with the McDonald 2·1-m reflector and a spectrometer with a 'reticon' receiver. They found the spectral features that interested them to be mildly weaker than average in HR 6286, as is typical for high-velocity stars, but the red lithium line was undetectably weak.

McAlister *et al.*[19], using their 'speckle camera' on the Kitt Peak 4-m reflector, found HR 6286 to be a binary system with an angular separation of only 0″·292; a few years later a fresh observation[20] gave a separation of 0″·198 and a position angle that differed from the previous value by about 11°, so it was evidently an orbital system, and they named it (after their organization, plus a serial number) as 'CHARA 58'. Their subsequent effort[21] to resolve it with an analogous instrument at Cerro Tololo, however, was unsuccessful, and so was an attempt by Hartkopf & Mason[22] to resolve it with the Mount Wilson 100-inch.

In 1999 de Medeiros & Mayor published[23] the results of a lot of radial-velocity observations made with their *Coravel* at Haute-Provence; in the case of HR 6286 the results included a mean velocity of –65·88 ± 0·36 km s^{-1}, with the uncertainty of the individual values listed as 0·51 km s^{-1}, evidently implying that they had just two measurements, which they have since provided individually and appear at the head of Table IV.

A recent paper by Jonsson *et al.*, mainly concerned with fluorine abundances, and allowed only a single page of print in the *Astrophysical Journal*[24], offers for HR 6286 (by computer) the quantities $T = 4193$°C, $\log g = 1{\cdot}70$, [Fe/H] = –0·48, and logarithmic abundances of 8·50 for oxygen and 3·89 for fluorine, hydrogen being taken as 12.

The star was placed on the observing programme of the Cambridge *Coravel* when that instrument first became briefly available in 1997. Although in retrospect one can see a modest discrepancy between the first two *Coravel* measurements, the star's behaviour did not encourage much interest, or frequent observations, until in 2010 the fifth measurement seemed higher than

TABLE IV

Radial-velocity observations of HR 6286

Except as noted, the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity km s⁻¹*	*Phase*	*(O–C) km s⁻¹*
1987 Aug. 10·91*	47017·91	−64·7	0·123	+0·1
1988 July 19·89*	47361·89	−64·0	0·286	0·0
1997 May 11·06	50579·06	−67·6	1·804	+0·1
2001 July 27·96	52117·96	−65·0	2·530	+0·2
2002 Mar. 29·14	52362·14	−65·9	2·645	+0·2
2010 May 13·12	55329·12	−66·4	4·046	+0·1
Nov. 15·75	515·75	−65·0	·134	−0·3
2011 Apr. 9·18	55660·18	−64·2	4·202	−0·1
June 17·08	729·08	−63·9	·235	+0·1
Aug. 8·97	781·97	−64·0	·260	0·0
Sept. 12·85	816·85	−64·0	·276	0·0
Nov. 19·73	884·73	−64·2	·308	−0·1
2012 Apr. 16·14	56033·14	−64·1	4·378	+0·2
July 23·93	131·93	−64·5	·425	0·0
Nov. 14·73	245·73	−64·8	·478	0·0
2013 Mar. 14·23	56365·23	−65·3	4·535	−0·1
May 1·15	413·15	−65·4	·557	−0·1
July 1·03	474·03	−65·7	·586	−0·1
Aug. 26·91	530·91	−65·8	·613	0·0
2014 Mar. 12·23	56728·23	−66·5	4·706	+0·1
Apr. 8·19	755·19	−67·0	·719	−0·2
June 6·07	814·07	−67·0	·747	0·0
Sept. 9·91	909·91	−67·5	·792	0·0
Nov. 12·72	973·72	−68·1	·822	−0·2
2015 Mar. 27·21	57108·21	−68·3	4·886	+0·2
July 8·98	211·98	−68·6	·935	0·0
Sept. 9·83	274·83	−68·2	·964	+0·1
Oct. 22·79	317·79	−67·9	·984	+0·1
Dec. 11·74	367·74	−67·9	5·008	−0·4
2016 Apr. 17·16	57495·16	−65·7	5·068	+0·2
June 7·06	546·06	−65·3	·092	+0·1
Aug. 15·93	615·93	−64·5	·125	+0·3
Nov. 28·74	720·74	−64·7	·175	−0·4

*Observed with OHP *Coravel* by de Medeiros & Mayor[23]

the previous one by a probably significant amount, so the object was transferred to the binary-star programme and scheduled for systematic observation. The velocity did seem to rise a bit further from its initial value during 2011, and then embarked on a small and slow (but definite) decline over the next three years, after which it began to recover. By the end of 2016 it was back to the level seen in 2010 and the period of about 6 years could be recognized. There are now 31 Cambridge observations, set out in Table IV after the two Haute-Provence ones.

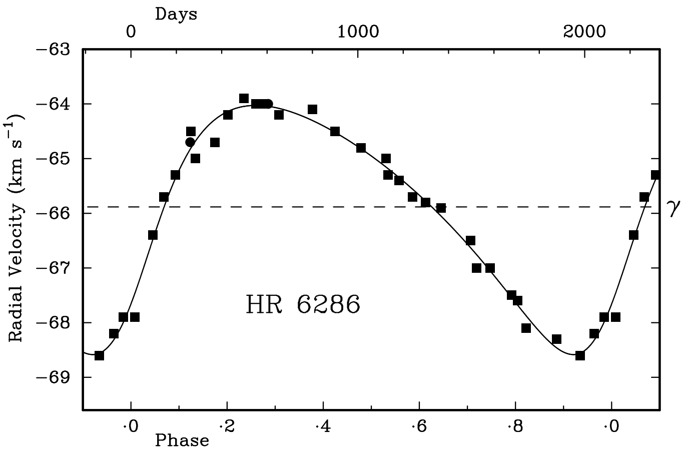

FIG. 3

The observed radial velocities of HR 6286 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. There are 31 Cambridge observations (squares), and two Haute-Provence ones (circles) provided by de Medeiros & Mayor, who published them previously[23] as a mean value.

With all the measurements given equal weight, the ensemble readily produces an orbit, shown in Fig. 3, albeit one having an amplitude of little more than 2 km s^{-1}, with the following elements:

P = 2119 ± 5 days	$(T)_1$ = MJD 55232 ± 22
γ = −65·88 ± 0·03 km s^{-1}	$a_1 \sin i$ = 63·1 ± 1·6 Gm
K = 2·28 ± 0·05 km s^{-1}	$f(m)$ = 0·00223 ± 0·00017 $M_{\odot}$
e = 0·311 ± 0·019	
ω = 234 ± 4 degrees	R.m.s. residual (wt. 1) = 0·17 km s^{-1}

HR 8972 (HD 222387)

This star is to be found in Ursa Minor, at a very high declination of just over 74°; it is nearly 4° directly south of the third-magnitude star γ Cep (itself a star of substantial interest, with more than 500 references listed by *Simbad*, and for which an orbit with a period of 66 years was presented[25] by the writer and his collaborators some 15 years ago). Photometry has been provided by *Tycho 2*, as $V = 5^{\mathrm{m}}{\cdot}97$, $(B - V) = 0^{\mathrm{m}}{\cdot}89$, and the spectral type has been classified by A. Cowley & Bidelman as G8 III. There is a *Gaia* parallax[26] of 5·23 ± 0·66 arc milliseconds, putting the distance at about 191 ± 24 pc or a distance modulus of about $6^{\mathrm{m}}{\cdot}4$, implying an absolute magnitude close to $-0^{\mathrm{m}}{\cdot}5$, with an uncertainty of about half a magnitude.

The radial velocity of HR 8972 was first measured a long time ago at the David Dunlap Observatory: Young[17] reported a mean velocity of +14·6 km s^{-1} with a 'probable error' of 1·4 km s^{-1} from five plates taken with the 74-inch reflector. Evidently the agreement between the plates was acceptable, because the result is given only as a mean, whereas the observations were listed individually in that publication for stars whose velocities were adjudged variable. Wilson

Table V

Radial-velocity observations of HR 8972

Except as noted, the observations were made with the Cambridge Coravel, but those made at Cambridge before the end of 2001 have been rejected

Date (UT)		*MJD*	*Velocity* $km\ s^{-1}$	*Phase*	*(O–C)* $km\ s^{-1}$
1936	Aug. 12·45*	28392·45	−6·4	$\bar{7}$·270	−18·8
1943	July 16·49*	30921·49	−0·6	$\bar{6}$·124	−10·9
1946	Sept. 11·30*	32074·30	+12·6	$\bar{6}$·513	−0·7
	Dec. 13·16*	167·16	+11·5	·544	−1·8
1976	Sept. 22·27†	43043·27	+16·8	$\bar{2}$·216	+4·9
	Oct. 10·26†	061·26	+17·4	·222	+5·4
1977	Sept. 26·22†	43412·22	+14·0	$\bar{2}$·340	+1·2
1978	Aug. 9·37†	43729·37	+13·2	$\bar{2}$·447	0·0
	Nov. 8·17†	820·17	+14·0	·478	+0·8
1982	Aug. 21·35†	45202·35	+7·8	$\bar{2}$·945	−0·8
1983	Sept. 2·25†	45579·25	+9·3	$\bar{1}$·072	+1·5
1993	Feb. 13·77‡	49031·77	+11·7	0·237	−0·4
	July 11·10‡	179·10	+12·7	·287	+0·2
	Dec. 26·89‡	347·89	+12·4	·344	−0·4
1994	Feb. 19·74‡	49402·74	+12·6	0·363	−0·3
	Aug. 3·02‡	567·02	+12·9	·418	−0·2
	Dec. 10·82‡	696·82	+13·1	·462	−0·1
1995	Jan. 1·84‡	49718·84	+12·8	0·469	−0·4
	Dec. 31·80‡	50082·80	+12·8	·592	−0·5
1996	Nov. 18·88	50405·88	+12·7	0·701	−0·5
	Dec. 25·85‡	442·85	+13·2	·714	0·0
1997	Jan. 26·77‡	50474·77	+13·0	0·725	−0·2
	July 19·11‡	648·11	+13·0	·783	+0·1
	Sept. 9·96‡	700·96	+12·3	·801	−0·5
	Dec. 23·80‡	805·80	+12·1	·836	−0·3
1998	July 9·07‡	51003·07	+10·3	0·903	−0·8
1999	Dec. 19·83	51531·83	+9·1	1·081	+0·6
2000	Jan. 8·78	51551·78	+10·4	1·088	+1·5
	June 18·08	713·08	+9·8	·143	−0·9
	Aug. 29·03	785·03	+9·1	·167	−2·1
	Oct. 20·02	837·02	+10·0	·184	−1·5
	Dec. 13·85	891·85	+11·6	·203	−0·2
2001	Feb. 14·77	51954·77	+12·2	1·224	+0·2
	June 25·05	52085·05	+11·5	·268	−0·9
	Aug. 25·09	146·09	+10·3	·289	−2·2
	Oct. 30·94	212·94	+11·5	·311	−1·2
	Dec. 20·82	263·82	+13·4	·329	+0·6

TABLE V (*continued*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2002 Feb. 14·76	52319·76	+13·0	1·347	+0·2
July 21·09	476·09	+12·9	·400	−0·1
Aug. 21·11	507·11	+13·0	·411	−0·1
Oct. 19·03	566·03	+13·0	·431	−0·1
Dec. 18·81	626·81	+13·4	·451	+0·2
2003 Feb. 17·77	52687·77	+13·3	1·472	+0·1
May 29·08	788·08	+12·9	·506	−0·4
July 28·12	848·12	+13·1	·526	−0·2
Sept. 18·02	900·02	+13·2	·543	−0·1
Nov. 27·92	970·92	+13·2	·567	−0·1
2004 Jan. 29·82	53033·82	+13·5	1·588	+0·2
July 3·09	189·09	+13·0	·641	−0·3
Sept. 2·04	250·04	+13·1	·661	−0·2
Nov. 14·94	323·94	+13·5	·686	+0·2
2005 Feb. 8·78	53409·78	+13·1	1·715	−0·1
May 28·08	518·08	+13·0	·752	−0·1
Aug. 7·06	589·06	+12·8	·776	−0·1
Oct. 5·03	648·03	+13·0	·796	+0·2
Dec. 10·83	714·83	+12·5	·818	−0·1
2006 Feb. 25·77	53791·77	+12·2	1·844	−0·1
July 17·10	933·10	+11·8	·892	+0·4
Sept. 11·06	989·06	+10·9	·911	+0·2
Nov. 25·98	54064·98	+9·1	·937	−0·2
2007 Jan. 20·78	54120·78	+7·1	1·955	−0·2
Feb. 14·80	145·80	+5·9	·964	+0·2
May 30·10	250·10	−15·3	·999	−0·2
31·11	251·11	−15·1	·999	+0·1
June 21·07	272·07	−12·8	2·006	−0·2
28·10	279·10	−10·3	·009	+0·3
July 7·07	288·07	−8·0	·012	0·0
19·08	300·08	−4·8	·016	+0·2
25·10	306·10	−4·0	·018	−0·2
Aug. 1·13	313·13	−2·6	·020	−0·2
11·07	323·07	−1·1	·024	−0·3
30·06	342·06	+1·4	·030	−0·1
Sept. 13·08	356·08	+2·6	·035	−0·2
30·00	373·00	+4·1	·041	0·0
Oct. 18·03	391·03	+5·2	·047	+0·1
Nov. 23·94	427·94	+7·0	·059	+0·3
2008 Jan. 5·84	54470·84	+8·1	2·074	+0·1
Feb. 4·76	500·76	+8·4	·084	−0·2
July 24·09	671·09	+10·9	·141	+0·2
Sept. 14·02	723·02	+11·0	·159	−0·1
Oct. 16·99	755·99	+11·3	·170	0·0
Nov. 25·92	795·92	+11·3	·183	−0·2
2009 Feb. 13·77	54875·77	+11·7	2·210	−0·1
July 5·10	55017·10	+12·4	·258	+0·1
Aug. 12·09	055·09	+12·6	·271	+0·2
Sept. 10·09	084·09	+12·7	·281	+0·2
Oct. 13·00	117·00	+12·6	·292	+0·1
Nov. 20·95	155·95	+12·8	·305	+0·2

TABLE V (*concluded*)

Date (UT)		MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
2010	Jan. 6·74	55202·74	+13·1	2·321	+0·4
	Feb. 1·77	228·77	+12·7	·329	–0·1
	Aug. 19·07	427·07	+13·1	·396	+0·1
	Sept. 13·00	452·00	+13·0	·405	–0·1
	Nov. 23·87	523·87	+13·1	·429	0·0
2011	Sept· 11·03	55815·03	+13·2	2·527	–0·1
	Nov. 9·85	874·85	+13·4	·548	+0·1
2012	July 25·08	56133·08	+13·4	2·635	+0·1
	Aug. 31·10	170·10	+13·3	·647	0·0
2013	Feb. 4·75	56327·75	+13·2	2·700	0·0
	Oct. 29·90	594·90	+12·9	·791	+0·1
	Dec. 27·90	653·90	+12·8	·811	+0·1
2014	Aug. 12·11	56881·11	+11·7	2·887	+0·2
	Sept. 11·01	911·01	+11·4	·897	+0·2
	Oct. 31·83	961·83	+10·6	·914	0·0
	Dec. 13·80	57004·80	+10·0	·929	+0·2
2015	July 18·05	57221·05	–15·2	3·002	+0·1
	23·12	226·12	–14·5	·004	+0·1
	Aug. 27·15	261·15	–5·4	·016	–0·1
	Sept. 7·04	272·04	–3·1	·019	–0·1
	19·03	284·03	–1·1	·023	–0·1
	28·06	293·06	+0·3	·026	+0·1
	Nov. 13·94	339·94	+4·5	·042	+0·1
	25·93	351·93	+5·3	·046	+0·2
2016	Aug. 16·12	57616·12	+10·8	3·135	+0·2
	Nov. 28·90	720·90	+11·3	·171	0·0

*Observed by Wilson & Joy[27] at Mt. Wilson; weight 0
† Observed by Beavers & Eitter[10] at Ames; weight 0
‡ Observed with Haute-Provence *Coravel*; weight ¼

& Joy[27] measured the radial velocity of the star four times with the Mount Wilson 60-inch reflector (under the name 'G 32872', referring to Boss's *General Catalogue*[28]); they obtained values sufficiently disparate from one another that they gave them separately in a note, as "–6, –1, +13, +12". Without the dates we would not be able to make any use of them, but Abt[9] very helpfully published a great many Mount Wilson radial velocities individually, including the four of HR 8972, which duly appear at the head of Table V here. There follow seven velocities published by Beavers & Eitter[10] from their Iowa spectrometer, which certainly appear to confirm changes in velocity.

HR 8972 was added to the Cambridge observing programme in 1993, and for five years was observed from time to time by the writer and Dr. R. E. M. Griffin with the Haute-Provence *Coravel*, until the *Coravel*-type instrument was routinely available in Cambridge in late 1999. As many as 89 measurements of HR 8972 have been made with that instrument. All the available radial velocities, 114 in total, are set out here in Table V.

Trial solutions of the orbit demonstrated that certain of the data were unhelpful. Two of the four old Mount Wilson observations have enormous residuals, so all four have now been zero-weighted. Some of the Iowa velocities

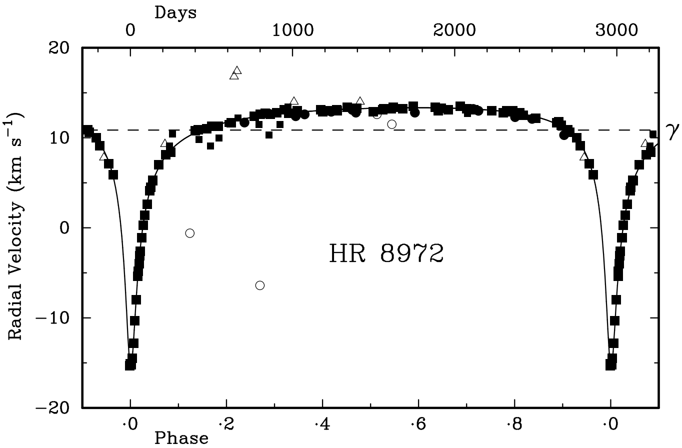

FIG. 4

The observed radial velocities of HR 8972 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The orbit largely depends on the 78 Cambridge velocities plotted as filled squares. The twelve earliest Cambridge measurements, which for no obvious reason include some with unacceptably large residuals, have been zero-weighted and plotted in smaller symbols. There are in addition four early Mount Wilson velocities[27] (open circles) and seven Iowa ones[10] (open triangles) that were not used in the solution of the orbit. Fourteen Haute-Provence velocities, obtained by the present writer and Dr. R. E. M. Griffin, appear in the plot as filled circles and have merited weight ¼ in the orbit.

gave bad residuals, though not on the scale of the Mount Wilson ones, so all of them too have been zero-weighted. Somewhat embarrassingly and seemingly unaccountably, there are also several unacceptable residuals among the early Cambridge velocities, and it has seemed best to reject *en bloc* the 12 that were made up till the end of the year 2001, leaving 77 accepted ones. In the solution of the orbit, shown in Fig. 4, they were given full weight, while the 14 Haute-Provence data were given a weight of ¼ to make the variances approximately equal. The resulting elements are shown in the informal table here:

P = 2962·3 ± 0·5 days	$(T)_1$ = MJD 54252·8 ± 0·4
γ = +10·856 ± 0·022 km s^{-1}	$a_1 \sin i$ = 325·7 ± 1·4 Gm
K = 14·37 ± 0·05 km s^{-1}	$f(m)$ = 0·1573 ± 0·0021 $M_\odot$
e = 0·8310 ± 0·0010	
ω = 174·35 ± 0·22 degrees	R.m.s. residual (wt. 1) = 0·17 km s^{-1}

The high formal precision of the γ-velocity is, of course, misleading as a measure of the real uncertainty of that quantity, although no doubt it reflects a mathematical property of the data set. An obvious shortcoming of the data set itself is the lack of observations on much of the declining 'branch' of the velocity curve, which is traversed in a matter of weeks and has occurred at a time of year (twice, since the observations began, the orbital period being close to the integer number of 8 years) when the star is not accessible to the Cambridge telescope, whose hour-angle coverage is quite limited at high declinations.

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CIGARETTE- AND TRADE-CARD ASTRONOMY: *C.*1900 – *C.*2000. A JOURNEY FROM ENGAGED IMAGINATION TO PASSIVE DATA CONSUMPTION.

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Of the many hundreds of cigarette- and trade-card sets that have been issued since *circa* 1900, just a rare few deal with the subject of astronomy. Those card sets, however, provide a pictorial history of popular astronomy and they afford us some insight into how the presentation of scientific ideas, to non-specialist audiences, has evolved over time. They also reveal many futures that never came to fruition in the case of space exploration. Across the breadth of the 20th Century we find that both the design and nature of astronomy and space-related card sets changed dramatically. The early card sets invite the imaginative involvement of the reader, who is considered to be a joint explorer of the cosmos; the later card sets consider the reader to be a passive bystander and simple consumer of facts and figures. While the early card sets acted to inspire a sense of wonderment at the Universe and the objects within it, the more contemporary card sets tend to inspire a sense of amazement at the tools, the telescopes, the spacecraft, and the 'big science' programmes that have been constructed to push science research forward.

Introduction

Barry Kent's recent review[1] of *Amazing Stories of the Space Age*, by Rod Pyle (Prometheus, 2017), began with the reminiscence of a trade card, that had been collected in the 1960s, "illustrating the wonders of space travel". Such cards have largely gone out of favour in the modern era, but in common with the subject matter of the text that was being reviewed, trade cards have a whole astronomy and space-race-related history of their own. Trade cards, as their name implies, were first used to advertise the products of a specific business, and they have been used commercially over many hundreds of years[2]. Beginning in the early 20th Century, however, trade cards morphed into their present form and were gradually incorporated into numerous mass-media advertising campaigns, supporting such outlets as sporting franchises, Hollywood film productions, and popular stage, radio, and TV personalities[3,4]. Cigarette cards, on the other hand, were first used in the early 1880s, primarily as packet 'stiffeners', and only later became a brand-advertising tool. In very general terms, cigarette cards may be considered a product of the first half of the 20th Century, while mass-media trade cards are a phenomenon of the second half.

While the distinction between cigarette and trade cards is mostly one of semantics, the clear aim of all such card sets is straightforward — they are distributed to encourage brand loyalty and to sell more of the associated product. Certainly some card sets were intended to be instructional, but the majority simply relate to aspects of popular culture and/or general interests (*e.g.*, famous national figures, flags, buildings, the armed forces, gardening, wildlife, transportation, and engineering wonders). A review of the cards issued[5] by W. D. & H. O. Wills and John Player and Sons, two of the most prolific producers of cigarette cards in Great Britain, for the years between 1892 and 1939 reveals that less than 1% of their card sets deal with the sciences. Additionally, it has been estimated that in excess of 16 000 cigarette- and trade-card sets have been published in the time interval from the late 19th Century to the present day, but only about 50 of those sets relate to space exploration and/or astronomy (about 0·3% of the total). Interestingly, of all the card sets published, the only science subject to be covered by either cigarette and/or trade cards is that of astronomy[6,7]. The author is not aware of any single card set directly relating to chemistry, physics, biology, or mathematics having ever been issued by a major manufacturer. That observation, in and of itself, indicates something special about astronomy: it is a science that is accessible to a mass audience.

It is also a science that the lay public is prepared to accept at a popular level, with any and all kinds of arcane astronomical knowledge being considered *useful* and *interesting*. In direct contrast it would seem that the fundamental concepts of, say, quantum mechanics, which underpins the very foundations of our understanding of matter, is not considered accessible knowledge — at least at a popular, or everyday-life, level. The reasons why such selection arises are complex, but at some level they must relate to the amount of mental effort and background study required to appreciate what it is that is being said, and to the everyday utility of the end result once it has been accommodated. So, in a seemingly contradictory sense, while the formation and evolution of galaxies, stars, and planets have absolutely no impact upon our everyday lives and/or our survival, they are none-the-less topics about which the lay public wishes to be informed. Indeed, Stoeger[8] has considered this integrating aspect of astronomy on culture and suggests that, "by acting as a source of continual wonder and as a cultural invitation to self-transcendence and mystery", astronomy is a powerful force in the shaping of cultural evolution. Astronomy literally takes us beyond ourselves and forces our collective imaginations to envisage bizarre and distinctly alien structures.

A brief history of astronomy cards

The art of card-set production is simple in principle, but challenging in practice[9]. The principle is to pick a subject and then divide it into 25 to 50 themes and/or sub-topics. Then, on the practical side, find a picture to illustrate each of the sub-topics and compose 50 to 75 words to describe each picture. This latter activity is a challenging one if the subject matter is to be given any great credit, and if, as H. G. Wells[10] put it in his 1894 article on popularizing science, "the mere obvious tinctured by inaccurate compilation" is to be avoided. On that basis, however, the first published sets of astronomy trade cards, *Constellations* (1903 by Liebig) and *Constellations* (1912 by Cadbury Ltd.), were rather poor affairs. As their titles imply, those card sets (six cards by Liebig and 12 cards by Cadbury Ltd.) were intended as basic guides to the constellations and stars. The Liebig set featured mostly pastoral scenes with poorly illustrated star configurations, and the card backs were concerned with the mythology of the variously pictured constellations, and perhaps surprisingly offered no practical information on how to find the featured stars. The Cadbury card set was certainly more instructive with respect to giving star names and star identification, but the actual diagrams were rather poorly rendered. The first astronomy card sets, therefore, were apparently intended to be utilitarian, but made no attempt to summarize the contemporary state of astronomical knowledge.

The first cigarette manufacturer to distribute a detailed set of astronomy-related cards was John Player and Sons Ltd. Published in 1914, that series of 25 cards, called *Those Pearls of Heaven*, offered summaries on numerous astronomical phenomena. Thirteen of the cards dealt with the identification of the constellations, while the remainder considered astronomical topics as diverse as the origin of lunar craters, the Kapteyn model of the Galaxy and star streaming, variable stars, and the 'mysterious canals' of Mars. The card figures and diagrams were printed in three-tone colour (light blue, dark blue, and red on a white background), and the card backs offered brief, but state-of-the-art summaries of the featured topics. The card backs also offered straightforward numerical facts concerning speeds, distances, and masses of the planets and stars. So, with *Those Pearls of Heaven* an attempt was made to introduce the reader to some aspects of then contemporary astronomy, but for all that, the presentation was not visually lavish.

W. D. & H. O. Wills published an extensive astronomy card set, entitled *The Romance of the Heavens*, in 1928. The 50 cards that constitute that series offered summaries on topics such as the fission theory for the origin of the Moon, the origin of the Solar System, the solar wind, the physical properties of giant stars, and stellar spectra. That card set is visually impressive and well produced. The pictures are colourful and vivid, and show detailed imaginary planetary landscapes. Clearly the aim was to capture the reader's imagination, and to inspire a sense of wonder at the Solar System and the stars. The rings of Saturn, for example, are depicted as they would appear if seen from one of its moons; lunar volcanoes (thought then to relate to the origin of lunar craters) are shown in full eruption; the surface of Venus is illustrated as a partially frozen, dark world. Indeed, during the early decades of the 20th Century it was generally believed that Venus underwent synchronous rotation, with one hemisphere continuously pointing towards the Sun. Remarkably, even 28 years later, the *Conquest of Space* card set, issued by Beano Bubble Gum in 1956, shows several astronauts stepping out of their lander into a then quite plausible desert and cactus-strewn Cytherean panorama. It was not until the mid-1960s, barely a human generation ago, that radar observations first enumerated the slow, but non-synchronous, rotation of Venus — it is in that sense of card sets being published over an extended period of time that we begin to build-up a picture of how dramatically astronomy has developed over the past century. The card backs in *The Romance of the Heavens* series convey complex details on relative distances and sizes, and several cards attempt to describe such topics as star formation (introducing the Laplacian nebula hypothesis) and planetary nebulae (not identified then as an end-stage of stellar evolution, but simply described as "a cloud of luminous gas"). It seems reasonably clear that the designers of *The Romance of the Heavens* set out to instil a sense of wonder at the strange worlds and objects that pervade the cosmos. They invited the reader to imagine and marvel at the other worlds in our Solar System, and they encouraged the reader to ponder the very mystery of our origins.

In addition to the two issues just discussed, the only other astronomy-related card sets to appear prior to 1950 were *Astronomers* (1906, Liebig — a set of cards dealing with historical figures), *Ancient Sundials* (1924, Fry and Sons), *Old Sundials* (1928, Wills), and *What the Stars Say* (1934, Millhoff and Co. — a series dealing with astrology). There is a gap of 24 years between the publication of *Those Pearls of Heaven* and the Liebig *Astronomy* series released in 1952. The latter set of six cards is certainly more contemporary in feel than *Those Pearls of Heaven*, and it introduces the reader to topics concerning the solar corona, the impact origin of lunar craters, the *canali* of Mars, Halley's Comet, the Andromeda Galaxy, and the 2·5-m Mount Wilson telescope. The Liebig *Astronomy* cards are stylishly produced in full colour and are visually compelling. Artistic rather than photographic, the cards interestingly portray a still-uncertain (by contemporary standards) Solar System. Mars, for example, is painted complete with canal-like markings, and the Moon's surface features are not accurately depicted. Indeed, the mysterious canals of Mars offer an interesting example of a long-running astronomical myth being perpetuated in popular culture long after it had been abandoned by main-stream science. In *Those Pearls of Heaven* (1914) the Mars-related card carries the caption "are these Waterways or merely deceptive appearances?" with the reader being left to ponder the consequences one way or another. In *The Romance of the Heavens* (1928) series the panorama of Mars shows linear canals described as "artificial waterways". The 1967 *Space* card set issued by Anglo-Confectionery shows a canal-crossed Mars with a string of craters near the night-side terminator — the existence of Martian craters being first revealed in 1965 through *Mariner 4* spacecraft observations. The 1969 issue of *The Space Age*, by Brooke Bond Tea, contains the first Mars-related image in which the planet is depicted with a barren and cratered surface. Remarkably, we additionally note, the *Race into Space* card set issued by Brooke Bond Tea in 1971 has a card describing a NASA planned mission to Mars in which six astronauts set out to complete a sample-return excursion to the planet, the mission landing date being given as 1982 August 9! The 2001 *Solar System* card set issued by Rockwell Cards includes a composite image of Mars made from *Viking* spacecraft observations — the Martian surface in that picture is quite definitely canal-less, but the image does reveal the incredible *Valles Marineris* canyon. With that latter image we see myth and speculation very definitely replaced by geological marvel. In terms of a real astronomical phenomenon, however, perhaps the *Meteorite* series released by Nestlé in 2001 is the most authentic. Each of the 20 cards in that particular set housed a plastic cell containing shavings from an actual iron meteorite — the associated "space fact" on each card, however, was completely unrelated to the meteorite sample.

With the launch of *Sputnik-1* in 1957 and the dawning of the space age[1], a great upsurge in astronomy trade-card production took place. In the ten years following the launch of *Sputnik-1* some 27 card sets related to astronomy and space exploration were issued, one-and-a-half times the total of all such card sets (18) published in the 55 years prior to the launch date. There was also a dramatic change in the astronomy component of card sets being produced towards the close of the 1950s. In issues such as *The Space Age*, a 50-card set distributed by Brooke Bond and Co. Ltd., we find, for example, that the astronomy themes are secondary to those describing the new instruments of space exploration. In similar vein, the series *Into Space* (by Musgrave Brothers Ltd., 1961) is largely concerned with human space exploration, and its themes looked presciently to the future, with cards depicting Earth-orbiting communication satellites, the construction of a space station complete with servicing shuttle craft, and a human-piloted lander descending towards the Moon's surface. As we move further into the modern era, card sets such as *Exploring our Solar System* (Sanitarium Health Food Company, 1982) and the *Solar System* (Rockwell Cards, 2001) the reader is introduced to a new level of visual realism. These more-contemporary card sets use high-quality colour reproductions of images obtained from specialized spacecraft (*e.g.*, the *Viking Landers*, the *Voyager* spacecraft, and the *Magellan* orbiter) as well as the *Hubble Space Telescope*. The images are *real* and *crisp* leaving the reader in no doubt that they are viewing alien worlds as they would truly appear if seen *in situ*. The mental transportation in these latter cards is now actual rather than imaginative, the role of the reader being shifted towards one in which data is passively assimilated, rather than one in which the scene is imaginatively constructed.

The development of a theme

In an attempt to chart the development of what constitutes popular astronomy, as portrayed by cigarette and trade cards, we have reviewed the

TABLE I

Year	*Series title and allied company*	*N*	*CT*	*ST*	*GN*	*SS*	*IN*	*SC*
1903	*Constellations*, Liebig.	6	6	0	0	0	0	0
1912	*Constellations*, Cadbury Ltd.	12	12	0	0	0	0	0
1914	*Those Pearls of Heaven*, John Player & Sons.	25	13	2	0	10	0	0
1928	*The Romance of the Heavens*, W. D. & H. O. Wills.	50	6	3	2	37	2	0
1952	*Astronomy*, Liebig.	6	0	0	1	4	1	0
1956	*Out into Space*, Brooke Bond Tea.	50	25	0	1	21	3	0
1956	*Conquest of Space*, Beano Ltd.	50	0	0	0	5	0	45
1960	*Planets and Fixed Stars*, Chocolate Tobler Ltd.	12	1	1	0	8	2	0
1963	*Wonders of the Heavens*, Tonibell ice cream.	25	0	0	3	19	1	1
1967	*Space*, Anglo-Confectionery Ltd.	66	0	0	0	13	0	53
1969	*The Space Age*, Brooke Bond Tea.	48	0	3	3	19	7	16
1970	*Astronomy* (2 sets), Liebig.	12	0	0	0	12	0	0
1982	*Exploring the Solar System*, Sanitarium Foods.	20	0	1	0	15	0	4
1983	*Exploration of Space*, John Player & Sons.	32	0	0	0	10	1	21
1986	*Halley's Comet*, Caltex Oil.	6	4	0	0	1	1	0
2001	*Solar System*, Rockwell Cards.	10	0	0	0	10	0	0
2001	*Meteorite*, Nestlé.	20	0	0	0	20	0	0

A selective survey of astronomical theme development. Columns one and two give the year of publication, the series title, and the distributing company. The key to the remaining headings is as follows: *N* refers to the number of cards in the set; *CT* indicates the number of cards relating to the constellations and/or sky maps; *ST* is the number of cards relating to the stars and stellar structure; *GN* gives the number of cards relating to galactic structure and the interstellar medium; *SS* is the number of cards related to the Solar System, including the Sun; *IN* relates to the number of cards concerning instrumentation; and *SC* denotes the number of cards relating to satellite and spacecraft engineering.

catalogues of card sets published during the 20th Century[5–7], and divided the card titles into six broad categories. Table I shows the breakdown of results against the year of publication. A few broad trends appear to be present in the data. Prior to the mid-1950s the bulk (50% or more) of cards, in any astronomy set, were concerned with the description of the constellations, the planets and smaller objects in the Solar System. Post mid-1950s, the astronomy cards become more narrowly focussed on the major planets and the spacecraft and instruments used to study them. Remarkably little, however, is said within the modern card sets on the structure, origin, and evolution of stars and/or galaxies — indeed, the astronomical topics that have arguably undergone the greatest amount of theoretical and observational development since the first card sets were published in the early 1900s. Fundamental discoveries relating to the existence of an expanding Universe full of individual galaxies, the interstellar medium, the structure of stars, supernovae, and nucleosynthesis are conspicuous by their very absence in the modern card sets. Interestingly, those topics are very often the subject matter of commemorative stamps — those other highly popular objects that people like to collect[11,12]. In the modern era, however, it would appear from trade-card publications that popular astronomy constitutes the study of the major planets within the Solar System (*i.e.*, objects that are essentially tangible to human experience) and the spacecraft used to study them. Gone, it would seem, is any apparent sense of universal wonder in the modern card sets. They deal with the hard facts derived from complex and extensive research and engineering programmes, and they offer the viewer little scope for imaginative transport or intellectual play. One has simply to learn about, not necessarily marvel at, the subjects described on modern astronomy cards.

Discussion

Our collective understanding of what constitutes astronomy and the make-up of the Universe around us has undergone tremendous change since the early 20th Century. Astronomy trade and cigarette cards have mirrored part of that change and provide us with a window, allbeit with a limited vista, through which the popularization of astronomy may be traced. Inasmuch as the physical content of astronomy having changed, so too has the manner in which the subject is portrayed. The early card titles invoke participation and wonder: *Those Pearls of Heaven*, *The Romance of the Heavens*, the very words suggest marvellous adventure; they suggest the discovery of shining jewels of knowledge, and they invite the reader to participate in a shared journey of discovery. The more contemporary card titles, in contrast, are seemingly harsh and dry: *Space*, *The Solar System*; these are titles that offer little sense of imaginative wonder, but they do convey a sense of scientific mastery. The modern card sets, in essence, are more matter of fact, and the reader is no longer required to be an inspired or joint explorer of the cosmos — rather, their role is reduced to that of the spectator and consumer of technical detail.

A picture paints a thousand words, and never was this more true than in the case of the early astronomy-card sets. As expressed by D. A. Hardy[13] and R. Miller[14] (both pioneering space artists) the early images of planetary landscapes had to portray both plausible and believable worlds. The landscapes had to be alien and yet sufficiently familiar that the viewer could imagine transportation to such a place. The detailed photographs used in more contemporary card sets tend to destroy this latter aspect of participation. A photograph shows the planetary world as it really is, and the role of the viewer is passive; they are simply required to 'take-in' the details, like a holiday snap shot, rather than participate in the imagined re-creation of the scene. Interestingly, the pivotal role of the artist in presenting a 'minds-eye' picture of plausible alien worlds has taken-on a new level of importance in very recent times with the discovery of exoplanets and the development of research interest in astrobiology. Today, however, it would also seem that the engagement of the public in such scientific exploration is being channelled through the impressive technology and the massive infrastructure behind the technology, rather than with the actual results being obtained. The public is well aware, for example, that scientists working at the *Large Hadron Collider* at CERN recently discovered the Higgs particle, but who amongst the lay public can actually explain what this discovery signifies?

Rauch[15] cuts to the very core of such issues when he comments upon the modern-day sensationalism that typically accompanies big-budget science programmes. Indeed, Rauch draws together a compelling analogy between the big-science programmes of today and the 'putting-on of a good show' required of the popularizing lecturers of yesteryear. Specifically he suggests, "what we now call big science retains this performance quality if only because it operates on a scale that is meant to astound, rather than engage, its audience". Christopher Horrocks[16] also reminds us that, "for although science infiltrates culture, it does not mean that it is necessarily understood. Exposure to science may lead only to a superficial … engagement at the level of the images or signifiers of science. Big Science's connection to everyday life is often matched by its disconnection from public understanding". During the later part of the 20th Century, for so it would seem, society has become the disengaged and docile observer of the machines that do the actual exploration. The greater public's interest has shifted away (perhaps necessarily because of the complexity of content) from that of an active participant to one engaged in simple data consumption. Any sense of a collective exploratory involvement, as was prevalent as recently as the Apollo lunar landings in the 1960s and 70s, has seemingly lapsed in modern times. This disconnect, however, need not be taken as a failure of science and/or scientists to communicate their research, but it is rather, one may argue[17], a sign of modern societal *distraction* — in the words of Stewart Brand[18], "civilization is revving itself into a pathologically short attention span". Yes, research scientists do have an obligation to present the results of their labours to the public, but it is equally as important that the public actually pays attention to what it is that is being conveyed.

One can perhaps take some solace in the recent rise of popular internet websites in which the public is actively invited to participate in data analysis — although in general the role of the participant is either to provide home-computer CPU time or to troll through massive visual data sets with an active pair of eyes. Again, however, it would appear that the public participation is essentially passive, with the viewer arranging data (admittedly a crucial job) rather than engaging with the data in an active investigative manner. As Marshall McLuhan warned us over half-a-century ago[19], the content of any medium is "the juicy piece of meat carried by the burger to distract the watchdog of the mind".

As we move beyond the close of the 20th Century, commercial trading cards are still with us, but their themes are now very much restricted to the topics of sporting, comic book, film, and music personalities. We should not necessarily lament what has been lost and what has gone before us, rather, as with the review presented by Barry Kent[1], we should enjoy the many "unanticipated pleasure[s]" that the cigarette and trade cards related to astronomy present. Indeed, such cards are part of the great mosaic of astronomical ephemera which encompasses historical leaflets, pamphlets, diaries, letters, stamps, and photographic reproductions.

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REVIEWS

John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy, by W. Orchiston (Springer, Heidelberg), 2017. Pp. 555, 24 × 16 cm. Price £112/$179 (hardbound; ISBN 978 3 319 44520 5).

John Tebbutt was born in Windsor, New South Wales, on 1834 May 25, the son of a local businessman, and after moving at the age of nine with his parents to a 250-acre tract of land on the eastern edge of town was to remain there for the rest of his life. His interest in astronomy appears to have been fired partly *via* his tutor and partly *via* the rector of the church in Windsor. Tebbutt nowhere mentions the Great Comet of 1843 so it may be assumed that his interest began after that. His observational activities began in 1853 with the appearance of a naked-eye comet in Orion that he observed with a small marine telescope. In 1854 he wrote an account of a large group of sunspots for the *Sydney Morning Herald*, the first of many articles that he would write for the press in which he would both report his own discoveries and announce any upcoming astronomical events of interest.

Tebbutt had an extraordinary range of astronomical and other activities. Primarily he was interested in comets, and authored 162 papers in that field, although as the author points out he occasionally sent the same paper to more than one journal. Amongst his discoveries were the great comets of 1861 (C/1861 J1) and 1881 (C/1881 K1). His remaining output was spread amongst Jovian-satellite photometry, planets, occultation of stars, variable stars, double stars, and minor planets. In addition, he kept meteorological records and maintained a time-keeping facility.

Although he was clearly a highly motivated individual observer, Tebbutt made a concerted attempt at organizing an Australian attack on hunting for new comets by his formation of the Australian Comet Corps in 1882, which happened to coincide with the discovery of three bright comets and preparations for the Venus transit in December of that year. One of the comets (C/1882 R2) actually appeared in the allotted zone of Corps member A. B. Biggs but was found by E. E. Barnard who was looking outside his own allocated area. The Corps failed to find any new comets and soon folded, but it was the first formal national scientific group of any kind in Australia.

Tebbutt does not come over as a completely sympathetic character, which may well be a result of a lifetime of observing alone. He did not suffer fools gladly and could be arrogant in his relations with others. One gets the feeling that he could certainly be cantankerous, and in his dealings with Henry Chamberlain Russell, the Director of Sydney Observatory, this reviewer's sympathy is to some extent on the side of Russell, who was under public pressure to supply meteorological data whilst under private pressure from Tebbutt and others to do more astronomical research. Tebbutt was actually asked to take the Directorship of Sydney Observatory on two occasions before the appointment of Russell but turned each offer down.

This is clearly a work that has been a long time in preparation. The author himself owns up to a lifelong interest in the life of Tebbutt and the Foreword is by Patrick Moore who died in 2012. The task that the author set himself can be easily appreciated by noting the number of references that he has consulted. A rough count shows about 2200 references covering over 70 pages. Some

300 references refer to the feud between Tebbutt and Russell, which takes up Chapters 11 and 12. All of the letters received by Tebbutt were carefully kept, and it appears that Tebbutt himself took copies of all his outward-going correspondence, but very little, if any, of it survives because of a fire at his home in 1897.

Dr. Orchiston leaves us in little doubt that Tebbutt was a man of immense skill, dedication, and productivity, and his efforts were appreciated by a whole range of professional astronomers worldwide such as W. W. Campbell at Lick, and H. H. Turner and F. W. Dyson in Britain who made the effort to go out to Windsor to see Tebbutt the year before he died. The Royal Astronomical Society awarded Tebbutt the Jackson-Gwilt Medal and Gift in 1904. The value of this book is that it not only gives a thorough description of Tebbutt, his life, and his work, but it also maps out the history of observational astronomy in Australia (including 44 potted biographies of contemporary astronomical figures) and highlights the vital part that Tebbutt had in it. — ROBERT ARGYLE.

Women Spacefarers, by U. Cavallaro (Springer, Heidelberg), 2017. Pp. 403, 24 × 17 cm. Price £24/\$44·99 (paperback; ISBN 978 3 319 34047 0).

Books on space travel are not rare nowadays, and neither are stamps that depict individual astronauts or space-vehicle crews, but this book by an 'astro-philatelist' and space-travel enthusiast brings the two together in a rather intelligent way. Commencing with the first female in space (the Russian Valentina Tereshkova), *Women Spacefarers* is a detailed *Who's Who?* guide to the first 60 women (and just the women) who have taken part in a space mission of some kind, whether to orbit the Earth, visit the *International Space Station* (*ISS*), or work on it for a length of time. Each entry occupies between two and eight pages. Listed in chronological order of the first launch date, each account summarizes the individual's background, motivation, and take-home message, rather than the technologies of the training or the challenges of living in microgravity. Those chapters are preceded by a detailed Preface that recounts the full history of the roles of women within both the Russian and the American space-flight organizations, and the added burdens laid on them by political propaganda.

That emphasis on the personal story of the individual sets this book a little aside from other histories of space travel. Often including quotations from statements or interviews, it dwells on what brought those women into the world of space travel, where their most effective mentoring and support came from, and — especially — what biasses or extra hurdles they had to overcome as women, adding juicy tidbits to the history of 'Equal Opportunity'. (One learns now that the UK, through the BNSC, did not support a manned space programme, despite unchecked wide-spread belief to the contrary. Was it only a coincidence that the first Briton in space was a woman?) The various records which each woman achieved within the context of space travel come in for special mention. Many of the women were very conscious of the encouragement that their achievements could and did offer to girls and younger women, and quite a few voiced a strong desire to become effective role models.

As with any encyclopaedia or *Who's Who?*, each entry is intended to stand alone and, since NASA-speak is heavily prevalent in all things to do with space travel, the same acronyms appear frequently, and even ones like *ISS* are spelled out in full at every occurrence. A short list of "References" that concludes each chapter should be renamed "Further Reading", as there are no actual citations in the text. The date of the *Challenger* disaster, which affected the subsequent flight histories of a number of astronauts as well as the two women who sadly perished then, is given in one place four days later than in all the other places, as if embedded within material copied *en bloc* from different sources. But these are minor grumbles. Though not innocent of typos or the occasional omission of a word, the book is well written, the amount and depth of detail is constant, and each chapter is tastefully illustrated with at least one astronautical stamp (from whichever country). The book certainly deserves a place in libraries of history of science, popular science, and gender studies, or in one's private collection; there is ample high-quality reading for everyone. — ELIZABETH GRIFFIN.

Star Ark: A Living, Self-Sustaining Spaceship, edited by R. Armstrong (Springer, Heidelberg), 2017. Pp. 492, 24 × 16·5 cm. Price £29·99/$39·99 (paperback; ISBN 978 3 319 31040 4).

This book is ostensibly built around what the editor calls the 'Interstellar Question' — an examination of the idea that humanity may one day travel to other stars. I say 'ostensibly' because, although this is certainly an underlying theme, no attempt is really made to pose the discussion as a question or to answer it. Certainly, there is no detailed discussion of the technical questions surrounding interstellar propulsion concepts (I recommend that readers interested in those aspects instead consult Kelvin Long's *Deep Space Propulsion: A Roadmap to Interstellar Flight* (Springer, 2012)). Nor, despite the book's sub-title, does it present a unified design study for a 'self-sustaining spaceship', although the importance of creating self-sustainable ecosystems in space is a recurring theme. What the book does do is discuss in some depth a wide range of human, societal, and environmental factors that will be important if humans are ever to venture deep into space.

The structure of the book is somewhat unusual: the first half is written by Rachel Armstrong, Professor of Experimental Architecture at the University of Newcastle, while the second part consists of an eclectic anthology of short essays by some two dozen additional authors. The reader is informed at the beginning that this structure is deliberate and that the book "should be read as an experiment into different modes of thinking". The eclectic range of subject matter necessarily implies that any given reader will find some chapters to be of greater interest than others, and this does make it quite a difficult book to read (and indeed to review).

It is probably fair to say that the book isn't really aimed at professional astronomers, such as are likely to be reading a review in *The Observatory*. Indeed, there are several minor astrophysical misunderstandings (*e.g.*, relating to stellar evolution on pp. 21 and 360), and scientifically meaningless statements (*e.g.*, p. 401: "light is a truly mysterious phenomenon — the essence of life"), that are likely to irritate readers of this *Magazine*. That said, I did find some of the sections to be of great interest, and I'm glad that I read them. I highlight especially Chapter 11 ('Space ecology', including an interesting discussion on the ethics and practicality of directed panspermia), Chapter 13 ('Space bodies', including interesting discussions on artificially enhancing, or otherwise adapting, the human body to cope better with deep-space travel), and Chapter 14.2 ('The dream that drives the action: toward a functional cosmology for interstellar travel', which makes a powerful case for developing a unifying scientific worldview to underpin the ethics and motivations of future interstellar exploration). Most of the chapters are well-referenced, giving readers the opportunity to follow-up points of interest.

All in all (but inevitably given its self-proclaimed eclecticism), I found *Star Ark* to be a bit of a mixed bag, with some parts mundane, or even banal, and others really fascinating. Other readers are likely to have similar experiences, albeit with completely different judgements regarding particular chapters. However, that having been said, I do think that Professor Armstrong is to be congratulated on weaving together many different perspectives on the far future of space exploration — in an age of ultra-specialisation, that in itself is stimulating and refreshing. — IAN CRAWFORD.

Time Machine Tales: The Science Fiction Adventures and Philosophical Puzzles of Time Travel, by P. J. Nahin (Springer, Heidelberg), 2017. Pp. 433, 23·5 × 13·5 cm. Price £15/$19·99 (paperback, ISBN 978 3 319 48862 2).

I immediately wanted to read this book as soon as I became aware of it because I own the author's *Time Machines*, one of the few books I have read more than once. I own the first edition[1] of the latter and know that there is a second, so, despite the slightly different title, I wondered whether this was the third edition. As the author explains in 'Some first words'*, yes and no. It is, in the sense that it updates his previous book, primarily by including more discussion of the philosophical literature. It is not, in that the newest book is less technical, leaving out the extensive technical notes of the two editions of *Time Machines*. The author is an emeritus professor of electrical engineering at the University of New Hampshire. Almost 20 other books, from *Oliver Heaviside* to *The Science of Radio* to *Inside Interesting Integrals*, give some idea of his interests.

The main chapters comprise a broad overview of time travel, a discussion of space-time, basic physics of time travel, time-travel paradoxes, communication with the past, and more advanced topics concerning the physics of time travel. Two things are immediately apparent: first, there is no debate about *whether* time travel can exist. The author assumes that General Relativity is correct, and GR permits time travel. Second, the author has an encyclopaedic knowledge of time travel as discussed by physicists, philosophers, and science-fiction writers.

Many quotations show that he knows the works, not just the references. Very often a topic was first discussed in science fiction then later by physicists or philosophers. I was surprised by the popularity of time-travel discussions among philosophers, published by the major journals in the field. Although some are concerned with *why* a time traveller would want to kill his grandfather, most address the same themes as in the science-fiction and physics literature, though of course from a somewhat different perspective.

There are a few illustrations, mostly line-drawing diagrams, throughout the text. These are highly reminiscent of those in Harrison's classic textbook[2], as are the few pages with a handful of topics 'For further discussion' at the end of each chapter. The production is good and, though not perfect, the editing as well: there are almost no typos and only a few (though often repeated) mistakes

*The structure of the book is somewhat unorthodox. The table of contents does not appear until p. *xlvii* and lists nothing which comes before it nor the 'About the author' which comes immediately after it. In addition to the usual front matter, it is preceded by a frontispiece featuring a photograph of Gödel and Einstein and one of H. G. Wells as well as some text. That is followed by 'Some first words' covering 14 pages, 2 pages of 'Acknowledgements', and a 19-page 'Introduction'. After the six main chapters come three appendices (the first two are short stories by the author, the third is a computer code), epilogue, glossary, and index.

of style. Unfortunately, when footnotes themselves are referred to, those in the first part of the book often are given the wrong numbers; that is probably due to some late-phase restructuring without updating the footnotes (which start again at 1 with each chapter). There are no obvious mistakes, other than the claim (repeated by many authors) that John Wheeler coined the term 'black hole' (he did popularize it, though)[3]. There are almost a thousand footnotes, containing clarification of the main text, references, or both — fortunately at the bottom of the pages, not at the end of the book. The only real goof concerns the computer code in Appendix 3: the text width is slightly less than the fixed-length lines of the code, causing most of the non-inline comments to wrap.

There isn't much astronomy here, though the fact that a Wells-style time machine can't work and instead one must always move through space in order to move non-trivially through time means that Relativity (both Special and General) is essential, which of course implies some overlap with astrophysics and cosmology. Nevertheless, I am sure that many readers of this *Magazine* will enjoy the book as much as I have, *i.e.*, considerably. The extensive references also make it a good starting point for more-detailed investigations, especially since few readers will be even roughly equally familiar with the physics, philosophy, and science-fiction literature concerning time travel, and few if any will have Nahin's command of even one of those areas, much less all three. — PHILLIP HELBIG.

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Ripples in Spacetime, by G. Schilling (Harvard University Press, London), 2017. Pp. 340, 20·5 × 14 cm. Price £23·95/$29·95 (hardbound; ISBN 978 0 674 97166 0).

What?! You still haven't written your book on the search for gravitational waves and the *LIGO* discoveries? Well, get a move on! The field is becoming very crowded. Competitors are Janna Levin's *Black Hole Blues and Other Songs from Outer Space* (2016), a revision of Marcia Bartusiak's *Einstein's Unfinished Symphony*, now subtitled *The Story of a Gamble, Two Black Holes, and a New Age of Astronomy* (2017), and Harry Collins has followed *Gravity's Shadow* (2004) and *Gravity's Ghost* (2014) with *Gravity's Kiss: The Detection of Gravitational Waves* (2017). Even V. Trimble has had her say in the now open-access *EPJH*, **42**, 261, 2017: "Wired by Weber: The story of the first searcher and searches for gravitational waves" — unlike the others, not cited by Schilling.

Where does the present volume fit among the others? Govert Schilling is an astronomy journalist and writer, as is Bartusiak (though she has also covered other subjects); Collins is a sociologist, and Levin a practising physicist. Each of the volumes has strengths, but also errors and omissions, different kinds in each. *Ripples* does a good job of explaining the contributions of Karsten Danzmann (Hanover) to the combined technologies of *LIGO*, *GEO600*, and *VIRGO*. Schilling makes clear that galactic redshifts are merely "like" Doppler shifts, and that the right use of the phrase Big Bang is to label the hot, dense, early state of the Universe, not the instant $t = 0$, and he reassures the reader that "the" binary pulsar PSR B1913+16 is still being monitored (and has still not shown anything inconsistent with General Relativity, even in minute detail).

On the 'political' side he rides lightly over the departures of Ron Drever and Rochus Vogt from the *LIGO* project. Collins (2004) has all the grimth [as 'warmth' is to 'warm', 'grimth' is to 'grim', at least in VT's lexicon. — Ed.] and is reasonably firm in saying that the field might still not exist had Joseph Weber not started looking for gravitational waves in 1965.

A most curious omission is that the author tells us, in connection with the 1919 solar-eclipse expedition that detected gravitational bending of starlight, that John Flamsteed was the first Astronomer Royal for England, but neglects to mention that the writer of his foreword, Martin Rees, is the current one. Also not noted is that Leopold Infeld (and even one living physicist) held to the view that gravitational radiation cannot carry energy and doesn't exist, long after Einstein had conceded or lost interest in the subject.

The 'oops' that bothered me most is Schilling's statement (repeated several times) that redshift tells us how long ago light (*etc.*) left a source, called the look-back time. Other relevant times are the age of Universe when the light left, and the age of the Universe now (the sum of the two previous). All three are dependent on your choice of cosmological model (Hubble's constant, and density in matter, radiation, and vacuum energy). The one thing redshift gives unambiguously is the ratio of the current scale parameter to that when the light was emitted, $a(\text{now})/a(\text{then}) = 1 + z$.

I naturally double-checked all the Weber and Trimble items, and I suppose I must have said that (never mind what!) at some time, since the author and I have chatted on a number of occasions, starting at least the year the Jim Peebles and Allan Sandage won the first Gruber Foundation Cosmology Prize*. But the caption to Fig. 4.1 says it shows Weber with one of his bar detectors in a vacuum tank. The quickest glance shows that the tank holds the disc detector meant to search for dipole gravitational waves, predicted by the Brans–Dicke scalar–tensor theory of gravity, in contrast to Einstein's purely tensor theory which admits only of quadrupole waves.

But to end on an up-note, we are told the name of the other party in the "too bad for the Good Lord" Einstein story (what he would have said if the eclipse data had not revealed his light deflection). It was Ilse Schneider, a graduate student. As for sad notes, the reader also learns of the deaths of Heinz Billing (2017 January 4 at age 102) and Ronald Drever (2017 March 7, considerably younger). — VIRGINIA TRIMBLE.

The Philosophy of Cosmology, edited by K. Chamcham, J. Silk, J. D. Barrow & S. Saunders (Cambridge University Press), 2017. Pp. 526, 25·5 × 18 cm. Price £49·99/$69·99 (hardback; ISBN 978 1 107 14539 9).

I've never seen *The Philosophy of Solid-State Physics*, *The Philosophy of Lasers*, or *The Philosophy of Electromagnetism*. *The Philosophy of Cosmology* doesn't sound nearly as strange as the other, hypothetical, titles. In the words of George Ellis, one of the contributors to this volume, "You cannot do physics or cosmology without an assumed philosophical basis."[1] As Malcolm Longair

*The 2016 one went to Ronald Drever, Kip Thorne, and Rainer Weiss of *LIGO*, who also that year won a Breakthrough, a Shaw, and a Kavli. The discovery announcement came after the deadline for nomination for 2016 physics Nobels (by 11 days), but by the time this appears, you will know who received the 2017 physics award.

pointed out[2], between 1963, when Peter Scheuer gave him a copy of Bondi's *Cosmology* textbook[3], and 1993, the number of facts in cosmology had grown from two-and-one-half to nine. A few decades ago, partly due to the dearth of observational data, the philosophy of cosmology was not an unusual subject, investigated by cosmologists rather than philosophers. Much of Bondi's book is concerned with it, and a leading cosmologist even had it in the title of a paper, 'A philosophy for Big Bang cosmology'[4]. Since 1963, and especially since 1993, cosmology has become a data-driven science, with a vastly larger number of facts. As a result, the broader, philosophical questions have been discussed less or not at all by most authors, though the tradition did survive, *e.g.*, in Harrison's classic textbook[5] and many contributions by Ellis.

This volume, based on a series of workshops and a conference, brings together contributions by cosmologists and philosophers. Twenty-five chapters of roughly equal length are collected into five parts of nearly equal length: 'Issues in the philosophy of cosmology', 'Structures in the Universe and the structure of modern cosmology', 'Foundations of cosmology: gravity and the quantum', 'Quantum foundations and quantum gravity', and 'Methodological and philosophical issues'. Some of the 30 authors are well known (not only) for their writings on the philosophy of cosmology, *e.g.*, Barnes, Barrow, Carr, Ellis, Rovelli; contributions range from the very philosophical, with little actual science, to reviews of cosmological topics having little if any philosophical content, though most are between those two extremes, discussing current scientific topics from a philosophical viewpoint, or *vice versa*. As a result, the book is something of a mixed bag, though in terms of subject matter, not quality; a somewhat shorter book without any of the non-philosophical chapters would have made it a better book. There is nothing wrong with the chapters I would leave out, but they aren't expected in a book with this title and the material is available elsewhere in similar form.

As expected, topics such as fine-tuning, the arrow of time, the anthropic principle, limits of knowledge, criteria for scientific testability, the role of observers, the multiverse, Boltzmann brains, the holographic principle, entropy, *etc.*, are covered. Although occasionally referring to one another, the chapters are largely self-contained. What has changed since the time of Bondi's textbook is the fact that our theories, philosophical and otherwise, are more tightly constrained by observational data. Again in the words of George Ellis, "Philosophy has to give way to observations."[6] Much of the book is rather technical; 'philosophy' should not be confused with armchair cosmology. Copious references make it a good starting point for those wishing to delve deeper. Perhaps surprising in the light of the fact that the Templeton Foundation played a significant role in making the book possible, almost all of the chapters have nothing to do with theology. An exception is the one by Don Page, who is not only religious but also an evangelical Christian, who believes "that the universe was created by a … personal God … who relates to it as His creation" who also may have created "new heavens and new earth for us after death". He states that at the beginning of his contribution, which includes rather technical details on the measure problem, methods of averaging, and so on, but also a syllogism with assumptions such as "Our universe could have had more pleasure". Unlike (perhaps) Anselm of Canterbury, however, even Page doesn't think that he has found "proof of the existence of God from universally accepted axioms". While only a small part of the book, and even though it is clear that not all authors agree on everything, I prefer a minimal consensus which would exclude such obviously non-scientific claims.

As is often the case with such multi-author collections, the style, especially of references, is not uniform. There are a few black-and-white illustrations; unfortunately, some are based on colour illustrations, which makes them less clear than they could be, and in some cases the text refers to specific colours in the figures. The book is well produced and reasonably well edited, though some contributions by those for whom English is not a native language could have been made more readable. A nine-page small-print index follows the main text.

I'm not sure who is the target readership. While some might read it cover to cover, the fact that the chapters are to a large extent self-sufficient means that this is not strictly necessary; many readers will probably use certain chapters as jumping-off points for deeper study, helped by the copious references. At the same time, the chapters are long enough to provide more than a cursory introduction to the topic at hand. Despite the fact that — or perhaps because — cosmology is now mainly a data-driven science, the philosophy of cosmology has become an active but not yet mature field; this book provides a good introduction. — PHILLIP HELBIG.

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(3) H. Bondi, *Cosmology, 2nd Edn.* (Cambridge University Press), 1960.
(4) W. H. McCrea, *Nature*, **228**, 21, 1970.
(5) E. R. Harrison, *Cosmology: The Science of the Universe, 2nd Edn.* (Cambridge University Press), 2000.
(6) Response to a question during Ellis' talk at the 27th Texas Symposium on Relativistic Astrophysics, Dallas, 2013 December 12.

The Lidov–Kozai Effect — Applications in Exoplanet Research and Dynamical Astronomy, by I. I. Shevchenko (Springer, Heidelberg), 2017. Pp. 194, 24 × 16 cm. Price £82/$129 (hardbound; ISBN 978 3 319 43520 6).

The *Lidov–Kozai Effect* is a detailed review book on the Lidov–Kozai mechanism and provides a few example applications in exoplanetary and stellar dynamics. The Lidov–Kozai effect refers to the dynamical evolution that takes place in a hierarchical three-body configuration, where a stable (inner) binary has a tighter orbital configuration than the orbit of their mutual centre of mass with a tertiary object. Gravitational perturbations from this distant companion can dramatically alter the inner binary's orbital configuration. In recent years this mechanism has proven useful in understanding various astrophysical systems from planetary and stellar to black holes, over a wide range of physical scales.

The book begins with reviewing the history of the field, specifically the breakthrough by Mikhail Lidov and Yoshihide Kozai. It proceeds by describing the details behind the secular double-averaging formalism and the classical results (Chapters 2 and 3). The book then continues to describe some of the more recent developments in the field, such as non-hierarchical systems, the effect near mean-motion resonances and higher-order approximations (Chapter 4). The last five Chapters (5–9) are devoted to applications from irregular satellites to triple stars (black holes are only briefly mentioned).

Overall the book provides a detailed review of the some of the new developments in the field. It presents the relevant equations and procedures (such as the double-averaging process, Chapter 3.2). Furthermore, it also gives a nice overview of the underlying physics, such as the origin of the resonance (Chapter 4.6).

I think that the book would have benefitted from re-ordering. For example, the description of the power-series approximation, which appears first in Chapter 4, could have appeared earlier as the classical results are based on the lowest level of approximation. Moreover, the discussion about the chaos in the system, which first appears at the end of Chapter 8, could have been discussed in the context of resonances, as the chaos arises from interacting resonances, and is not specific to planetary evolution. Furthermore, pairing the octupole-level of approximation with the 'stellar problem' (Chapter 4.4) is confusing since the consequences of expanding to the octupole-level are independent of the astrophysical problem, and was shown to have significant effects on various systems.

The book can be a good read for PhD students, postdocs, or any other researchers who are interested in entering the field. For those, I would suggest starting from Chapter 4 and then going back to Chapter 3. In general, this book could be very useful to the astrophysicist who is interested in learning about hierarchical three-body systems and getting a 'big picture' view of some possible applications of this mechanism in astrophysics. — SMADAR NAOZ.

Modern Elementary Particle Physics, 2nd Edition, by G. Kane (Cambridge University Press), 2017. Pp. 226, 25·5 × 19·5 cm. Price £44·99/$59·99 (hardbound; ISBN 978 1 107 16508 3).

The second edition of *Modern Elementary Particle Physics* is a comprehensive overview of the Standard Model and the main experimental results that led to that theory and confirmed its predictions. The first eight chapters cover all necessary introductory material, from notations used in the particle physics, introduction of Lagrangians and fields, gauge invariance, non-Abelian theories, spontaneous symmetry breaking, Higgs mechanics, *etc*. That part should be accessible and supplemental for students who already are taking particle-physics or gauge-theory courses. Kane has decided to discuss the equations associated with each of the topics rather than show how to derive them, with only a few exceptions, but that might be what is different from other textbooks.

In Chapters 9–21 many aspects and experimental predictions from the Standard Model and results from various experiments are presented. The experimental methods, accelerators, and detectors are described only briefly with the information necessary for the rest of the textbook. The discovery and production channels of all elementary particles, fermions, and bosons including the Higgs, are discussed. Colour is introduced together with quarks and gluons and the experimental observation of jets and quantum numbers of mesons and baryons. That is followed by a description of ground-state mesons and baryons and their decays. Surprisingly, the mixing of quarks and the CKM matrix is introduced a few chapters later, and is followed by the discussion of CP violation in the quark sector. One of the last chapters of this part describes coupling constants and their high momentum-transfer dependence finalized with visualisation of the changes of the running coupling constants for all Standard Model forces.

What may be most distinguishable about this textbook is the discussion of what is beyond the Standard Model physics in Chapters 23–26. Among many topics, it covers unifications of quarks and leptons, unification of forces, proton decay, neutrino masses, dark matter, and supersymmetry. Those topics are covered only briefly but sufficiently for general undergraduate students. Those especially interested in those topics will need to find a different textbook.

In the final part, several appendices describe basics of group theory, relativistic kinematics, and scattering amplitudes and cross section.

In summary, *Modern Elementary Particle Physics* is an approachable textbook for advanced undergraduates and good supplemental material for a particle-physics course. — JAREK NOWAK.

High Energy Astrophysical Techniques, by R. Poggiani (Springer, Heidelberg), 2017. Pp. 163, 24 × 16 cm. Price £57·99/$89·99 (hardbound; ISBN 978 3 319 44728 5).

Rosa Poggiani of the University of Pisa is part of the *VIRGO*/*LIGO* gravitational-wave-detection collaboration and has been teaching observational astrophysics for some years. Her 2006 text covered optical, infrared, and radio techniques and technology. Here she moves on to ultraviolet, X-ray, and γ-ray photons, cosmic rays, neutrinos, gravitational waves, dark energy, and dark matter. This is a lot to cover in 160 pages (plus index), and, yes, it is sketchy in several ways. The author gives us many equations, but almost no numbers. Units when indicated are the hodge-podge we all have invented over the decades, so the flux density from the Crab Nebula is said to be (Table 11.1) 1000 millicrabs, whether or not it is fading; and the Molière radius* of air at sea level is 8·83 g cm^{-2}.

The volume is really not suitable for self-instruction. Every chapter has a couple of so-called problems, but nearly all are of the form: 'Discuss the direct methods for dark-matter search' (16.1). 'Discuss the differences between the telescopes for soft X-rays and hard X-rays' (11.2). 'Discuss the problems related to the operation of gas-ionization detectors in space' (5.2). 'Discuss the mechanisms of energy loss for particles and their behaviour as a function of energy' (2.1), and so forth. Each could, of course, lead to an interesting term paper. And the very last one is 'discuss the techniques of data analysis in gravitational-wave astronomy', with plots of strain *versus* time for the GW150914 event given near the end of the text … . A version for self-instruction would have many problems per chapter in which the student-reader calculates things, starting either with an observed number for something and deducing the properties of the source or starting with source properties and calculating what sorts of detectors (*etc.*) would be needed to find fainter, more-distant ones or more detail about known sources.

Each chapter has a few references, nearly all to other texts (many from the same publisher) and data compilations. Lots of specific observatories, missions, surveys, projects and so forth appear, most with reference to their web sites (whose half-lives one hopes will be long). Only Chapter 3 (interaction of particles and radiation) picks up much history — the 1952 and 1954 texts on particles by Bruno Rossi and on quantum radiation by Walter Heitler, and the original 1966 papers by Greisen and by Zatsepin & Kuzmin on 'Their Effect' (the upper limit to the energy spectrum of cosmic rays).

*About 95% of the energy of a shower due to a very-high-energy photon is contained within a cylinder with a radius of two Molière radii.

Curiously, nuclear emulsions for particle detection appear only as "historical", though they are currently being used by Japanese volcanologists as muon detectors to find magma chambers under potentially active volcanoes.

The author — who dedicates the book to her mother, Anna, who did not live to see it published — clearly knows an enormous amount about observational (if you are an astronomer) or experimental (if you are a physicist) high-energy astrophysics. She could have written a text that would permit either a reader to learn alone or a much-less-knowledgeable instructor to guide students through the subject, but this is not that book. And it would have had to be two or three times the present length, plus, I suppose, two or three times the present price. Of course, if you actually purchase the volume, my review copy will have added about 30¢ to the price you paid. — VIRGINIA TRIMBLE.

Astrochemistry: From the Big Bang to the Present Day, by C. Vallance (World Scientific, Singapore), 2017. Pp. 201, 23 × 15 cm. Price £37 (paperback; ISBN 978 1 78634 037 5).

This book arose from a course given to chemistry students, but could appeal to astronomers interested in interstellar and circumstellar matter who would like to know more about the processes in them from a chemist's perspective in a modern textbook. The core of the book covers interstellar chemistry and laboratory-based astrochemistry, both theory and experiment. Before we reach those, we have chapters surveying the measurement and origin of the chemical elements. Unfortunately, they get off to a shaky start: the absorption lines in the solar spectrum, nicely shown in the first of many excellent illustrations, are described as emission lines! Each chapter concludes with essay questions and numerical problems, which look a very useful part of the instruction. One of the problems at the end of Chapter 1 relates to the measurement of Jupiter's rotation from the Doppler (for some reason printed as Döppler throughout) shifts of Hα lines — but these are called Lyman α lines in the text and figure.

The author is careful to point up the differences between laboratory and interstellar chemistry: given the low density of the ISM, the chemistry is better considered in terms of individual collisions rather than bulk chemical kinetics. Different types of reaction and the significance of cosmic rays are well covered. This would have been a good place to direct the reader to the survey of the molecular astronomy by Tielens (*Rev. Mod. Phys.*, **85**, 1021, 2013). After discussion of energy levels and transition frequencies, there is substantial coverage of collision dynamics, leading on to introduction of the concept of the potential-energy surface. I found these sections to be well organized and — for someone who hadn't studied chemistry for decades — easy to follow. Different types of reaction are discussed, together with examples. A wide variety of experimental techniques and apparatus are introduced, but I was puzzled by the footnote that "Heterodyne detection shifts the detected signal to higher frequencies by mixing it with a carrier frequency, thereby improving the signal-to-noise ratio of the measurement". Although astronomers may never use the apparatus described, it is worth knowing how the laboratory data that they use are determined.

Following on, the formation of the Solar System and evolution of the Earth are surveyed, covering a lot of ground well. The statement regarding moons having constant directions of rotation about their planets should have been qualified by a footnote to the effect that many of the moons about the giant planets have irregular, often retrograde and/or inclined, orbits — but as a result of capture by their host planets after formation of the Solar System.

Overall, I found this book very informative and clearly written. Production, illustrations, and referencing are good and the questions at the end of each chapter are valuable. The book is also welcome in another context. Just as atomic spectroscopy is no longer of great interest to physicists, so chemical processes in the extreme conditions of the ISM may not be at the core of chemistry research. Therefore the introduction of the next generation of chemists to the excitement — the author includes origin of life — and challenges of chemistry in the ISM can only benefit astronomy. — PEREDUR WILLIAMS.

Multi-Object Spectroscopy in the Next Decade: Big Questions, Large Surveys, and Wide Fields (ASP Conference Series, Vol. 507), edited by I. Skillen, M. Balcells & S. C. Trager (Astronomical Society of the Pacific, San Francisco), 2016. Pp. 476, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 898 5).

Thirty-five years ago, when David Carter, Peter Gray, John Dawe and I began experimenting with multi-fibre spectroscopy on the *AAT* and *UKST*, we were confident that this radical new technique would be astronomy's silver bullet. The fine volume now under review is living proof that we were right — almost. What we lacked was a knowledge of exactly what silver bullet would be required by the time the technology had fully matured. In those days of perforated field-plates and glued-on fibres, cosmology was king, and we all believed that was where the long-term future lay*.

A glance through the seventy or so contributions in this book shows how the technique has, indeed, revolutionized our science — and how it will continue to do so. It is a marvellous advertisement for the capabilities of multi-object spectroscopy in solving many of astronomy's outstanding problems. Yes, the extragalactic Universe was first to succumb to the deluge of data it provided (rather before the technology had fully matured, as it turned out). But the real surprise is in the breadth of research that is currently being addressed. The book's four main science sections tell it like it is: 'Galactic structure and archaeology'; 'Star formation and evolution'; 'Galaxy evolution'; and 'Cosmology'. Remarkably, the last one has the fewest papers.

While the conference in which these contributions were presented took place in 2015, the book still provides an excellent snapshot of the state of the art in multi-object spectroscopy. Not to mention a warm glow of satisfaction for those of us who were in at the beginning — even if we didn't get it quite right. — FRED WATSON.

The B[e] Phenomenon: Forty Years of Studies (ASP Conference Series, Vol. 508), edited by A. Miroshnichenko, S. Zharikov, D. Korčáková & M. Wolf (Astronomical Society of the Pacific, San Francisco), 2017. Pp. 417, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 900 5).

The B[e] phenomenon was discovered nearly 120 years ago by the indefatigable Dundonian spectroscopist, Williamina Fleming. One might, therefore, be forgiven for assuming that astronomers could by now explain why some B stars show forbidden lines in emission. However, to quote from the wrap-up talk in these conference proceedings, "… research has reached a critical moment at which to take stock of whether we even know what we're talking about". Indeed, the field has taken many new directions.

*Although John Dawe and I did quietly aspire to large-scale stellar spectroscopy.

There are definitions of the B[e] phenomenon, there are theoretical models, and spectroscopic and photometric time series, but the challenge appears to be that the phenomenon is shared by many classes of star, from pre-main sequence, through massive stars and symbiotic binaries, to post-asymptotic-giant-branch objects. The common feature appears to be a disc (or maybe a ring?), but identifying a physical structure supported by such diverse central stars to produce common spectral characteristics is a challenge. These proceedings lead the student or informed onlooker through a rich variety of potential solutions and supporting evidence. Whether the challenge is compounded or simplified by the discussion of parallel questions concerning Be stars (no brackets) depends on your standpoint. Naturally (and perhaps confusingly), these proceedings draw heavily on analyses of both phenomena.

There is much of value to be learned; most of the contributions are ably written and informative. The formal structure is less obvious, so a random walk from paper to paper is as illuminating as a linear reading. Nevertheless, students of both Be and B[e] stars will find this text to be a useful companion. — Simon Jeffery.

20th European White Dwarf Workshop (ASP Conference Series, Vol. 509), edited by P.-E Tremblay, B. Gänsicke & T. Marsh (Astronomical Society of the Pacific, San Francisco), 2017. Pp. 579, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 902 9).

This proceedings volume from the 20th binennial European white-dwarf workshop represents the work of 244 authors, at least minus 96 of whom were at the meeting (assuming that the 148 participants included no non-authors). Egalitarian considerations have kept all the contributions at 4–8 pages, whether 15-minute talks or posters, and the scientific content is actually very impressive, though not very easy to access. As is now customary, there is no index except that of authors.

Two other frustrations: the participant list has only affiliations, no e-dresses. Some, but not all, appear on title pages of the contributions, so what if I should want to reach, say, young Dr. J. Farihi, co-author of two papers, but e-dresses none. And an increasingly serious issue is, I think, photographs of the participants. The group photo suggests that many of them were human, but not much beyond that. In addition, however, lots of pages have been given over to larger-scale colour pictures, mostly two per page, of folks eating and drinking, speaking, listening (rare), and looking at posters (very rare). No names are attached to any of these 124 individuals who might be recognizable (a few may appear twice, but how would I know?). Two things can be said — the few I know are older than they used to be; and, while many of the portrayed may feel they are better looking than their images here, just wait, you guys, until the 35th or 40th workshop — look back at the photos in this book, and be astounded by just how handsome, beautiful, and otherwise wonderful-looking you were in 2016.

Seriously, an index would have made the volume much more useful now, and names under the photographs would have made it much more useful for someone planning to attend the 21st workshop and wanting to recognize leaders in the field before getting close enough to read name tags (these, as usual, required a reading distance that is actionable in some cultures). Europe, by the way, is getting bigger. The 21st workshop is scheduled for 2018 in Austin, Texas, which never adhered to the EU, so there is no risk of a 'Texexit' in the interim.

Now about the science. First some new, or almost new, items: (*i*) in 2007 April, GW Librae experienced the largest detected outburst of any dwarf nova, which heated the WD surface above the range of the instability strip and stopped the pulsations (P. Chote *et al.*); (*ii*) the first six examples of a new category of variability, cool DA pulsators with outbursts up to 15% of unknown origin, which recur in days (all found with *Kepler* (K. J. Bell *et al.*)); (*iii*) new sorts of data on hydrogen and helium at very high temperature and pressure (appropriate to WD layers below the photosphere, both from Sandia National Labs — R. E. Falcon *et al.*, M. Schaeuble *et al.*); and (*iv*) a category of forbidden lines not previously seen for 'metals' (carbon in this case) in astrophysical sources. which are components of an allowed transition but with $\Delta l = 0$ or 2 (K. Werner *et al.* on PG1159 stars).

Updates on answers to older questions (or anyhow updates on the questions) also appear. (*i*) Double-degenerate progenitors for type-Ia supernovae? Still no pairs with total mass in excess of the Chandrasekhar limit and spiral-in times less than the Hubble time, though central stars of planetary nebulae may be a good place to look for them (T.C. Hillwig *et al.*), and S. Geier *et al.* have found a WD–sdB pair, CD –30° 11223, models of which suggest future mass transfer onto the C/O WD sufficient to ignite helium on its surface and then CO in the core, a double-detonation supernova. (*ii*) Many white dwarfs with polluted H atmospheres are indeed accreting planetary material from discs best seen in the infrared (A. Bonsor *et al.*), but levitation also occurs (T. Rauch *et al.*). (*iii*) The bottom of the WD cooling sequence is (suitably supported by models) an indicator of the age of a stellar population, more or less independent of main-sequence turnoff. Turnovers in N(L) have been reported for two different samples of nearby field stars. A. Darveau-Bernier *et al.* do not associate an age with theirs, while T. D. Oswalt reports a best fit of 10 Gyr for their sample of stars within 25 pc (still not, of course, complete). (*iv*) The globular cluster ω Cen is, say E. Garcia-Berro *et al.*, at least 13 Gyr old, which is sufficient for some of the stars of the helium-enriched second epoch of star formation to have left helium-core WDs from single stars without CBS mass transfer.

Two topics I had hoped for, but did not find. First, data showing the distribution of effective temperatures for DA (hydrogen spectra) and non-DA (mostly helium-spectra, DB) stars, to say whether there is still a gap for the non-DAs, and if so why. Second, a bit about chromospheres and X-ray emission for single magnetic white dwarfs. But A. Nitta *et al.* indicate that it is still uncertain whether the magnetic stars develop fields from their own surface convection or have preserved them from their days as massive Ap/Bp stars. The same paper reveals that magnetic WDs are generally more massive than the non-magnetic sort. This brings us to my very own King Charles' Head and Betsey Trotwood's donkeys, the average mass of white dwarfs as determined various ways, and how to reconcile them.

Once upon a time, there were astrometric masses for Sirius B (big), Procyon B (medium), and 40 Eri B (small). Modellers of WD atmospheres pulled out values of log g from colours and, later, line profiles, especially the group working with Volker Weidemann, and mostly in the medium–small range. And gravitational redshifts yielded larger values of M or M/R than implied by the log g (which gives you M/R^2). In 2016, K. Gesicki *et al.* found masses of 0·53 to 0·58 $M_\odot$ for central stars of planetary nebulae, though their primary focus was on post-AGB evolution speed. But it's all upward from then. Using various samples and methods, S. D. Kepler *et al.* put the mode at 0·624, and for P. E. Trembley *et al.* the mean is at 0·680 or 0·619 (medians and modes close to 0·6).

A. D. Romero *et al.* looked at pulsation frequencies for a few ZZ Ceti stars observed by *Kepler* and re-did the spectroscopic analysis as well for GD1212. Previously at 0·62 $M_\odot$, it now logs in at 0·815 $M_\odot$. Another ZZ Ceti (pulsating) star with data from China and Mexico lands at 0·98 $M_\odot$ (C. Li *et al.*), but GD 133 comes in at 0·63 $M_\odot$ (data from the same telescopes, J.-N. Fu *et al.*)

Even gravitational redshifts are creeping back into respectability. P. E. Falcon *et al.* note that their laboratory data on line profiles at high electron density will eventually be applicable. And coming back to the very first white dwarf, Sirius B, M. A. Barstow *et al.* have compared log g and gravitational z results with the astrometric number (allowing for all sorts of corrections to both that are at the level of 1–10 km/s). If we assume that the (Newtonian!) astrometric 1·016 $M_\odot$ is correct, then the log g version of 0·94 $M_\odot$ is too small and the gravitational redshift number, 1·10 $M_\odot$ is too big. They even cite Greenstein, Oke & Shipman for $z = 86 \pm 16$ km/s in 1971 (though nobody cites Greenstein/Trimble for the other 100 or so gravitational redshift measurements in the same time frame). The *HST* number is 79·9 observed, 89·6 ± 0·75 corrected. The variable DVs (DBV, V777 Her stars) have somewhat smaller log g than the ZZ Ceti stars, at least in this volume (V. Van Grootel).

Lots more is to be found in workshop 20, but you will have to bring your own prejudices to your own copy of the index-free proceedings to find what you want. — VIRGINA TRIMBLE.

To Measure the Sky: An Introduction to Observational Astronomy, 2nd Edition, by F. R. Chromey (Cambridge University Press), 2016. Pp. 461, 24·5 × 19 cm. Price £44·99/$79·99 (paperback; ISBN 978 1 107 57256 0).

This is an undergraduate astronomical textbook based on lectures given by the author at Vassar College. The author has sixteen years' experience of teaching and this is clearly reflected in the presentation. The book is plentifully illustrated in black and white, and each chapter is followed by a summary and exercises for the student.

The book is mostly confined to optical and infrared wavelengths, covering the nature and behaviour of radiation, both physical and geometric. The physics of telescopes and detectors is well balanced with the methods needed to extract useful data from the observations. The distinction between accuracy and precision is well explained and is followed by a discussion of the statistical methods which are often needed in discussing observational data. The most elementary data of astronomy are the positions and motions of stars. Early astronomers were able to name stars individually but as telescopes increased in size, and detectors became more sensitive, it was necessary to arrange them in catalogues, first on paper and now in computer files.

If optical design is confined to geometrical reflection and refraction from spherical surfaces, it is difficult to make perfect images of the night sky. The difficulties are explained and then followed by a discussion of the *Large Synoptic Survey Telescope*. Three mirrors and a three-element corrector lens provide a field of 3°·5. This is smaller than the field of current Schmidt telescopes which are limited in light-gathering power by the field stop. The Earth's atmosphere limits the performance of telescopes by the brightness of the night sky, so it necessary to place them on dark sites. Adaptive optics is now well established and can reduce the effects of atmospheric turbulence. In fact the 30-metre telescopes now under development would be white elephants without adaptive optics. Telescopes in space have their own problems and are orders of magnitude more expensive than those on the ground.

To understand astronomical detectors it is necessary to understand the interaction of light with matter. There is an exhaustive account of charge-coupled devices, and other panoramic detectors for the infrared. When matching a detector to a telescope it is essential to over-sample. The raw images must be cleared of the instrumental signature before useful data can be extracted. Numerical filters can enhance the appearance of images but do not add to the information. The information lies in the position and magnitude of stars on the image which are still affected by interstellar reddening and the Earth's atmosphere. Magnitudes were originally a rough aid to star identification but are now tightly defined in terms of recognized physical quantities.

Every star has a continuous spectrum and a line spectrum, both of which carry detailed information about the temperature, pressure, and chemical composition of the star's atmosphere. The material on spectroscopy is largely based on dispersive instruments with particular emphasis on gratings. Echelles with cross-dispersion are now widely used. Multi-object spectrographs are usually fed by optical fibres but there is the additional time overhead from placing the fibres in the telescope focal plane. Again it is difficult to exploit the light grasp of increasingly large telescopes. However, there have recently been significant improvements in grating fabrication which partially offset the drawbacks.

As well as the textbook material, the book finishes with ten useful appendices of tabular data. It can be recommended for its lucid style; occasionally the author betrays a wry sense of humour, such as the illustration of Fermat's principle in the way that Tarzan rescues Jane from crocodile-infested waters. The book would be especially useful at universities which have access to a well-equipped observatory. — DEREK JONES.

Stamping the Earth from Space, by Renato Dicati (Springer, Heidelberg), 2017. Pp. 429, 26 × 18 cm. Price £24/$44·99 (hardbound; ISBN 978 3 319 20755 1).

There are two basic aspects of space research, 'out' and 'down'. In the first we either travel out to the planets, moons, and minor bodies in the Solar System, or we peer out at the stars and galaxies in the Universe. In the second we look down at our planet Earth and its atmosphere, surface, and seas.

Likewise there are two basic aspects to the book under review. Firstly, it is a well written, authoritative review of geocentric space-age satellite achievements, the 'down' part of the space exploration mentioned above. We start with astronautics — human space missions from *Vostok*, *Soyuz*, *Salyut*, *Mir*, *Skylab*, and *Shuttle* ending with the *International Space Station*. Then follows a discussion of geodesy, gravitation, atmospheric chemistry, geocorona, airglow, ozone, ionospheric layers, aurorae, geomagnetism, Van Allen belts, magnetosphere, meteorology, weather, micrometeorites, multispectral surface imaging, cartography, resource mapping, oceanography, sea-surface temperatures, and topography.

The second aspect of the book is the philately. The science is illustrated using carefully selected philatelic items from the author's own collection (Dicati is one of the councillors of the Unione Stampa Filatelica Italiana). Over fifty percent of the page surface of this book is devoted to illustrations of postage stamps, first-day covers, special cancellations (many from launch sites, tracking stations, research laboratories, and mission-control facilities), miniature sheets, cachets (the illustrated designs on envelopes), maxim cards, and pre-printed-stamp envelopes and post cards. This rockets the book into the 'unusual' category. I have not come across a philatelic survey of the history of Earth exploration from space before. For anyone who has ever had a stamp album, or who has admired a postage stamp, this makes the book really special. The stamps are shown full size and in accurate colour reproduction. Well over 1100 stamps are illustrated. Satellites from *ADEOS* to *Zond* leap from every page. Nearly every country in the world is represented. I dragged out my old stamp collection. I nearly jumped in the car to visit my local stamp dealer. This book will probably cost me a fortune. It is marvellous. — DAVID W. HUGHES.

Earths of Distant Suns, by M. Carroll (Springer, Heidelberg), 2017. Pp. 234, 23·5 × 15·5 cm. Price £19/$24·99 (paperback; ISBN 978 3 319 43963 1).

Michael Carroll's very reasonably priced new book is an intelligent (and often amusing) essay about discovering the location of distant Earth-like worlds, the question of communication, and the possibility of interstellar travel. The text is enlivened with a large number of his own beautiful and evocative artworks. In a more expensive book these pictures would have been reproduced on a coffee-table scale upon glossy paper, so doing them better justice, but their excellence is sufficiently apparent here.

I was particularly interested in a diagram of those stars from which the Earth would be observed to transit the Sun (Figure 3.4). Of the 82 known systems discovered out to about 3000 light-years, only a handful exist within 100 ly. Carroll nicely makes the point with Figure 7.9 that the laws of physics may dictate similar engineering designs for radio telescopes throughout the Galaxy.

In one or two places more detail would have helped. We are told very vaguely that tholins are organic chemicals and that they may occur in Figure 6.11: this hardly informs the reader! The slight disadvantage for those wanting to know more is that only a few dozen references are given. Nevertheless, I think *Earths of Distant Suns* will gain a wide readership. — RICHARD MCKIM.

Life Through Time and Space, by Wallace Arthur (Harvard University Press), 2017. Pp. 277, 22 × 14·5 cm. Price £23·95 (hardbound; ISBN 978 0 674 97586 6).

When it comes to astrobiology there are two things we know. One is that life exists on Earth and has done so for about 3·8 billion years, about 85 % of our planet's existence. The second is that we have no certain proof that any other life-form has been to see us or has even tried to get in touch by radio. The later fact is rather worrying because we now estimate that the galaxy we live in contains about as many planets as stars. And a conservative estimate is that at least 0·5 % of these planets are Earth-like. As life broke out on Earth as soon as it could, we therefore confidently expect our Galaxy and the Universe to be teeming with it. So every astronomer must think about biology and genetics and procreation and evolution. And this is where Wallace Arthur, the emeritus professor of zoology at the National University of Ireland in Galway, comes to our aid.

His book is eminently readable, intriguing, thought-provoking, and aimed accurately at a readership with very little initial knowledge of biology. We are encouraged to look very carefully at life on Earth and how it advanced from the primordial organic molecular soup to today's complexity. In that context we are asked to consider what life on other planets might be like, and how far that life might have progressed. We are taken carefully through our understanding of the way in which humans develop from the meeting of spermatozoa and egg, through the embryonic stage, to the changes from childhood to maturity. We are asked to consider the animal kingdom and wonder why Earth at present has over a million species. We are asked to worry about the onset of consciousness and the effects of background extinctions and random mass extinctions. We are introduced to recent advances in evolutionary developmental biology.

At its heart this book is aiming to get us ready for that future day when we actually have our first contact with extraterrestrial life. There is little chance that it will be humanoid. To quote the parody song *Star Trekkin*, "It's life, Jim, but not as we know it". Wallace Arthur aims to ready us for this momentous meeting. I wish I knew how long we have to be prepared to wait. — DAVID W. HUGHES.

Universe: Exploring the Astronomical World, edited by Rosie Pickles, with introduction by Paul Murdin (Phaidon, London), 2017. Pp. 352, 29 × 25 cm. Price £39·95 (hardbound; ISBN 978 0 7148 7461 6).

If you don't have a coffee table, go out and get one — and make sure it's sturdy. And if you do have such a table, clear away the usual detritus (coffee cups, newspapers, *etc.*) and get a copy of *Universe*. Lay the copy on the table and prepare for a visual feast which will educate, inspire, and delight you — and anyone invited to share the experience. In this beautifully produced volume you'll find almost 300 pages of superb pictures, ranging from the most dramatic vistas secured by the most modern of telescopes (across the full spectrum) (such as SNR 0509–67·5, p. 121), through diagrams reflecting key stages in the development of astronomy (like the Nebra Sky Disc from 1600 BC, p. 288), to interpretations of astronomical phenomena from across the Earth's cultural diversity (see the Dunhuang Star Atlas from *circa* 700, p. 262), and more-modern artistic endeavours (a well-known one being van Gogh's *The Starry Night*, p. 114). One of my favourites has to be the photo of untethered astronaut McCandless floating in space away from space shuttle *Challenger* (p. 235) — reminding me of the films *2001* and *Gravity*. Each image is accompanied by an insightful description to give it context, and a time-line is included near the end of the book, spanning the entire history of our Universe (right up to 2017), allowing many of the images to be slotted into sequence. A foreword by Paul Murdin explains the rationale for the book and a glossary of astronomical terms is also included to allow those who approach from a non-scientific background to tune in to the full story. As a wonderful attempt to draw links between astronomy and the wider community, C. P. Snow would have praised this enterprise. And at less than £40 it's a real bargain. — DAVID STICKLAND.

Observing Nebulae, by M. Griffiths (Springer, Heidelberg), 2016. Pp. 289, 23·5 × 15·5 cm. Price £26·99/$34·99 (paperback; ISBN 978 3 319 32882 9).

This book on observing nebulae is part of the Springer *Practical Astronomy* series and is intended for amateur astronomers who wish either to observe visually or image planetary and reflection nebulae, supernova remnants, H II regions, and dark nebulae. It starts with a couple of background chapters on the history of our understanding of nebulae, and their astrophysics. These are rather brief and supply some context, and are probably sufficient for the target readership, but don't expect anything in-depth here.

The next four chapters seem to be rather obligatory these days, on observing techniques, equipment, astrophotography, and image processing. While these will be useful for anyone starting out in astronomy, those with some experience will probably just skip over these chapters rather quickly. The image-processing chapter is particularly scant, a topic on which a whole book could be written.

There are a lot of catalogues available that list different sorts of nebulae and so the author has chosen just three to focus on in Chapter 7. I think it is a bit unfortunate that the author did not describe other catalogues that are available for the observer. For bright nebulae there is a listing of Lynds' *Catalog of Bright Nebulae* — this has over 1000 objects, but it is rather difficult to discern what is worth looking for and what is not. Although there is a brief discussion of the fields, I found I had to refer to Beverly Lynds' original paper to get a better appreciation. And it is worth noting that coordinates here are equinox 1950. For dark nebulae there is a listing of Barnard's Dark Nebulae — these have helpful discussions (actually they are Barnard's own descriptions), but the table is marred as the hour column is missing from the right ascension. Again, reference to source and other materials will really be needed. The third catalogue is one of planetary nebulae devised by the author. This has an interesting range of objects of varying size and brightness, and may be useful for anyone wishing to go beyond Messier and *New General Catalogue* lists. Also it includes many southern-hemisphere objects which are often not covered. These tables are all printed black on gray, which I found rather difficult to read at times. The format could have been unified across the tables and presented more consistently

The remaining five chapters provide detailed descriptions of about 100 objects in the classes of dark, H II, planetary, and reflection nebulae, and supernova remnants. Each object is accompanied by an image and finder chart, but these are rendered rather small, limiting their usefulness, but the selection of objects may be useful to a new observer.

One area in which the book is let down is the index — which just seems to be plain wrong. Objects which are in the final chapters seem to be out by ten pages, so perhaps the body of the book has been updated without an update to the index to match.

On balance I think there are too many problems with the book to give a positive recommendation, which is a pity as there is certainly a gap in the literature for the amateur observer. — CALLUM POTTER.

Video Astronomy on the Go, by J. Ashley (Springer, Heidelberg), 2017. Pp. 205, 23·5 × 15·5 cm. Price £19·50/$34·99 (paperback; ISBN 978 3 319 46935 5).

Video Astronomy on the Go demonstrates how a relatively inexpensive low-light video camera can be combined with a small telescope, such as the ubiquitous 80-mm *f*/5 refractor, to create a portable video telescope. The author describes the anatomy of a video camera and how it can integrate short exposures and stack multiple frames to improve the signal-to-noise ratio. The book discusses entry-level video cameras and in subsequent chapters covers the topics of small telescopes, mounts, focal reducers, filters and light pollution, video observation of the Sun, Moon, planets, the brighter deep-sky objects, and image-processing software. Later chapters cover the subjects of public viewing sessions ('outreach' events), giving lots of advice on equipment and planning; how to undertake and manage live video broadcasting across the Internet; and in the final chapter the author discusses future trends in video astronomy, such as CMOS sensors and digital cameras, using a Windows 10 tablet instead of a laptop computer, and 3-dimensional video astronomy.

There is a useful Glossary of terms and the Index correctly references the corresponding page numbers. (Not all authors take such care.) Appendix C is a novel set of monthly star charts (brighter than magnitude 1·5, mid-northern and southern hemisphere) for aligning a small telescope in light-polluted skies. Printing two charts per page would have avoided the large blank spaces. The book is well written and the author shares his extensive experience with clear explanations, helpful descriptions, and illustrations of target objects. Some of the figures of Solar System bodies such as the Sun, Moon, and Jupiter are stock NASA photographs. I would have preferred to see images of them obtained using the equipment described in the book.

The author recommends mainly American suppliers of video equipment; observers in Europe and Australasia should have little difficulty obtaining the same or similar cameras from their regional vendors or on the Internet. The subject of sensor care is not discussed. Never expose it to direct sunlight and permanent use of an IR blocking filter is advised to improve stellar images and to minimize the problem of dust ingress.

I found very few typos or spelling mistakes. The text uses American spelling, although English-speaking readers should have no problem reading the book. In a few instances it refers to the wrong figure or table, such as on page 21 where it confuses Table 2.3 with Table 2.4, and on page 25 which refers to Fig. 2.5 instead of Fig. 2.2, and page 115 should refer to Table 2.4, not 2.3. There is repetition of the hints and tips, but this helps to reinforce the concepts for the beginner, and the chapters will serve as handy references after some experience has been gained.

In *Video Astronomy on the Go* Joseph Ashley achieves his aim of providing an introduction to anyone new to video astronomy with a small telescope who wishes to get started with relatively inexpensive entry-level equipment. — ALEX PRATT.

OTHER BOOKS RECEIVED

Magnetospheric Multiscale, edited by J. L. Burch & R. B. Torbert (Springer, Heidelberg), 2017. Pp. 745, 24 × 16 cm. Price £44·99/$59·99 (hardbound; ISBN 978 94 024 0860 7).

Reprinted from *Space Science Reviews* (**199**, nos. 1–4, 2016), this book describes NASA's *Magnetospheric Multiscale* (*MMS*) four-spacecraft mission, launched in 2015, to study magnetic reconnection in the Earth's magnetosphere.

ASTRONOMICAL CENTENARIES FOR 2018

Compiled by Kenelm England

The following is a list of astronomical events, whose centenaries fall in 2018. For events before 1600 the main source has been Barry Hetherington's *A Chronicle of Pre-Telescopic Astronomy* (Wiley, 1996). For the 17th to 19th Centuries lists of astronomical events came from *wikipedia* and other on-line sources, supplemented by astronomical texts. Discoveries of comets, asteroids, novae, and other objects for 1918 appeared in the February issue of *Monthly Notices of the Royal Astronomical Society* in the following year. There were also references from *Popular Astronomy*, *Journal of the British Astronomical Association*, and *Publications of the Astronomical Society of the Pacific*. Professional discoveries and observations were followed up in *Astronomische Nachrichten*. Details of individual astronomers were supplemented by articles published in *Biographical Encyclopedia of Astronomers* (Springer, 2007). Gary Kronk's *Cometography* Volumes 1–3 (Cambridge University Press, 1999–2007) provided details on all the comets. Finally NASA's *Five Millennium Canon of Solar Eclipses* and planetary tables were consulted for information on eclipses and planetary events.

1918

January 3: Max Wolf (Heidelberg Observatory) discovered the Amor-type asteroid (887) Alinda, which was observed until May 3.

January 8: Birth of Frank John Kerr. He was an Australian radio astronomer who mapped the gas disc of the Milky Way and its spiral arms, using the 21-cm hydrogen line; died 2000.

January 15: George Ritchey (Mount Wilson) discovered a nova (magnitude 17·1) in the Andromeda Galaxy that faded very quickly [nova N7 in M 31].

January 25: Birth of Armin Joseph Deutsch. He studied the spectra of A-type stars, in particular those with apparently anomalous abundances (Ap stars); he also successfully wrote science-fiction stories; died 1969.

January 27: Birth of Antonín Mrkos. He was a Czech astronomer at the Skalnaté pleso and Klet Observatories. He discovered 13 comets, including the bright comet C/1957 P1 and the short-period comets 18D, 45P, 124P, and 143P, as well as 273 asteroids; married to Ludmila Pajdusakova; died 1996.

February 4: Max Wolf (Heidelberg Observatory) discovered a nova in Monoceros (magnitude 8·5). A pre-discovery image on January 1 showed it was magnitude 5·4 [GI Mon].

February 5: Birth of Edith Alice Mueller. She was a Spanish astrophysicist who studied the Sun and was General Secretary of the International Astronomical Union; died 1995.

February 9: George Ritchey (Mount Wilson) discovered a nova (magnitude 17·7) in the Andromeda Galaxy [nova N8 in M31].

February 9: John Duncan (Mount Wilson) discovered a nova (magnitude 17·2) in the Andromeda Galaxy [nova N9 in M 31].

February 28: Walter Adams (Mount Wilson) obtained a spectrum of the nova GI Mon showing bright emission lines.

February: Harlow Shapley (Mount Wilson) showed that the globular clusters formed a spherical halo around the galactic centre in Sagittarius.

March 7: A bright aurora was seen across North America.

March 13: Max Wolf discovered an outburst of the recurrent nova RZ Leonis (magnitude 10·5).

March 21: First firing of the German *Paris Gun*, whose shells reached an altitude of 40 km [first man-made objects to reach the stratosphere].

March 29: Comet 4P/Faye reached perihelion but was not observed, despite attempts in February and March.

March: Heber Curtis (Harvard Observatory) discovered the relativistic jet coming from the elliptical galaxy Messier 87 in Virgo.

April 4: Birth of Joseph Ashbrook. He studied variable stars and co-discovered comet 47P/Ashbrook–Jackson in 1948; died 1980.

April 25: Birth of Gérard Henri de Vaucouleurs. He was a French astronomer who studied galaxies and co-authored *The Third Reference Catalogue of Bright Galaxies*; died 1995.

May 1: Death of Grove Karl Gilbert. Born in 1843, he was an American geologist who studied Meteor Crater in Arizona in 1891 and concluded that it was formed by volcanic action. He explained lunar craters as impact events.

May 6: First light of the 72-inch *Plaskett* reflector at the Dominion Astrophysical Observatory, British Columbia [becoming the second-largest telescope in the world].

May 11: Birth of Richard Feynman. He was an American physicist and Nobel Laureate, who sat on the Rogers Commission investigating the Shuttle *Challenger* disaster; died 1988.

May 21: Comet 9P/Tempel 1, last seen in 1879, reached perihelion but was not observed [the comet was recovered in 1967].

June 8: A total solar eclipse was seen across the United States. Attempts to observe the gravitational displacement of starlight predicted by Einstein failed due to thin cloud [Saros 126].

June 8: The sudden appearance of a very bright nova in Aquila (magnitude 0·8). It reached magnitude –1·1 on the 9th, before rapidly fading to magnitude 4 by the end of July. Pre-discovery images on Harvard plates revealed the nova as magnitude 6·5 on June 7. The nova continued to fade to magnitude 6 by the end of the year and more slowly during 1919 [V603 Aql, the brightest nova of the 20th Century].

June 12: William Reid (Rondesbosch, South Africa) discovered an 8th-magnitude comet in Hydra. It moved south and faded rapidly; last seen on July 17 [Comet C/1918 L1 (Reid)].

July 4: Death of Charles-Joseph-Étienne Wolf. Born in 1827, he was an astronomer at the Paris Observatory and studied emission spectra of recurrent nova T Coronae Borealis and other hot stars with Georges Rayet [Wolf-Rayet stars].

July 7: Death of George Mary Searle. Born in 1839, the younger brother of Arthur Searle, he discovered six galaxies and asteroid (55) Pandora, before becoming a Catholic priest.

July 9: After a two-month search Robert Jonckheere (Greenwich Observatory) recovered comet 14P/Wolf at magnitude 15–16. The comet slowly brightened to magnitude 10 in October, before fading; last seen on 1919 April 2.

July 13: Death of Karl Wilhelm Lorenz. Born in 1886, he was an astronomer at the Heidelberg Observatory and discovered four asteroids: (665) Sabine, (674) Rachele, (678) Fredegundis, and (685) Hermia.

July 28: Birth of Albert George Wilson. He was an astronomer at the Palomar Sky Survey, discovering five asteroids, including the near-Earth object (1620) Geographos, and co-discoverer of three comets: 107P/ 1949 W1, C/1951 P1, and D/1952 B1; died 2012.

August 7: Gaston Fayet (Paris Observatory) recovered comet 19P/Borrelly close to the predicted position, when it was magnitude 13. In December the comet brightened to magnitude 9 and displayed a short tail. Then it slowly faded and was last seen on 1919 May 2.

September 27: Birth of Sir Martin Ryle. He was a British radio astronomer at the Cambridge and Mullard Radio Astronomy Observatories. He observed quasars and was a strong proponent of the expanding-universe model of the Big Bang theory. He won the Nobel Prize for Physics in 1974; died 1984.

October 7: Roscoe Sanford (Mount Wilson) discovered a nova (magnitude 17·3) in the Andromeda Galaxy that faded slowly [nova N10 in M 31].

October 7: Roscoe Sanford (Mount Wilson) discovered a nova (magnitude 17·6) in the Andromeda Galaxy that faded rapidly [nova N11 in M 31].

October 9–12: First conference held in London to set up the International Astronomical Union.

October 12: Kiyotsugu Hirayama (Yale University) identified several groups of main-belt asteroids related to asteroids (158) Koronis, (221) Eos, and (24) Themis [Hirayama families].

November 19: Birth of Hendrik Christoffel van de Hulst. He was a Dutch astronomer at the University of Leiden and predicted the 21-cm line due to hydrogen; died 2000.

November 23: While observing asteroids, Richard Schorr (Hamburg Observatory) discovered a faint 14th-magnitude comet on photographic plates. The comet slowly faded and was last seen on December 31. Its orbit had a period of about 6·7 years but remains lost [D/1918 W1 (Schorr)].

November 26–29: Second conference held in Paris to set up the International Astronomical Union.

December 9: Eclipse of Saturn's moon Iapetus.

1818

January 3: Venus transited across Jupiter, visible in the Pacific; not observed [last planet-on-planet transit until 2065].

February 23: Jean Louis Pons (Marseille) discovered a telescopic comet without a tail in Cetus. He only observed it until the 27th. The comet was recognised by Andrew Crommelin as being identical to comets in 1873 and 1928 [Comet 27P/1818 D1 (Crommelin)].

February 28: Death of Johann Sigismund Gottfried Huth. Born in 1763, he was professor of physics at Frankfurt-an-der-Oder University and a member of the 'Celestial Police' in the search for asteroids. He independently discovered comets 2P/1805 U1 (Encke), 3D/1805 V1 (Biela), and C/1807 R1, before taking up posts at Kharkov and Dorpat.

March 13: Birth of William Swan. He was a British physicist, who studied in 1856 the spectrum of diatomic carbon, seen as *Swan bands* in the spectra of carbon stars and comets, and recognized in 1857 that Fraunhofer's *D*-line in the solar spectrum was due to sodium; died 1894.

June 18: Birth of Pietro Angelo Secchi. He was a Jesuit astronomer who studied the spectra visually of more than 4000 stars and in 1868 created a scheme of four spectral classes. He also made extensive studies of the Sun; died 1878.

August 1: Birth of Maria Mitchell. She made astronomical observations with her father, independently discovering three comets. Then she discovered her own comet C/1847 T1 (Mitchell). She became Director of the Vassar College Observatory and inspired many women astronomers in the United States; died 1889.

November 26: Jean Louis Pons discovered a very faint telescopic comet in Pegasus. The comet brightened to magnitude 6 in December and was last seen on 1819 January 12. Johann Franz Encke calculated an orbit and identified it with comets seen in 1786, 1795, and 1805 [Comet 2P/1818 W1 (Encke)].

November 28: Jean Louis Pons discovered a faint comet in Hydra. He found it again on December 14 and 19, as it moved rapidly north. Other astronomers began observing it, although there was some confusion as to whether there were two different comets; last seen on 1819 January 30 [Comet C/1818 W2 (Pons) passed 0·15 AU from the Earth on December 15].

1718

January 18: Christfried Kirch (Berlin) discovered a 2nd-magnitude comet in Ursa Minor. He observed the comet moving very rapidly south to Andromeda until February 5 [Comet C/1718 B1 passed 0·10 AU from the Earth on January 18].

April 15: Birth of Christian Pedersen Horrebow. He was Director of the University of Copenhagen Observatory, made a long-term series of sunspot observations, and believed he had observed a moon of Venus in 1764 and 1768, while preparing for the Venus transits; died 1776.

April 21: Death of Philippe de la Hire. Born in 1640, he was an active observer of the Sun, Moon and planets and discovered comets 6P/1678 R1 and C/1702 H1.

May 4: Birth of Jean-Philippe Loys de Chéseaux. He discovered eight nebulous objects, including the clusters M4, M16, M25, M35, and M71, as well as two comets (the spectacular C/1743 X1 and C/1746 P1). He also questioned why the sky was black (Olbers' paradox); died 1751.

November 23: Birth of Antoine Darquier de Pellepoix. In 1779 he discovered the Ring Nebula (Messier 57) while searching for comet C/1779 A1 (Bode); died 1802.

Edmond Halley discovered the proper motion of stars, using ancient and contemporary positions of Sirius and Arcturus.

1618

February 19: Birth of Johannes Phocylides Holwarda. He was professor of philosophy at the University of Franeker in Friesland and was a staunch supporter of Kepler. He recognized that the variable Mira had a period of about 330 days; died 1651.

March–May: Johannes Kepler published his third law of planetary motion in the first part of *Epitome astronomiae Copernicanae* (*Summary of Copernican Astronomy*).

August 25: A bright comet was seen before sunrise in Hungary and was widely seen across Europe and China. Cysat and Kepler made detailed observations of the coma and nucleus; last seen on September 25 [Comet C/1618 Q1 was the first comet studied with a telescope].

October 22: Chinese astronomers observed a comet with a 5-degree tail.

November 4: Transit of Mercury; not observed.

November 11: A comet with a tail 60 degrees long was seen shortly before dawn from Isfahan, Persia. The comet was seen widely in Europe, the Philippines, China, Korea, and India. Cysat and Kepler made detailed observations; last seen on December 2 [Comet C/1618 V1].

November 25: Another bright comet was seen from China and Persia. It was widely observed from Europe and also seen from the Philippines and Korea. Cysat and Kepler made detailed observations; last seen on 1619 January 22 [Comet C/1618 W1].

Birth of Jeremiah Horrocks. He was an English amateur astronomer who calculated and observed the Transit of Venus on 1639 November 24. He also noted the elliptical orbit of the Moon, influenced by the Sun and proposed that comets also travelled in elliptical orbits; died 1641.

1518

April: A comet was seen.

May 26: Transit of Venus; not observed.

1418

Henry the Navigator, Prince of Portugal, founded an astronomical observatory at Sagres near Cape St. Vincent to improve tables for navigation.

1318

March 12: Joannes de Muris observed the vernal equinox from Evreux, near Paris [revealing the need for calendar reform].

1218

July 9: A lunar eclipse was observed from England. The eclipse was partial, as the Moon rose [Saros 97].

1118

April 13: An aurora was seen.

April 23: The Japanese observed a comet.

May 22: A solar eclipse was observed from Flanders. The eclipse was annular across the Arctic, but most of Europe could see the partial phase [Saros 94].

Summer: An aurora was seen.

November 30: A lunar eclipse was observed. The eclipse was partial across Europe [Saros 111].

December 17: The Chinese observed a very large sunspot.

December 20: A brilliant auroral display was observed from Europe [related to the large sunspot group observed by the Chinese].

1018

April 18: A partial solar eclipse was observed, as the Sun set. Totality was over the Atlantic, but a partial phase was visible from France [Saros 103].

August 3: A comet was seen in the northwest from Western Europe and the Far East; last seen on September 8 [Comet C/1018 P1].

918

February 1: An aurora was observed.

November 7: The Japanese observed a comet for three nights.

818

July 7: A solar eclipse was observed from Paris. The annular phase was only visible from the Arctic Ocean [Saros 88].

718

June 3: A solar eclipse was observed from Spain and Constantinople. The track of totality passed over Spain and Egypt [Saros 97].

November 13: A partial lunar eclipse was observed from Ireland [Saros 76].

November–December: Korean astronomers viewed a very bright fireball.

December 8: The Japanese observed a comet close to the Moon in the sky.

Chinese scholars completed the translation of the *Chiu-chih Li*, a treatise on the Indian calendar.

618

October 9: Stephane of Alexandria observed a lunar eclipse. This eclipse just reached totality as the Moon set [Saros 85].

Chu-t'ai Chuan, a Hindu astronomer, was employed by the Chinese Bureau of Astronomy to devise a new calendar.

418

June 24: The Chinese observed a comet in the Plough. It was seen from Constantinople on July 19. On September 15 the Chinese saw a comet with a long tail in Virgo. It could have remained visible to the Byzantines until November. All the observations can be explained by a single comet reaching perihelion on October 5 [Comet C/418 M1].

July 19: A total solar eclipse was seen from Constantinople, when the comet appeared. Totality crossed through Spain, Italy, Greece, Asia Minor, and Persia [Saros 91].

218

April: Comet Halley was observed from China and the Roman Empire. It appeared in the eastern sky and then moved to the evening sky in the west, displaying a long tail and remaining visible until June [Comet 1P/218 H1 (Halley) reached perihelion on April 6].

October 7: A solar eclipse was observed from the Roman Empire. It was annular across southern Gaul, northern Italy, Macedonia, and Asia Minor [Saros 76].

118

June 9: The Chinese observed Mercury close to the Praesepe Cluster in Cancer.

September 3: There was a solar eclipse observed from the Roman Empire. It was total across the northern provinces [Saros 85].

183 BC

An aurora was seen from Rome.

383 BC

December 23: A partial lunar eclipse was calculated and observed from Babylon and Athens [Saros 38].

OBITUARY

William ('Bill') Nicholson (1926–2017)

Bill was born in Sunderland, the eldest child and only son of Joseph and Elsie Nicholson. As a young boy he moved to Richmond, Yorkshire, in 1935, the town that became Bill's home until he joined the Royal Air Force in 1944. In 1937 he passed the scholarship exam that led to him attending Richmond Grammar

School; he was the only one from his group to pass. In 1939 two life-changing events impacted on Bill, now 12 years old. Firstly he joined the Scouts; the ethics of that organization guided him in most of his subsequent choices throughout his life. Bill always encouraged others to lead an adventurous life and to achieve the best they can for themselves and others. Secondly, he met his future wife, Jean, when they were both 12. They married in 1948.

Bill's career started with a six-year stint as a navigator in the Royal Air Force during the 1940s flying first in Lancasters, Wellingtons, and Mosquitoes. This no doubt stimulated his subsequent great interest in gliding. He was a long-time member of the gliding club at Ringmer where he was active in training others. He suffered a brain clot in the 1990s which stalled his participation for some time, but was then told he could go up if he went on his own!

On leaving the RAF he studied mathematics, physics, and astronomy at St. Andrews University, before joining the Nautical Almanac Office at Herstmonceux in 1954. Initially his work was concerned with the preparation of the routine navigational material for the Nautical and Air Almanacs. Later he worked with Leslie Morrison on the NAO's lunar-occultation programme, which involved the prediction and reduction of timings of lunar occultations of stars. Significantly, in the 1960s that programme was widened to include predictions of lunar occultations of radio sources. In particular, he made predictions for the bright radio source 3C 273B. Successful observations of the occultation pin-pointed its position accurately, and led to its identification with an optical source, which proved to be the first quasar.

In 1966 he moved to the Astrometry Department to lead the *GALAXY* project — the automated measuring machine for determining accurate positions and brightnesses of stars on photographic plates. The first task was to write control software and then develop programmes to carry out a number of long-term projects. The most significant of those involved the measurement of the 5820 plates secured between 1962 and 1972 at the Royal Observatory in Cape Town, giving an overlapping coverage of the whole southern sky. *GALAXY* measurements began in 1978 and were completed a decade later. In a talk after his retirement Bill noted that "the measures were put together like a gigantic jigsaw puzzle — and just after the results were published the *Hipparcos* satellite did the whole job in about 18 months, including the northern hemisphere!"

Also in 1966, Andrew Murray took over as the Department Head of Astrometry and left his post as an Editor of this *Magazine*. He was replaced by Bill, who served until 1973. Bill was also a regular observer, taking direct plates with the photographic refractors in the Equatorial Group as well as occasionally riding in the prime-focus cage of the *Isaac Newton Telescope*. In other RGO roles he was joint Press Officer (with Humphry Smith) from 1968, and active in the affairs of the staff association IPCS and the RGO club (Secretary 1963–68). Together with those of a number of colleagues, his reminiscences are included in the Science Projects book *Astronomers at Herstmonceux in their own words*.

After his retirement (with much regret!) from the RGO in 1986, Bill continued with his favourite pastimes of gliding and croquet. In 1997 he and his wife Jean moved from Bexhill to Exeter where he continued his interest in astronomy at the Norman Lockyer Observatory in Sidmouth. He died on 2017 August 1. He leaves two daughters: Susan born in 1952 and Diane in 1955, and one grandson, Peter, born in 1980.

I am indebted to Bill's daughter Diane, Trish Fosbury, Geoff Harvey, Dorothy Hobden, Leslie Morrison, George Wilkins, and Roger Wood for providing material for this appreciation. — R. W. ARGYLE.

Here and There

RAPID TURN-AROUND

October 6: Moon 0·7°N of Aldebaran, 3h; October 9 Moon 0·6°S of Aldebaran, 18h — RAS Diary for 2017, Astronomical Phenomena.

RESEARCH COUNCILS TAKE US BACK TO THE DARK AGES

References to "particle physics and astrology" — *Research Councils UK – Public Insight Research*, March 2017.

BOLDLY GOING … INTO NOTHING

Scientists at Nasa have dubbed the void around Saturn "the big empty" after astronauts made their first dive into the space between the planet and its rings and encountered no dust or debris. — *i*, 2017 May 4.