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COMPLEX VARIATIONS OF THE DOUBLE-MODE CEPHEID VARIABLE V2853 ORI

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V2853 Ori is already known as a double-mode first/second-overtone pulsator with an additional combination frequency, $f_1 + f_2$. Two new combination frequencies have been discovered, $f_2 - f_1$ and $2f_1 + f_2$. The primary period has also changed at least once in the past 20 years with $\Delta P/P = +1{\cdot}2\times10^{-5}$, equivalent to a continuous change, $\dot{P} = +0{\cdot}029 \pm 0{\cdot}005$ s/yr, which is probably consistent with a first crossing of the instability strip. The secondary period has shown discrete changes of $\Delta P/P = \pm7\times10^{-5}$ on a time-scale of 2000 days. A comparison of the periods and Fourier decomposition components of V2853 Ori with other Galactic first/second-overtone Cepheids confirms it as a member of that class.

Introduction

RR Lyrae and Cepheid variables are fundamental to understanding the distance scale, galactic structure and its chemical evolution, and the properties of individual stars, particularly the double-mode variables, provide a valuable insight into the internal structure of those stars. RR Lyraes and short-period Cepheids are driven by the same mechanism and apart from a relatively small difference in mass and luminosity they present in very similar ways[1,2]. Observations over the past twenty years from ground-based projects (MACHO, OGLE) and space (*MOST*, *CoRoT*, *Kepler*) have revealed increasing levels of complexity in both types of variable. The number of double-mode RR Lyrae[3,4] and Cepheid variables[2] has dramatically increased and the prevalence of combination frequencies has become clearer[5–7].

Complications like the Blazhko effect have been recognized for a century in RR Lyrae stars but only recently has the extent of this effect become clear[3,8], and has now also been found in Cepheids[9]. Stars with frequency splitting, period doubling, and unusual period ratios indicate non-radial modes[10,11], and a small number of anomalous stars have been found[2,4] including triple-mode variables[12,13].

The history of V2853 Ori (= GSC 00717–01091) is very short as it was only identified as a variable by the ASAS3 survey[14] in 2002. It is catalogued as ASAS 060623+0803·8 and was given a preliminary classification MISC/RRC, with a period of $1^{d}{\cdot}0$, which is usually an indicator that the real period is $\sim 1/n$ days. And this turned out to be the case as Koppelman[15] found the true period of 0·33225 days, and on this basis it was identified as an RRc variable. However, there were some inconsistencies in the light-curve which presumably led Khruslov[16] to re-examine the entire ASAS3 data set, and this revealed that the star is multiperiodic with a dominant frequency f_1 = 3·010758 and f_2 = 3·767927, giving f_1/f_2 = 0·7990. Khruslov also found the two main harmonics $2f_1$ and $2f_2$, and the combination frequency, $f_3 = f_1 + f_2$. The normal period ratio for double-mode fundamental/first-overtone (F/1O) RR Lyraes and Cepheids is ~ 0·74 so the period ratio identifies this star as a first/second-overtone (1O/2O) pulsator. However, as an RR Lyrae star V2853 Ori would have been unique as no other 1O/2O pulsator had been identified at that time, and that is still the case. Of the 78 000 RR Lyrae stars in the latest OGLE Galactic bulge and disc survey[4] only 458 (0·6%) are classical double-mode (RRd stars F/1O) pulsators, and 63 (0·08%) are anomalous RRd variables; these are mostly first-overtone pulsators with unusual period ratios belonging to the P_x/P_{1O} = 0·61 group, and a small number of triple-mode stars. On the other hand double-mode 1O/2O classical Cepheids are relatively populous, at least in the Magellanic Clouds. The latest OGLE survey lists 9650 classical Cepheids of which 163 (1·7%) are double-mode F/1O pulsators and a substantially larger number 561 (5·8%) are 1O/2O pulsators, distributed more or less evenly between the LMC and SMC[17]. By contrast Galactic double-mode 1O/2O pulsators are rare with currently only 72 stars in the OGLE bulge and Galactic-disc fields[2], and a further 22 stars identified in the Galactic field[13,18,19].

In their 2016 preprint Khruslov & Kusakin[20] reclassified V2853 Ori as a double-mode Cepheid on the basis of its low (–6°·2) galactic latitude. The star was only recently given its official name[21,22] although the GCVS still classifies it as an RR(B) variable. In the following sections the complex variations are explored and the star is compared with other double-mode Cepheid variables.

Observations

Following Koppelman's time-series observations in 2004 several more runs were made between 2006 and 2009 by other observers. The equipment used for all these is given in Table I and details of the longer time-series runs are given in Table II. All the images were dark-subtracted and flat-fielded, and then analysed with MAXIM DL or API4WIN aperture-photometry packages, relative to a sequence of comparison stars (GSC 00717-02702, V = 10·364, $B - V$ = 1·161; 00717-00975, V = 10·678, $B - V$ = 1·200; 00717-01361, V = 10·257, $B - V$ = 1·723) to give V magnitudes.

The data set analysed by Khruslov is from the ASAS3 project and were taken from 2002–2009 as single observations on a cadence of just under three days. In total 498 points can be used which have a median internal error of $0^{m}{\cdot}038$.

TABLE I

List of equipment used

Observer	*Telescope*	*CCD*
Di Scala	LX-200 0·31-m SCT	SBIG ST9XE
Huziak	LX-200 0·31-m SCT	SBIG ST-9XME, ST-10XME, STL-1301E
Koppelman	LX-200 0·35-m SCT	SBIG ST-9XME
Petriew	LX-200 0·31-m SCT	SBIG ST-7XME

TABLE II

List of time-series observations

JD – 2450000		*Hrs.*	*Observer*
Start	*End*		
3022·564	·856	7·0	Koppelman
3023·551	·771	5·3	Koppelman
4069·693	·982	6·9	Petriew
4092·742	·927	4·4	Petriew
4136·671	·714	1·0	Petriew
4145·591	·706	2·8	Petriew
4489·643	·830	4·5	Huziak
4526·923	·036	2·7	Di Scala
4527·896	·052	3·7	Di Scala
4528·943	·052	2·6	Di Scala
4534·654	·751	2·3	Huziak
4536·646	·738	2·2	Huziak
4539·643	·723	1·9	Huziak
4770·859	·043	4·4	Huziak
4863·552	·870	7·7	Huziak
4871·590	·676	2·1	Huziak

The other main data set used here comes from the ASAS-SN project[23,24] which provides *V*-band data from the 2014/15 observing season until 2019, and *g*-band data for 2018/19–2020. From 2014–2019 on average 225 *V*-band observations were made each season but these were concentrated in the central three years. With the adoption of many new instruments and the transition to the Sloan *g* filter the number of observations has greatly increased, so that during the last two seasons the star was observed more than 500 times per season. The *V* data are provided by just two cameras but six have been used for the *g* data, as new ones have been phased in. The individual observations are typically made in groups of three in the space of $0^{d}{\cdot}003$ or 4 minutes, although not all of these survive, so on average ~ 75% of the groups contain three points. The groups were averaged to produce a mean data set with the standard deviations of the groups or the individual internal error carried forward. At this point the median errors were $0^{m}{\cdot}008$ in both *V* and *g*, and points with errors above 4σ in each band were rejected so as to remove the most obviously doubtful data.

For completeness two other data sets should be mentioned. The first and earliest comes from the Northern Sky Variability Survey (NSVS)[25,26] which ran during 1999/2000. Unfortunately most of the NSVS data are flagged as unreliable but they have proved useful as explained later. The other data set comes from The Amateur Sky Survey (TASS)[27] but these do not cover a useful phase range and show some inconsistency, so have not been used.

Analysis

There are three main sets of data of which two have overlapping epochs. The ASAS3 data from 2002–2009, the time-series data from 2004–2009, and the ASAS-SN data from 2014–2020, each with their different challenges. The data sets were all analysed with a multi-frequency Fourier fitting routine of the form

$$V_k = \sum_{j=1}^{m} \sum_{i=1}^{n} a_{i,j} \cos(2\pi i f_j T_k + \phi_{i,j}) + c_z \qquad (1)$$

where V_k is the observed magnitude at time T_k, $j = 1,\ldots,m$ is the number of frequencies, $i = 1,\ldots,n$ is the number of harmonics for each frequency, $\phi_{i,j}$ is the phase offset for each i, j, and c_z is the constant level for any particular subset of the data. For the time-series data both the observer and individual run offsets were used and for the ASAS-SN data the different sets were based on the cameras.

The data have been analysed by repeated application of a period-search fitting-and-subtraction loop until the noise level has been reached. The ASAS3 data set is the simplest and three frequencies have been identified. The first two are the same as those found by Khruslov, $f_1 = 3{\cdot}010754(30)$ and $f_2 = 3{\cdot}767930(84)$ c/d, and these agree well within the errors. Khruslov found two harmonics for f_1 but four have been used here as the light-curve is clearly complex, and all four have significant power. The second frequency also has two harmonics as found by Khruslov. The third frequency found by Khruslov, $f_3 = 6{\cdot}778710$, is identified as f_1+f_2, but the one found here is 6·68569(11) c/d, which is substantially different, and there is no clear explanation, except perhaps that this is noise. In subsets of the data discussed later f_3 has been recovered but generally it is absent.

While the ASAS3 data sample the mean light-curve over a long period of time the time-series data provide short, detailed snapshots at a small number of epochs, but spread over some years. Alignment of the individual light-curves immediately shows the effects of multiperiodicity but there is also a suggestion of small observer offsets as well. These data have been analysed as before, but in one case with the offsets between the different observers allowed in the fitting, and in the second case with each time-series allowed to find its own level. There are four observers but 22 time-series runs so there are far fewer constraints on these solutions. In both cases f_1 is found as this is obviously the dominant frequency, and in the case of the observer offsets f_2 is the second frequency found, but f_3 is weak and cannot be independently identified. The third frequency found is a new one, $f_4 = 9{\cdot}786885(62)$ c/d, which translates as $2f_1+f_2$. The time-series offsets produce fragile data sets and there is not always a clearly dominant frequency at any particular stage; however, f_2, f_3, and the new f_4 can be identified (Fig. 1). Here also f_4 is more prominent than f_3.

The ASAS-SN data have again been treated in the same way, in the first case with camera offsets, which are typically ~ $0^{m}{\cdot}01$ and at the same level as the amplitude of most of the minor frequencies, and in the second case without any offsets. Analysis of the V and g-band data, with and without the offsets, produces a surprising number of frequencies, but a picture does emerge. The principal frequencies f_1, f_2, and f_3 are all present, with some 1-day aliases, and in addition two other weak frequencies emerge. These are $f_4 = 9{\cdot}79008(48)$, which also appears in the time-series data, and $f_5 = 0{\cdot}75763(29)$ c/d, which is equivalent to $f_2 - f_1$. In addition to these, other prominent features appear close to f_1 and f_2, and their 1-day aliases. These features have significant power, with semi-amplitudes in excess of $0^{m}{\cdot}01$ and can swamp the weaker frequencies. These are later referred to as the f_1' and f_2' (prime) series. In the V data f_4 and f_5 can

TABLE III

Frequency Table

No.	*f*	*Frequency* (c/d)	*Amplitude* (mag.)	*Data set*
1	f_1	3·010754(30)	0·1831(23)	ASAS3
	f_1	3·010752(20)	0·1831(7)	Time-series observer
	f_1	3·010753(25)	0·2012(11)	Time-series data
	f_1	3·010698(36)	0·1844(12)	ASAS-SN *V*
	f_1	3·010669(61)	0·2189(13)	ASAS-SN *g*
	$2f_1$	2x	0·0383(22)	ASAS3
	$2f_1$	2x	0·0444(6)	Time-series observer
	$2f_1$	2x	0·0413(10)	Time-series data
	$2f_1$	2x	0·0397(12)	ASAS-SN *V*
	$2f_1$	2x	0·0460(12)	ASAS-SN *g*
	$3f_1$	3x	0·0175(23)	ASAS3
	$3f_1$	3x	0·0149(6)	Time-series observer
	$3f_1$	3x	0·0121(11)	Time-series data
	$3f_1$	3x	0·0179(12)	ASAS-SN *V*
	$3f_1$	3x	0·0219(12)	ASAS-SN *g*
	$4f_1$	4x	0·0100(22)	ASAS3
	$4f_1$	4x	0·0090(5)	Time-series observer
	$4f_1$	4x	0·0106(9)	Time-series data
	$4f_1$	4x	0·0068(11)	ASAS-SN *V*
	$4f_1$	4x	0·0069(11)	ASAS-SN *g*
2	f_2	3·767930(84)	0·0251(21)	ASAS3
	f_2	3·767958(44)	0·0255(6)	Time-series observer
	f_2	3·767976(82)	0·0211(16)	Time-series data
	f_2	3·76811(26)	0·0269(22)	ASAS-SN *V*
	f_2	3·76810(80)	0·0261(48)	ASAS-SN *g*
	$2f_2$	2x	0·0047(21)	ASAS3
	$2f_2$	2x	0·0025(5)	Time-series observer
	$2f_2$	2x	0·0023(8)	Time-series data
	$2f_2$	2x	0·0014(9)	ASAS-SN *V*
	$2f_2$	2x	0·0016(11)	ASAS-SN *g*
3	f_3	6·77352(12)	0·0040(6)	Time-series observer
	f_3	6·776034(88)	0·0160(11)	Time-series data
	f_3	6·77863(17)	0·0069(10)	ASAS-SN *V*
	f_3	6·77918(31)	0·0154(12)	ASAS-SN *g*
4	f_4	9·786839(54)	0·0114(5)	Time-series observer
	f_4	9·786831(99)	0·0112(10)	Time-series data
	f_4	9·79008(48)	0·0064(11)	ASAS-SN *g*
5	f_5	0·75763(28)	0·0074(11)	ASAS-SN *g*
1′	f_1'	3·01010(18)	0·0106(21)	ASAS3
1′	f_1'	3·00997(20)	0·0103(10)	ASAS-SN *V*
2′	f_2'	3·76826(45)	0·0106(21)	ASAS-SN *V*
2′	f_2'	3·76880(67)	0·0307(43)	ASAS-SN *g*
?		6·68569(11)	0·0110(21)	ASAS3

be seen in the periodograms but never appear as dominant frequencies before other systematics in the data take over (Fig. 2). All the frequencies identified in the different data sets are collected in Table III.

By way of illustration the periodograms of the ASAS-SN *g*-band data are shown in Fig. 3 as this set shows all the frequencies found. The periodograms are calculated prior to the removal of f_1, f_2, and f_3 and in each case the dominant frequency is obvious. In the final panel f_3 and the f_2' prime series residual frequency can be seen with their aliases, together with f_4 and f_5. The periodograms of the other data sets similarly show low noise levels but more confusion due to aliases and other systematics in the data.

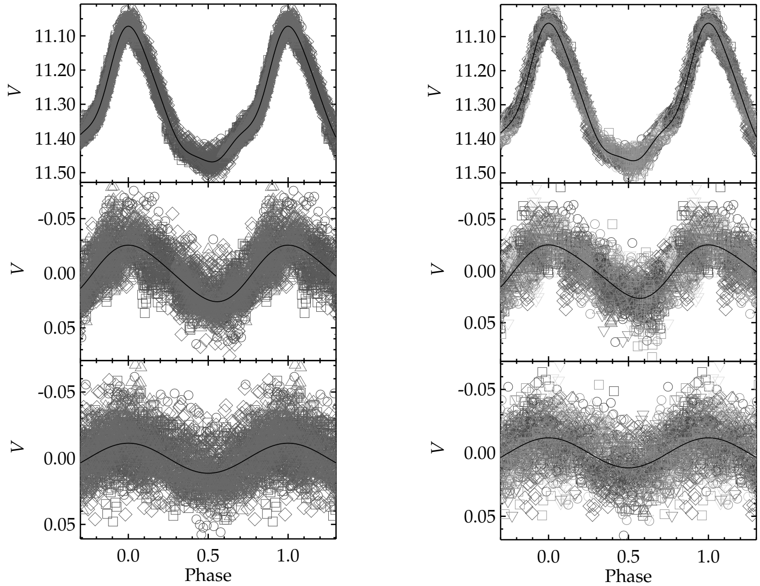

FIG. 1

(Left) Phase diagrams of f_1, f_2, and f_4 for the time-series data with observer offsets applied. (Right) Similarly for the time-series data with the data offsets applied. Although f_3 is weakly present in the data it could not be recovered independently.

Period changes

The re-emergence of a major frequency with residual power is a strong indication of phase shifting or frequency modulation. So, with that in mind, the time of maximum light has been calculated separately for both f_1 and f_2 from multi-frequency fits to suitable subsets of the data. The main effect perturbing the time of maximum light is the presence or asymmetry of other frequencies, so fits to subsets of the data were made using various combinations of frequencies and harmonics to determine on one hand what consistency could be achieved, and on the other if any significant deviations could be found. The value of f_1 was fixed at the mean of the whole data set, f_2 was allowed to float, and where a third frequency was allowed in the fit this was one appropriate to the particular data set. Depending on the quality and quantity of data f_1 was fitted with two or four harmonics, f_2 was fitted with one or two, and the third frequency when present had just one.

The data sets have been divided into shorter sections in an effort to track any changes in phase of the two principal frequencies. For this exercise the NSVS data have been included, even though f_1 is not well defined and f_2 is undetectable, but the results have only survived because they are more consistent than expected. The ASAS3 data have been divided into four 2-year sets, and the time-series data treated as one despite the spread in time. The ASAS-SN *V* data have been divided into five annual sets and the *g*-band data into seven groups of approximately 50 points.

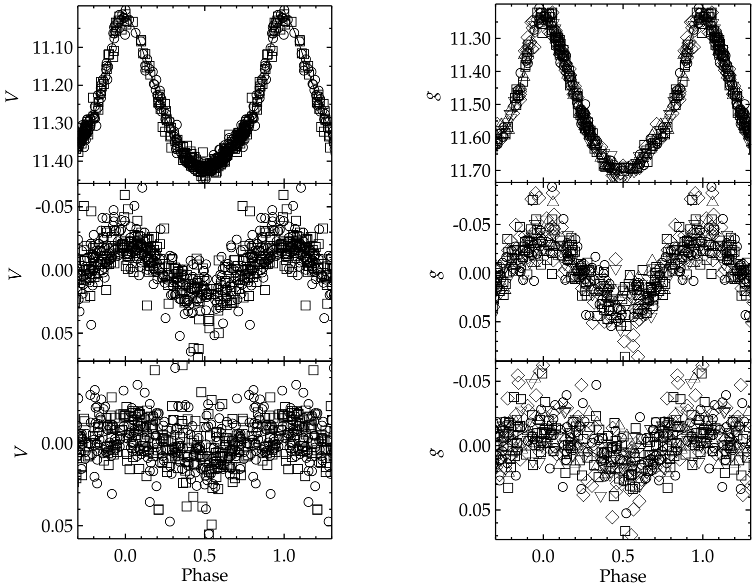

FIG. 2

(Left) Phase diagrams of the ASAS-SN V-band data showing the most prominent frequencies, f_1, f_2, and f_3. The two other frequencies, f_4 and f_5 are present at a low level in the V data but are swamped by the f_1' and f_2' prime series signals. (Right) Similarly for the ASAS-SN g-band data. All five frequencies are independently recoverable from the g data.

Times of maxima have been calculated for both major frequencies for the different subsets of data and various fitting schemes. These are shown in Fig. 4 and the means for each epoch are collected in Table IV. The results speak for themselves. The upper panel of Fig. 4 shows the residuals of the dominant period which has been arguably constant for much of this time. The early points from the NSVS data show at least that there was no major change, but suggest that the period might have been shorter at the earliest epochs. The most recent data show a slightly longer period but exactly were the change occurred is not clear, probably during the early ASAS-SN V data. The plot is constructed using the mean period from the ASAS3 and time-series data, although the residuals of the early ASAS-SN V data are also consistent with this period. The ephemeris of the main constant-period section is,

$$HJD_{\mathrm{Max}\,f_1} = 2451513{\cdot}8371(30) + 0{\cdot}33214275(37) \times E \qquad (2)$$

and that of the longer period section from the ASAS-SN data is

$$HJD_{\mathrm{Max}\,f_1} = 2451513{\cdot}765(8) + 0{\cdot}33214689(38) \times E \qquad (3)$$

giving $\Delta P = +4{\cdot}1 \times 10^{-6}$ and $\Delta P/P = +1{\cdot}2 \times 10^{-5}$.

The residuals of the second period are shown in the lower panel of Fig. 4 and show clear changes in period between constant-period sections.

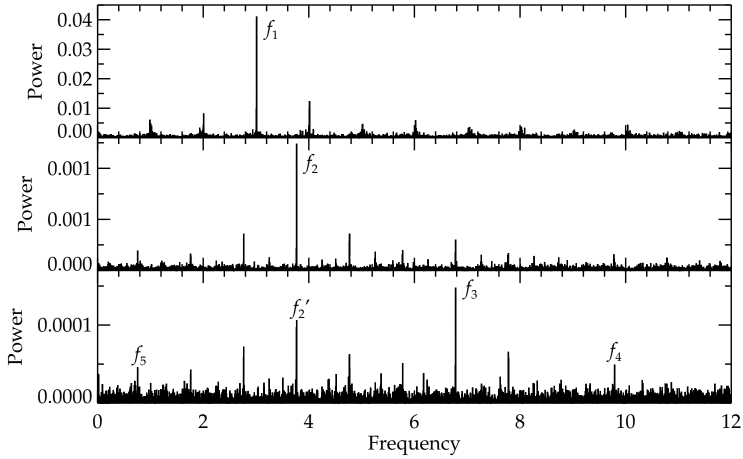

FIG. 3

The periodograms of the ASAS-SN *g*-band data prior to the removal of f_1, f_2, and f_3, and in each case the dominant frequency is obvious. In the final panel the f_2' prime series residual frequency can also be seen together with f_4 and f_5. The other significant features are aliases of f_2' and f_3.

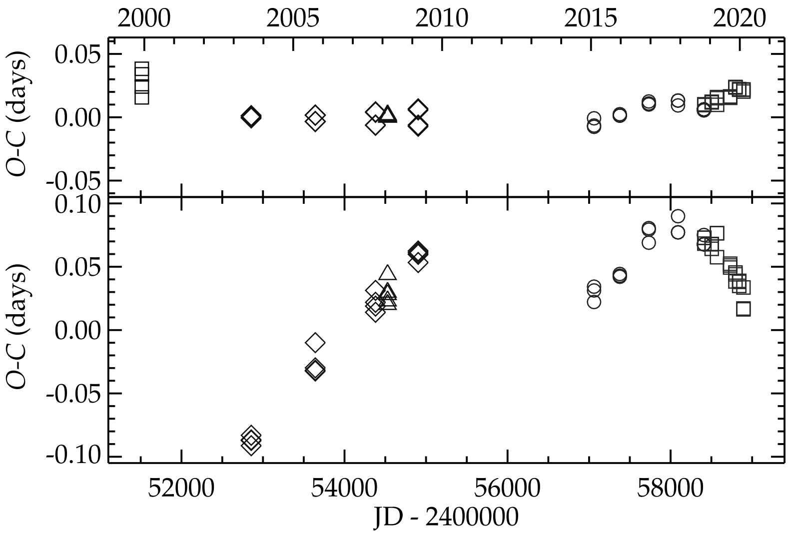

FIG. 4

Residuals of the time of maximum light from the mean ephemeris for f_1 (upper panel) and f_2 (lower panel). The times from the NSVS data were only determined for f_1 so only appear in the upper panel. The other points are ASAS3 data (diamonds), time-series data (triangles — just one epoch), ASAS-SN *V*-data (circles), and *g*-data (squares). The upper panel was constructed using the ephemeris for the ASAS3 and time-series data (Equation 2) which probably also applies to the early ASAS-SN data. The lower panel was constructed using the mean period of the two constant-period sections (Equations 4 and 6).

TABLE IV

Times of maximum light for the two main periods

HJD	*Error*	*Period*	*O–C*	*Filter*	*Data set*
2451513·8651	0·0101	1	0·0280	*R*	NSVS
2452855·6943	0·0009	1	0·0005	*V*	ASAS3
2453641·8749	0·0029	1	−0·0008	*V*	ASAS3
2454380·2280	0·0060	1	−0·0011	*V*	ASAS3
2454528·0334	0·0007	1	0·0008	*V*	Time series
2454903·3537	0·0074	1	−0·0002	*V*	ASAS3
2457060·9483	0·0036	1	−0·0050	*V*	ASAS-SN
2457376·8227	0·0006	1	0·0017	*V*	ASAS-SN
2457732·8892	0·0012	1	0·0111	*V*	ASAS-SN
2458091·2720	0·0022	1	0·0119	*V*	ASAS-SN
2458408·4623	0·0005	1	0·0060	*V*	ASAS-SN
2458413·7806	0·0003	1	0·0099	*g*	ASAS-SN
2458504·7898	0·0003	1	0·0120	*g*	ASAS-SN
2458569·8914	0·0033	1	0·0136	*g*	ASAS-SN
2458730·6507	0·0006	1	0·0159	*g*	ASAS-SN
2458795·4264	0·0002	1	0·0237	*g*	ASAS-SN
2458841·9247	0·0003	1	0·0220	*g*	ASAS-SN
2458893·4061	0·0009	1	0·0213	*g*	ASAS-SN
2452855·5243	0·0034	2	−0·0871	*V*	ASAS3
2453641·9022	0·0107	2	−0·0260	*V*	ASAS3
2454380·2329	0·0073	2	0·0215	*V*	ASAS3
2454528·0563	0·0091	2	0·0290	*V*	Time series
2454903·3318	0·0040	2	0·0592	*V*	ASAS3
2457060·8298	0·0063	2	0·0292	*V*	ASAS-SN
2457376·9095	0·0011	2	0·0431	*V*	ASAS-SN
2457732·8154	0·0063	2	0·0763	*V*	ASAS-SN
2458091·3470	0·0074	2	0·0814	*V*	ASAS-SN
2458408·1978	0·0043	2	0·0701	*V*	ASAS-SN
2458413·7719	0·0027	2	0·0713	*g*	ASAS-SN
2458504·5267	0·0021	2	0·0666	*g*	ASAS-SN
2458569·8133	0·0109	2	0·0701	*g*	ASAS-SN
2458730·6135	0·0015	2	0·0509	*g*	ASAS-SN
2458795·3576	0·0037	2	0·0426	*g*	ASAS-SN
2458841·7935	0·0021	2	0·0373	*g*	ASAS-SN
2458893·5274	0·0098	2	0·0223	*g*	ASAS-SN

The ephemerides of the two longer-period sections are

$$HJD_{\mathrm{Max}\,f_2} = 2452855{\cdot}3936(32) + 0{\cdot}2653971(6) \times E \tag{4}$$

for the ASAS3 and time-series data, and

$$HJD_{\mathrm{Max}\,f_2} = 2452855{\cdot}474(36) + 0{\cdot}2653973(21) \times E \tag{5}$$

for the majority of the ASAS-SN V data, prior to JD = 2458000. The ephemeris for the shorter-period section is

$$HJD_{\mathrm{Max}\,f_2} = 2452856{\cdot}200(41) + 0{\cdot}2653601(19) \times E \tag{6}$$

and this covers the data from JD = 2458000, which includes two subsets from the ASAS-SN V data and all the g data. The two longer-period sections have the same period within the uncertainties so the most likely scenario is that the second period switches between two constant periods on a time-scale of

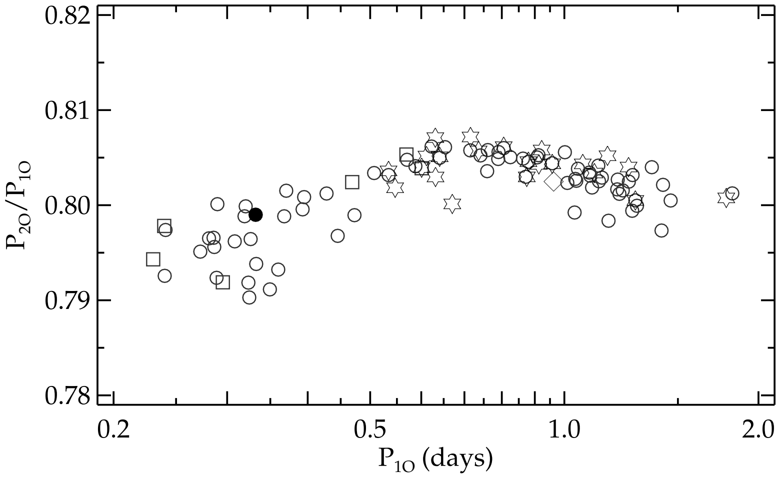

FIG. 5

The Petersen diagram of the 1O/2O mode for the Galactic Cepheids. The field stars are shown as stars, with the OGLE GD and BLG 1O/2O stars (circles), the triple-mode 1O/2O/3O stars (squares) and a single F/1O/2O star (diamond). V2853 Ori is the filled symbol.

about 2000 days. The period changes are $\pm7\times10^{-5}$ of the mean period. It is possible to imagine this saw-tooth effect in the O–C diagram by extrapolating and repeating sections of data but it is also clear that pattern is uneven. The change in the dominant period appears to coincide with the period reversal at JD ~ 2457000, and it is possible that the same occurred at JD ~ 2453000. So it is possible to conjecture that the period reversals of the second period from the shorter to longer period are mirrored by a small increase in the dominant period. It might not need another two decades of observation to test this as the star is currently part way through one of these short-period episodes and might reasonably be expected to undergo another period reversal within the next five years or so.

Comparison with other double-mode Cepheids

A comparison of the period ratio for V2853 Ori and other Galactic 1O/2O Cepheids is shown in Fig. 5. The 22 stars in the Galactic field are taken from the listings of Fernie *et al.*[18], Jurcsik *et al.*[13], and Khruslov *et al.*[19], and the OGLE data are taken from the Galactic disc (GD) and bulge (BLG) fields[2]. The OGLE data comprise 72 1O/2O stars, six triple-mode 1O/2O/3O stars, and a single F/1O/2O star. The field and OGLE sample align well and there is no obvious separation of the triple-mode stars. V2853 Ori falls well within the group but has a much shorter period than the other Galactic field stars.

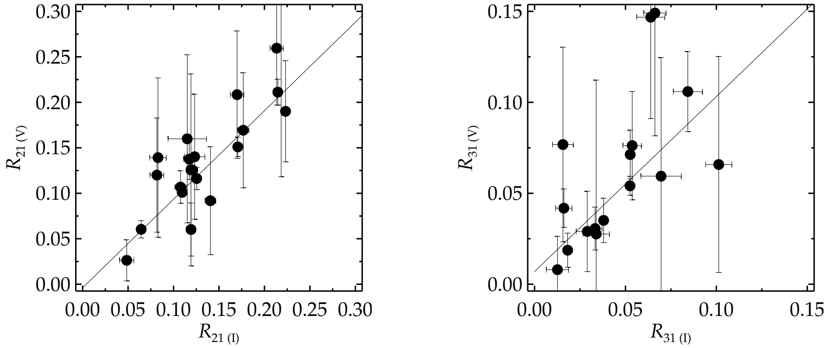

FIG. 6
(Left) The plot of R_{21} for V *vs.* I. (Right) Similarly for R_{31} for V *vs.* I.

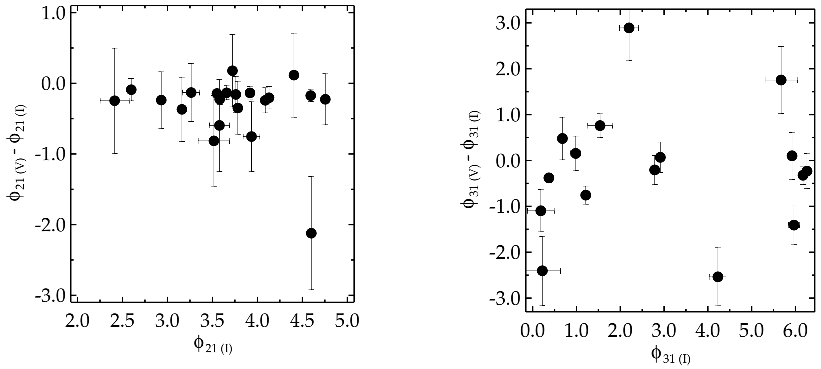

FIG. 7
(Left) The plot of the phase difference $\phi_{21(V)} - \phi_{21(I)}$ *vs.* $\phi_{21(I)}$. (Right) Similarly for ϕ_{31}.

The Fourier decomposition components determined from the fits to the ASAS3, time-series, and ASAS-SN data may also be compared with the OGLE data, but as the published OGLE components refer to the *I*-band photometry a correction is necessary for the *V*-band components. Fourier decomposition components have been calculated for all the OGLE 1O/2O stars where there are sufficient *V* and *I*-band data. Unfortunately, for many of the OGLE stars there is little or no *V*-band photometry, so ultimately components have been derived for only 21 stars, and for some of those the errors are large.

The plots of the amplitude components R_{21} and R_{31} for V *vs.* I are given in Fig. 6 and similarly for the phase components ϕ_{21} and ϕ_{31} are given in Fig. 7. Despite the small sample there is a clear relationship between the *V* and *I*-band R_{21} values. The line is the weighted linear fit and suggests a simple ratio between the two, giving

$$R_{21}(I) = (1{\cdot}06 \pm 0{\cdot}02) \times R_{21}(V), \tag{7}$$

which is more reliable than the linear fit. For R_{31} both the component amplitudes are much smaller and consequently the errors are larger leading to a more confused plot. Some points had such low weight that they were not used and the fit was restricted to the best 75% of the data. Nevertheless, the weighted linear fit again suggests a simple ratio between the two, although it is not as well defined as R_{21} and gives

$$R_{31}(I) = (0{\cdot}90 \pm 0{\cdot}06) \times R_{31}(V). \tag{8}$$

The results are similar for the phase components. These are viewed in terms of the phase difference $\phi_{21}(V) - \phi_{21}(I)$ *vs* $\phi_{21}(I)$, and similarly for ϕ_{31}. The $\phi_{21}(I)$ values cover a relatively restricted range between 2 and 5 radians and the difference between the V and I-band values is consistent for the most part with the weighted value, giving

$$\phi_{21}(I) = \phi_{21}(V) + 0{\cdot}17 \pm 0{\cdot}02. \tag{9}$$

There is no additional structure that might indicate any variation with phase, and the reduced χ^2 does not require a more sophisticated interpretation. For ϕ_{31} the errors are larger and again the fit was restricted to the best 75% of the data. Both the V and I-band values are distributed through the whole of phase space. In the plot $\phi_{31}(V) - \phi_{31}(I)$ has been cast into the $\pm\pi$ range and all that can be said is that the most reliable values cluster around zero. Formally the weighted difference leads to

$$\phi_{31}(I) = \phi_{31}(V) + 0{\cdot}32 \pm 0{\cdot}17. \tag{10}$$

However, as will be seen later, there is strong correlation between ϕ_{31} and ϕ_{21}, and unlikely as it may seem ϕ_{31} is distributed over a range $> 2\pi$.

The Fourier decomposition components of V2853 Ori are compared with those of the OGLE GD and BLG sample in Fig. 8. The plot of the amplitude ratios R_{31} *vs.* R_{21} for the 1O/2O stars and the single-mode 1O stars shows a broad correlation, with the double-mode stars concentrated in the lower half of the space occupied by single-mode stars. The wider distribution of both the double- and single-mode stars is broadly similar, but of course there are far fewer double-mode stars. The conversion from the V to I-band values determined above has been applied to the solutions for V2853 Ori and although the corrections are relatively small — comparable to the dispersion of the three solutions — they do place the star more firmly within the OGLE 1O/2O sample. The plot of the phase components ϕ_{31} *vs.* ϕ_{21} for the same set of stars shows a clearer but more complex relationship between ϕ_{31} and ϕ_{21} but in this case the double-mode stars appear to cluster along the upper boundary of the space defined by the single-mode stars, and only two 1O/2O stars lie outside this band. The three points for V2853 Ori also lie close to this boundary placing the star with the OGLE 1O/2O sample.

Luminosity

The absolute magnitude of Classical Cepheids is primarily dependent on period, but metallicity, and even age may have an effect[28,29]. In an extensive review of the period-luminosity relationship, Groenewegen[30] explores many variants but two solutions appropriate to V2853 Ori — the general V-band and

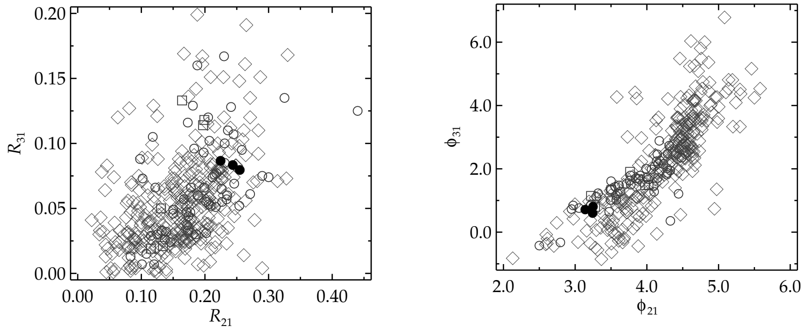

FIG. 8

(Left) The plot of the first-overtone Fourier amplitude components R_{31} *vs.* R_{21} for the OGLE GD and BLG 1O/2O stars (circles) and the triple-mode 1O/2O/3O stars (squares). In addition, the components for the single-mode 1O stars are also shown (diamonds). All the values refer to the OGLE *I*-band data. Corrections based on the calibration derived above have been applied to the *V*-band solutions for V2853 Ori and are shown as filled symbols. The double-mode stars tend to be concentrated in the lower half of the space occupied by single-mode stars but the wider distributions are similar.

(Right) The plot of the phase components ϕ_{31} *vs.* ϕ_{21} for the same set of stars. There is a clear, non-linear relationship between ϕ_{31} and ϕ_{21} and the double-mode stars appear to cluster along the upper boundary of the space defined by the single-mode stars. Both the amplitude and phase components of V2853 Ori are well aligned with the OGLE double-mode stars.

a low-galactic-latitude solution — give $M_V = -1{\cdot}3$ and $M_V = -1{\cdot}0$, respectively. It should be pointed out that this calibration is based on stars with periods over 3 days. *Gaia*[31,32] has provided a distance of 1396 ± 140 pc for V2853 Ori which at $l = 200^\circ{\cdot}6$, $b = -6^\circ{\cdot}2$ places the star beyond the local, Orion Arm and in the region of the Perseus Arm[33]. The total reddening in this direction from the calibrations of Schlegel *et al.*[34] and Schlafly & Finkbeiner[35] is $E_{B-V} = 0{\cdot}38 \pm 0{\cdot}01$ and $0{\cdot}44 \pm 0{\cdot}01$, respectively. However, the recent 3-D reddening map by Green *et al.*[36] gives the same total reddening as $E_{g-r} = 0{\cdot}37$, but out to 1400 pc $E_{g-r} = 0{\cdot}22 \pm 0{\cdot}02$. Assuming $R_V = 3{\cdot}1$, then depending on the conversion used $A_V = 0{\cdot}60$ to $0{\cdot}68 \pm 0{\cdot}06$, when combined with the distance and $V = 11{\cdot}26$ yields $M_V = -0{\cdot}10 \pm 0{\cdot}25$, which is significantly fainter than the range from the period-luminosity relationship. First-overtone Cepheids in the Magellanic Clouds are about $0^{\rm m}{\cdot}5$ more luminous than fundamental-mode stars so V2853 Ori appears substantially less luminous than might be expected[17]. These values are barely brighter than the absolute magnitude of field RR Lyrae stars, which occupy the range of $M_V \sim 0 - 1$ (see *e.g.*, refs. 37–39).

Another way of examining the luminosity of V2853 Ori is through the reddening-free Wesenheit Index, W_I, which is used extensively by the OGLE project[17]. Their version is defined as, $W_I = I - 1{\cdot}55 \times (V-I) - DM$, where *DM* is the distance modulus of the star, but unfortunately a reliable mean *I*-band magnitude is not available. So $(V-I)$ has been recovered from the *Pan-STARSS* *g* and *i* magnitudes using the calibration of Jordi *et al.*[40] as $(V-I) = 1{\cdot}14 \pm 0{\cdot}08$. Combining this with the distance modulus of V2853 Ori, $m - M = 10{\cdot}72 \pm 0{\cdot}22$ and $V = 11{\cdot}26$ gives $W_I = -2{\cdot}4 \pm 0{\cdot}26$, which is $\sim 0^{\rm m}{\cdot}8$

brighter than the LMC first-overtone pulsators of the same period[17]. Similarly, the V-band luminosity calibration of the LMC first-overtone stars gives $M_V \sim -0{\cdot}1$, which also places V2853 Ori ~ $0^{m}{\cdot}8$ brighter than the LMC 1O pulsators, and is consistent with the value derived above.

Discussion

Historical period changes have been observed in Classical Cepheids with $\log|\dot{P}|$ in the range –3 to +4 s/yr and these are broadly consistent with evolutionary models of different crossings of the instability strip[29,41–44]. From the upper panel of Fig. 4 the secular period change for the primary period, excluding the early, NSVS data, is $\dot{P} = +0{\cdot}029 \pm 0{\cdot}005$ s/yr, which is probably consistent with the extrapolation of the first-crossing period changes, if they can be extrapolated from longer periods down to that of V2853 Ori[42]. For the secondary period the continuous period change was calculated for the data from JD = 2457000 in the lower panel of Fig. 4, which gives $\dot{P} = -1{\cdot}09 \pm 0{\cdot}08$ s/yr. Negative evolutionary changes are about 5 orders of magnitude smaller than this and positive changes about 1–2 orders of magnitude smaller, again depending on how the values can be extrapolated. Clearly these are not evolutionary changes, both in terms of their magnitude and because they reverse on a time-scale of roughly 2000 days.

Non-evolutionary period changes are seen in around 40% of LMC first-overtone pulsators, and in about 20% of fundamental-mode stars, but these relate to the primary period[45,46]. In the case of V2853 Ori the change in the primary period may be evolutionary but that of the secondary in clearly not. Similar stars seem to be rare but Khruslov *et al.*[19] have identified two Galactic 1O/2O Cepheids that show period variations in both the primary and secondary periods. Although it is a very different type of object the single-mode, first-overtone RRc star, MACHO 050918·712 – 695015·31, also shows alternating period changes, but in this case the variation is almost exactly sinusoidal as opposed to the obviously discrete changes seen in V2853 Ori, and its origin is not clear[47].

When discussing the Petersen diagram (Fig. 5) earlier it was pointed out that V2853 Ori was unusual among the Galactic field Cepheids in having a particularly short period. All the other 20+ similar stars have $P > 0{\cdot}5$ days and yet the OGLE disc and bulge stars are distributed more or less evenly throughout the period range $P \sim 0{\cdot}25$–$1{\cdot}3$ days. Clearly there is nothing special about V2853 Ori so this must be a selection effect. The OGLE stars are examined *en masse* in a consistent way and are classified accordingly — if not always perfectly. By contrast the Galactic field stars are discovered individually, by chance, and are not treated in a consistent way. The missing short-period stars are probably misclassified as RR Lyraes — as was V2853 Ori itself — or more likely as high-amplitude δ Scuti stars given their Galactic distribution. Based on Fig. 5 there are probably ~ 20 Galactic field 1O/2O Cepheids that have already been discovered but are masquerading as something else.

Conclusions

V2853 Ori is confirmed as a double-mode first/second-overtone Galactic Cepheid through its position in the Petersen diagram (Fig. 5) and its Fourier decomposition components (Fig. 8), which closely match those of the OGLE GD and BLG sample. The star is a much more complex variable than previously thought with two further combination frequencies identified, $2f_1 + f_2$ and $f_2 - f_1$ in addition to $f_1 + f_2$, which was also confirmed. The primary period has shown one small change in the twenty years of observation, equivalent to a continuous change, $\dot{P} = +0{\cdot}029 \pm 0{\cdot}005$ s/yr, which is probably consistent with a first crossing of the instability strip. The secondary period shows much larger changes with $\Delta P/P = \pm 7 \times 10^{-5}$, and appears to oscillate between two constant values on a time scale of some 2000 days. There is no obvious change in amplitude of the two main periods over this time. A lack of short-period Galactic field 1O/2O stars has been noticed and it is suggested that these stars have been misidentified as other variables, probably high-amplitude δ Scuti stars.

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FORGOTTEN 'OUT-OF-TOWN' MEETINGS: THE ROYAL ASTRONOMICAL SOCIETY IN BRISTOL 1956

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Background

The Observatory has reported on Royal Astronomical Society meetings of all kinds ever since it was launched in 1877. Indeed, the very first page of *The Observatory*[1] carried a report on the 1877 April RAS meeting.

The National Astronomy Meeting (NAM) arranged by the RAS is now a well-established part of the UK astronomical scene, with its site moving around the country from year to year since its first appearance under that name at Durham in 1992[2]. However, the idea of 'out-of-town' meetings (*i.e.*, outside London) goes back much further, with the first taking place in Edinburgh in 1948[3]. These were arranged in order to allow more non-London-based fellows the opportunity to attend an official meeting and were additions to the standard RAS programme, held during the Society's traditional recess ('long vacation') over the summer months. In their original form they ran intermittently until the 1960s. Another series, where one of the regular RAS meetings was held outside London, ran from 1976[3] until the first actual NAM. As we would expect, *The Observatory* covered all these meetings. Given that there were very few university astronomy groups at the time, how were these now nearly forgotten out-of-town meetings organized, who attended them, and what was discussed? An example is explored below.

Bristol 1956

One of the early run of out of town meetings was held, 65 years ago, at the University of Bristol, in 1956 July. This was the RAS's second visit to the south-west, University College of the South West of England (now the University of Exeter) having hosted the 1951 out-of-town event[3]. One might have imagined that Bristol's connection to the astronomical community at this point would have been through Cecil Powell's famous work in what was effectively experimental particle physics, utilizing cosmic rays. After all, this work had won

Powell the Nobel Prize in 1950 for the discovery of the pion. However, Powell and his Cosmic Ray Group appear to have had only peripheral involvement in the RAS meeting.

In fact, the link was through the Physics Department's Applied Optics Group. One of their research areas was the optics of Schmidt-type cameras, the topic of a colloquium at the meeting, as described below. Furthermore, immediately after the war and up to 1949, they had been in discussion with RAS President H. H. Plaskett and Astronomer Royal Harold Spencer Jones on the possibility that "one or more 100″ telescopes be developed at Bristol" for the planned Newton Observatory, *i.e.*, what eventually became the *Isaac Newton Telescope* at Herstmonceux. One member of the Applied Optics Group, Cecil R. ('Bill') Burch FRS, was on the Newton Observatory Board and discussions reached as high as Bristol's Vice-Chancellor, Philip Morris[4]. Though nothing came of it in the end, in 1956 it was, indeed, the Vice-Chancellor whom the RAS President thanked for inviting the Society to Bristol. Dr. W. John Bates, another member of the Applied Optics Group, was thanked for undertaking much of the work involved in the local organization of the meeting. (Burch remained in Bristol until his retirement in 1966 and, indeed, continued his research there until the early 1980s. Bates was later a reader at the University of Aberdeen, continuing to work on optical instrumentation.)

Events

The Bristol meeting was reported both in *MNRAS*[5] and *The Observatory*[6] and much of what follows concerning the structure of the meeting borrows heavily on the latter of these accounts.

The two days of events began at $10^{h}{\cdot}00$ on Monday 1956 July 9 with a Colloquium on 'Schmidt Optics', held in the H. H. Wills Physical Laboratory, with Dr. E. H. Linfoot in the chair. Edward Linfoot had been a lecturer in Pure Mathematics in Bristol who had developed an interest in the work in applied optics, but by 1956 was Assistant Director and John Couch Adams Astronomer at the Cambridge Observatories. He was involved as a consultant in the design of the *INT* and later the *AAT*.

Linfoot began the discussions with a review of the history and development of variants of the Schmidt design. After a couple of questions from the audience (from Mr. George Sisson, the general manager of Grubb Parsons, and the Rev. Patrick J. Treanor, SJ, of the Oxford University Observatory — he was later the director of the Vatican Observatory), the next speaker was Dr. W. R. Bradford on 'A Meniscus Schmidt Meteor Camera'. Bradford was a member of the Bristol Applied Optics Group, on secondment from the University of Manchester, who had been working on building meteor cameras for Jodrell Bank for some years, originally under the direction of Dr. Dorothy Hawkins in Bristol. He described a camera nearing completion which had a 56-degree-diameter field of view. At the end of his talk, his colleague Dr. Burch commented that "We should congratulate all concerned on completing this major manufacturing operation." Considerable discussion followed, with comments and questions from a distinguished trio of future luminaries, Mr. J. Ring, Dr. P. A. Wayman, and Dr. P. B. Fellgett. Jim Ring, later head of astronomy in Imperial College and a key figure in the history of *UKIRT*, was at that time a lecturer in Manchester (though he hadn't yet completed his PhD), Patrick Wayman was at the RGO, prior to becoming director of Dunsink Observatory, and Peter Fellgett was the Senior Assistant Observer at Cambridge before moving to the ROE and then becoming the UK's first professor of cybernetics, in Reading.

Burch then gave the next talk 'The Theory of Figured Thin Lenses'. He gave a mathematical treatment of how to remove aberrations from correcting lenses in Schmidt telescopes. At the end, Linfoot commented, it would appear rather condescendingly, that "We all appreciate Dr. Burch's interesting contribution." Although Linfoot had initially worked with Burch, apparently there was no love lost between the pair by the time Linfoot had left Bristol[4].

Dr. Wayman spoke on 'Small Stellar Images'. He discussed the combined effects on image size of atmospheric seeing, Schmidt-camera optics and, particularly, of photographic emulsions, and how these affected the limiting magnitude of a telescope. Dr. David W. Dewhurst had recently been promoted to Senior Assistant Observer and Librarian in Cambridge (the latter a post he held for many years) and he gave the final talk, on 'In-focus Photometry with Schmidt Telescopes'. He noted that it was surprising that there had been no major advance in this subject as larger Schmidt telescopes came into use. (Recall that at this time stellar photometry often used out-of-focus images so that the light was more spread out on the emulsion.)

The chairman then called for questions on the final two papers. This elicited comments from Dr. E. J. Öpik (see below), Miss Middlehurst, Mr. Ring, Mr. G. Turner, and Dr. A. Hunter. Barbara Middlehurst, then at St. Andrews Observatory, subsequently moved to the USA where she worked on Transient Lunar Phenomena. She was also an editor of the epic nine-volume *Stars and Stellar Systems*. Geoffrey Turner was at the University of Manchester and published on lunar topology. Alan Hunter was Chief Assistant at the RGO, the head of the Astrometry section, and ultimately its Director and a CBE.

The afternoon and some of the following day was free for more informal events. "Trips to places of interest included a number of excursions to points of archaeological and scenic interest in Somerset; a visit, kindly arranged by Mr. Jack Miller, to the H. H. Wills tobacco factory in Bedminster; and an inspection of work in progress at the University Physics Laboratory" (whose building, like many others around Bristol University, was built with money from the Wills family). The last of these events leads to the only mention of Powell's group during the whole meeting: "Many fellows … saw with especial interest both the cosmic-ray section which has pioneered the use of high altitude balloons and the large Meniscus Schmidt Meteor Camera."

The less formal report in *The Observatory* notes that "A smaller number of the more worldly inclined preferred instead a visit to Messrs Wills' Tobacco Factory … . The interest of the tour offset the discomfort of those addicted to 'the habit', who seemed to find the non-smoking rule in the factory in the presence of so much tobacco a little trying: the increased opacity of the atmosphere in the returning coach was remarked by several."

Given his outside career, it seems likely that the 'Mr. Miller' who arranged the trip was Jack Gordon Miller, actually born Pinchas Mogilvsky in a Russian village north of Odessa. He had come to England in 1904, changed his name to Miller, and later joined his father-in-law's wholesale tobacco business. His RAS obituary credits him with the idea of setting up tobacconist's kiosks at railway stations. A keen solar observer, who went on two eclipse expeditions, he joined the British Astronomical Association in 1933, and became a fellow of the RAS in 1953. He personally purchased the Palomar Observatory Sky Survey for the Society. His wife's nephew was the legendary violinist Yehudi Menuhin.

After a sherry party in Wills Hall as guests of the University, in the evening the Astronomer Royal Spencer Jones gave a public lecture on 'The *Isaac Newton Telescope* Proposals', evidently considered a hot topic at the time; the *INT*, effectively first proposed in 1945 actually came into operation in 1967.

In the early part of the Tuesday, the previously mentioned excursion to Somerset took place while other Fellows "went on a pilgrimage to Bath, where the guide was persuaded to modify his usual tour to include visits to places associated with William Herschel."

In the afternoon of July 10, the 'Additional Meeting' of the Society, in the Physics Lecture Theatre, was chaired by the RAS President, Professor Sir Harold Jeffreys. Jeffreys, FRS since 1925, was a distinguished mathematician, statistician, and geophysicist and was Plumian Professor of Astronomy in Cambridge from 1945. (Hermann Bondi (see below) was one of his doctoral students in the 1940s.)

After some Society business (including accepting a 'present', from its publishers, of the book *The Planet Venus* by a then relatively unknown P. A. Moore — *Sky at Night* was still a year away), Dr. Ernst Öpik spoke on 'changes which had recently taken place in the *ADH* organization'. Öpik, educated in Tsarist Russia and remembered these days for his 1922 paper predicting the distance to the Andromeda Nebula from dynamical considerations, was on the staff of Armagh Observatory and *ADH* was the Armagh–Dunsink–Harvard telescope. As per the talks the previous day, the *ADH* was a large telescope of modified Schmidt design. The changes referred to were the withdrawal of Harvard and the addition of new partners from Hamburg, Uccle (Belgium), and Stockholm, though the telescope still went to Harvard's Boyden Station, now Boyden Observatory, near Bloemfontein, South Africa.

According to the report in *The Observatory*, a convention-defying novelty was to have the tea break in the middle of the meeting.

However, in time-honoured fashion, there followed the reading of papers recently received by the Society. Dr. Donald E. Blackwell presented a paper on 'Observations of the Zodiacal Light at Small Elongations using an Aircraft'. He noted that the zodiacal light was (at the time) generally supposed to be the outer extension of the Solar Corona. A test of this was to observe the polarization of the zodiacal light as near to the Sun as possible, and this was best done through a clear atmosphere and when the zodiacal light was nearly perpendicular to a sea horizon. He reported that the Cambridge Solar Physics Observatory (where he was Assistant Director, before a long career as Savilian Professor at Oxford) had been able to carry out such an observation from a New Zealand Air Force Sunderland flying boat off Fiji. Blackwell had 'previous' for such perilous observing; in 1954 he had observed an eclipse from the open hatch of a Lincoln bomber at 30 000 feet! After the talk he answered queries from Professors Bondi (see below) and Stratton and Miss Cecily M. Botley.

Lieutenant-Colonel Frederick John Marrian Stratton DSO OBE, to give him his full title, had served in both World Wars, was third wrangler, behind Arthur Eddington, at Cambridge in 1904, and was Professor of Astrophysics and Director of the Solar Observatory there from 1928 to 1947. Miss Botley, according to Patrick Moore's obituary of her in *Quarterly Journal* in 1992, "was certainly a 'character' … [who] spent her time collecting data — many of which were obscure". She was a noted historian of astronomy and was a well-known figure at RAS meeting for very many years, having been elected a Fellow in 1938.

Mr. J. E. Geake presented a paper by Dr. W. L. Wilcock and himself on 'An Astronomical Photoelectric Spectrophotometer'. He reported on using a photocell to scan across a prism spectrum in order to measure directly intensity as a function of wavelength. John Geake was then a PhD student at the Physical Laboratories, University of Manchester, and went on to a career at UMIST as a noted lunar scientist, analysing lunar samples for both NASA and the Soviet space agencies. Leslie Wilcock was also in Manchester and both he and Geake collaborated with Ring (see above) on instrumental projects. Like Ring, Wilcock gravitated to Imperial College and worked on early image intensifiers.

In a lengthy discussion of the paper, questions were asked by Mr. R. F. Berrill, Mr. H. N. Ryan, Dr. R. d'E. Atkinson, Dr. R. H. Garstang, Dr. M. J. Smyth, Rev. Treanor, and Dr. Dewhurst. Roland Fabien Berrill, the rather eccentric co-founder of MENSA, was a keen amateur who went on the joint RAS–BAA eclipse expedition to Lysekil, Sweden, in 1954. Hugh Norman Ryan, presumably another amateur, joined the BAA in 1949 and was elected FRAS in 1950. He was entrusted with the role of 'scrutineer of the ballot' for Council membership a few years later. Robert d'Escourt Atkinson was Chief Assistant at the RGO. Before the war he had made theoretical models of fusion processes in stars which were well ahead of their time, but at the RGO he worked primarily on instrumentation. An expert in atomic transitions, Roy Garstang was, at the time, a lecturer at UCL, later becoming Chairman of JILA in Boulder, Colorado. He was also an editor of *The Observatory* at this point so may well have been the anonymous author of the meeting report. Michael Smyth, an instrumentalist and solar physicist, formerly at ROE, was at Dunsink.

Mr. B. Elsmore then described a paper by Messrs C. H. Costain, G. R. Whitfield, and himself on 'Radio Observations of a Lunar Occultation of the Crab Nebula'. He noted that the centre of the Moon as seen from Cambridge had passed almost over the centre of the nebula and that the occultation timing implied that the radio source had different extents at the two observed wavelengths. The observed length of the occultation being slightly different to that calculated was also taken as evidence for refraction in the [assumed] lunar atmosphere. Hermann Bondi was unconvinced by the latter though, stating that "it is difficult to believe that any significance can be placed on your result … I regard your interpretation to be an unjustifiable deduction from the observation." Messrs J. Kershaw, Berrill and Ryan, Drs. Atkinson and Dewhurst and 'A Fellow' had less-damning queries. Mr. Elsmore got his own back, too, noting that Bondi's suggestion that it would be better to use the smaller Cas A or Cyg A radio sources would not work as they were never occulted by the Moon!

Bruce Elsmore had been one of the first recruits to Martin Ryle's radio astronomy group and became a pioneer in aperture-synthesis observations. He was a co-author on the *1st Cambridge Catalogue* with Ryle and Graham Smith. Elsmore and student George Whitfield, who was compiling radio-source spectra, were the first to observe *Sputnik 1* passing over England on 1957 October 4. Carman Costain was the first Canadian to obtain a PhD in radio astronomy, for work on Galactic radio emission (supervised by Graham Smith), and continued this at the Dominion Radio Astronomy Observatory. Questioner James Kershaw was elected as a Fellow in 1952 and appears to have been active in Merseyside astronomy, proposing several other Fellows from that area.

The President then stated that Professor Bondi had agreed to describe two papers by Mr. F. Hoyle and Mr. C. B. Haselgrove entitled 'A Mathematical Discussion of the Problem of Stellar Evolution with Reference to the use of an Automatic Digital Computer' and 'A Preliminary Determination of the Age of Type II Stars'. The first paper described a method for following the evolution of a stellar model using the *EDSAC 1* computer at Cambridge. The model allowed for changes in opacity and for "energy generation from the helium reaction, producing oxygen, as well as the carbon–nitrogen cycle and the proton–proton chain". The second paper considered the evolution of the structure of a 1·26-

solar mass star at 15 different stages ending, at the top of the Population II giant branch, after just over 6 billion years. Questions were asked by Dr. P. A. Sweet, Dr. Atkinson and Mr. Berrill. These concluded the session.

Hermann Bondi was already, as we have seen, a professor (at King's College, London) by this time. He had arrived from Austria before the *Anschluss* at the invitation of Eddington, and after the war he lectured in mathematics at Cambridge, becoming most famous for the Steady State Theory of the Universe which he devised with Hoyle and Gold in 1948. (This was actually first presented at the Edinburgh out-of-town meeting mentioned earlier.) He was later Director General of ESRO (now ESA) and a government Chief Scientific Adviser.

Fred Hoyle first met Bondi and Gold during the war when working for the Admiralty on radar research with Maurice Pryce, who coincidently was head of Physics in Bristol in 1956. Returning to Cambridge to lecture, he not only worked on cosmology, but also stellar structure and particularly stellar nucleosynthesis (the famous B^2FH paper with the Burbidges and Fowler). Still 'Mr. Hoyle' in 1956 (he never bothered with a PhD), he became Plumian Professor two years later and then the founding Director of the Institute of Astronomy in Cambridge. His collaborator on the 1956 papers, Brian Haselgrove, was a Cambridge mathematician, a number theorist, who was among the first to use computer programmes to solve problems in pure mathematics. Peter Sweet, who asked one of the questions, had actually been Hoyle's graduate student and was currently Assistant Director of the University of London Observatory. He was later the long-serving Regius Professor of Astronomy in Glasgow.

On the Tuesday evening, Fellows were guests of the Lord Mayor and Council of the City at a reception in the (recently completed) Council House on College Green. The programme ended with a dinner in Wills Hall, the student residence where the attendees had been housed. Summarizing, *The Observatory*'s correspondent stated that "Good weather, the comfortable accommodation … and the hospitality of the City and University combined to make a most successful provincial meeting."

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 2: THE ECCENTRIC SOLAR-TYPE SYSTEM KX CANCRI

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KX Cancri is an eclipsing binary containing two G-type stars with an orbital period of $31^{\rm d}\!\cdot\!2$ and an eccentricity of 0·47. These qualities make it a promising candidate for a benchmark solar-type binary system. We analyse the first light-curve of this system to have complete coverage of both primary and secondary eclipses, obtained using the *Transiting Exoplanet Survey Satellite* (*TESS*).

We augment these data with published radial velocities and measure the masses to be $1{\cdot}134 \pm 0{\cdot}003\,M_{\odot}$ and $1{\cdot}124 \pm 0{\cdot}005\,M_{\odot}$ and the radii to be $1{\cdot}053 \pm 0{\cdot}006\,R_{\odot}$ and $1{\cdot}059 \pm 0{\cdot}005\,R_{\odot}$. A ratio of the radii near unity is strongly preferred by the *TESS* data, in contrast to existing ground-based light-curves. The distance to the system measured from the radii and $T_{\rm eff}$ values of the stars agrees well with the trigonometric parallax from the *Gaia* satellite. The properties of the system are consistent with theoretical predictions for a super-solar metallicity and an age of 1·0–1·5 Gyr. A detailed analysis of the photospheric properties of the stars based on high-resolution spectra is encouraged.

Introduction

Eclipsing binary stars provide our main source of direct measurements of the physical properties (mass, radius, luminosity) of normal stars[1,2]. Their properties can be measured using only observational data and algebra[3,4] so are valuable in calibrating and assessing our understanding of stellar physics[5–7], the chemistry of the Universe[8,9], and the cosmological distance scale[10,11].

Arguably the most important class of eclipsing system is that of the detached eclipsing binaries (dEBs), because their component stars have experienced no mass transfer so are representative of normal stars. The best benchmark system has well-separated stars so tidal effects are negligible, and precise measurements of the masses, radii, effective temperature ($T_{\rm eff}$) values, luminosities, and photospheric chemical abundances of the two components.

dEBs containing stars similar to our Sun are particularly useful because they allow a direct comparison with the star by far the best-understood by humans, and thus aid the understanding of stellar structure as a function of time and chemical composition around the solar fiducial point. Those with an orbital period longer than approximately $10^{\rm d}$ are negligibly affected by tides and thus are most directly comparable to single stars such as our Sun; examples of such systems are V1094 Tauri[12], LL Aquarii[13,14], Kepler-34[15], and KIC 7177553S[16].

This is the second of a series of papers aimed at providing improved measurements of the physical properties of dEBs using data that have recently become available in photometric surveys performed by space telescopes[17–19]. A particular aim is curation of the *DEBCat*★ (*Detached Eclipsing Binary*

TABLE I

Basic information on KX Cnc

Property	*Value*	*Reference*
Henry Draper designation	HD 74057	22
Hipparcos designation	HIP 42753	23
Gaia DR2 ID	709910784966516992	24
Gaia parallax	20·282 ± 0·051 mas	24
B magnitude	7·76 ± 0·01	25
V magnitude	7·19 ± 0·01	25
J magnitude	6·509 ± 0·021	26
H magnitude	6·278 ± 0·027	26
Ks magnitude	6·213 ± 0·018	26
Spectral type	G0V + G1V	This work

Catalogue) list of dEBs with precise mass and radius measurements[20]. A detailed justification is given in the first paper of the series[21], which presented a reanalysis of the bright B-type dEB ζ Phoenicis.

In this work we analyse the dEB KX Cancri (HD 74057), which contains two solar-type stars on a relatively long-period orbit so is an excellent candidate for becoming a benchmark system. Basic observational properties of the system are given in Table I. KX Cnc was discovered to be eclipsing by Davies[27,28] and independently by Sowell *et al.*[29]. The latter work presented extensive photometry in the Strömgren *b* and *y* passbands plus radial velocities (RVs) for the two stars from a total of 26 high-resolution coudé spectra. They determined the masses and radii to precisions of 0·3% and 0·2%, respectively. Such a precision in radius is surprising, as the system does not show total eclipses and the first and last contact points of the secondary eclipse were not observed. However, a space-based light-curve of this system, with full coverage of both primary and secondary eclipses, is now available. The analysis of KX Cnc using these new data is described below.

Observational material

As with Paper I[21], the new data for the target dEB come from the NASA *TESS* satellite[19]. KX Cnc was observed in camera 1 during Sector 21 (2020/01/21 to 2020/02/18). The light-curve covers $27^{d}\cdot4$, with a break near the midpoint for download of data to Earth, at a cadence of 120 s.

For this work we used the simple aperture photometry (SAP) and not the pre-search data conditioning (PDC) light-curve[30]. Our experience of *TESS* data is that the PDC light-curves, which receive additional processing beyond that for the SAP data, can become unreliable when there is strong variability in the target star (*e.g.*, deep eclipses such as found in KX Cnc).

We retained only data with no flagged problems (QUALITY = 0), comprising 17327 data-points. The data were further trimmed by removing points more than 1·5 eclipse durations from the midpoint of an eclipse, as the out-of-eclipse data are essentially devoid of information on the masses and radii of the stars, leaving a total of 1618 data-points. We ignored the error bars of the measurements, as they are far too small.

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

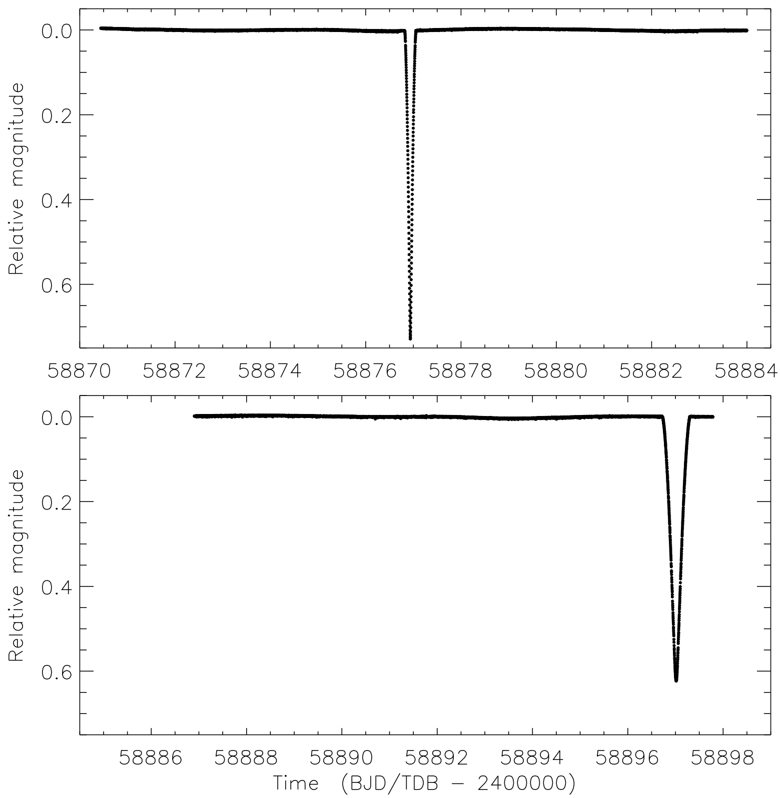

FIG. 1

TESS simple aperture photometry of KX Cnc. The upper and lower plots show the observations either side of the mid-sector pause for data download.

Analysis of ground-based light-curves

The stars are well-separated and almost spherical, so the system can be reliably modelled using the JKTEBOP code*, for which we used version 40[31,13]. Results from the use of JKTEBOP have been found to be in good agreement with other codes for well-detached systems[32]. We follow the definition that the primary star is the one eclipsed during the deeper eclipse; we designate this as star A and the secondary star as star B. In the case of KX Cnc, star A has a larger mass and higher $T_{\rm eff}$ than star B, but not by significant amounts.

The radii of the stars in the JKTEBOP fits were parameterized by sum and ratio of the fractional radii ($r_{\rm A} = R_{\rm A}/a$ and $r_{\rm B} = R_{\rm B}/a$ where $R_{\rm A}$ and $R_{\rm B}$ are the true radii and a is the orbital semi-major axis). The orbital shape was parameterized by the Poincaré elements ($e \cos \omega$ and $e \sin \omega$ where e is the orbital eccentricity and ω is the argument of periastron). We included $r_{\rm A} + r_{\rm B}$, k ($= r_{\rm A}/r_{\rm B}$), $e \cos \omega$, $e \sin \omega$, the orbital inclination and the central surface-brightness ratio as

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

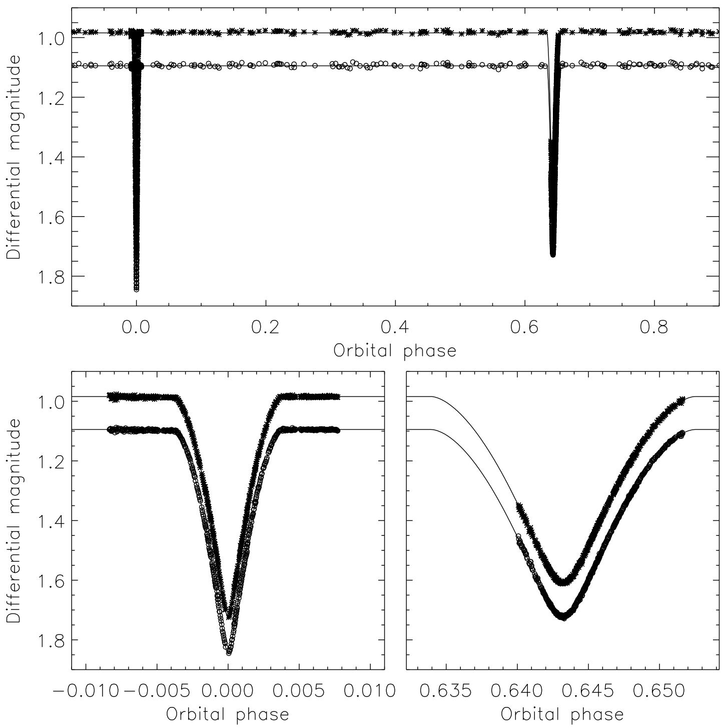

FIG. 2

The Strömgren *b*-band (crosses) and *y*-band (open circles) data obtained Sowell *et al.*[29] *versus* the JKTEBOP best fits from the current work (solid lines). The full light-curve is shown in the upper panel, and close-ups of the primary and secondary eclipses in the lower panels.

fitted parameters. Limb darkening was represented using the quadratic law, the coefficients were assumed to be the same for both stars, the linear coefficient was fitted, and the nonlinear coefficient was fixed to a suitable value from Claret[33,34]. These assumptions were checked and found to have a negligible impact on the best fits.

We began by modelling the photometry and RVs of the two stars from Sowell *et al.*[29]. We fitted the *b*-band and *y*-band data separately as JKTEBOP can only deal with one passband at once. Uncertainties were computed using Monte Carlo simulations[31] after adjusting the data errors so that the reduced χ^2 of each of the three datasets (*y*-band light-curve and RVs of each star) was unity. The orbital period and reference time of minimum were included as fitted parameters. We found similar results to Sowell *et al.*, but with error bars typically slightly larger. Sowell *et al.* used the Wilson–Devinney code[35,36] and give no information on how their error bars were obtained. Their error bars are likely to be formal errors, which are known to be underestimated in many cases[37–42]. Our best fits to the *y* and *b* data are shown in Fig. 2.

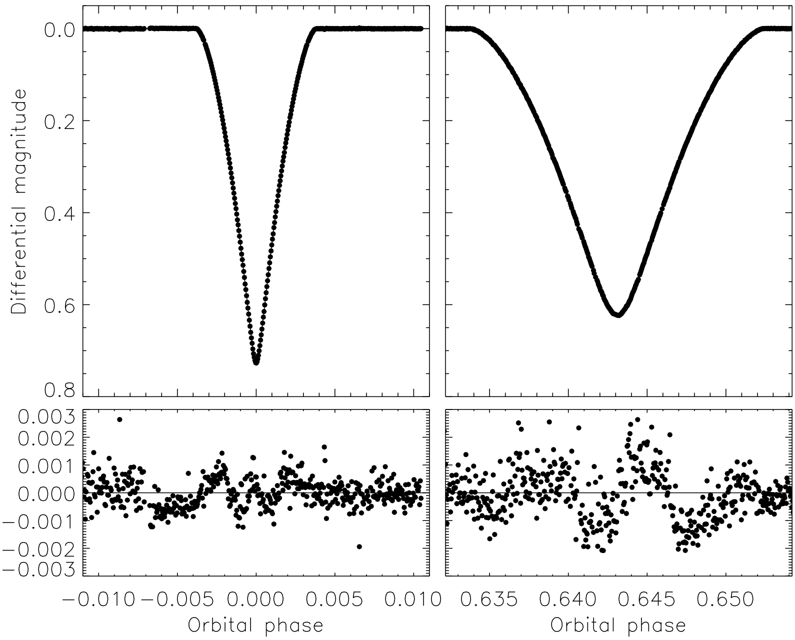

FIG. 3

The *TESS* light-curve of KX Cnc around the primary (left) and secondary (right) eclipses. The JKTEBOP best fit is shown using a solid line. The lower panels show the residuals of the fit on a magnified scale.

Analysis of space-based light-curve

We then moved to modelling the *TESS* photometry, using only the data near eclipse. The orbital period and reference time of minimum were fitted, and we included the measured time of primary minimum from the analysis of the ground-based data above in order to increase the precision of the ephemeris. Quadratic functions were applied to the brightness of the system through each eclipse, to remove any remaining slow trends in brightness arising from either astrophysical or instrumental causes. We also retained the RVs of the two stars to help define the orbital shape of the system. Third light was checked for and found to be negligible, so was fixed at zero. The quality of the fit (Fig. 3) is good but not perfect, and the systematics in the residuals can be attributed to the presence of dark starspots on one or both stars (see below). The secondary eclipse occurs at an orbital phase of 0·6431.

The best fit of the *TESS* data occurs for a noticeably larger ratio of the radii than for the *b*- and *y*-band ground-based data. To investigate this we ran a default solution, and used this to scale the error bars of each individual dataset (*TESS* light-curve and the RVs of each star) to force a reduced χ^2 of unity. We then performed fits to these data with the ratio of the radii fixed at values from 0·9 to 1·1 in intervals of 0·002, and repeated this process for the *b* and *y* data.

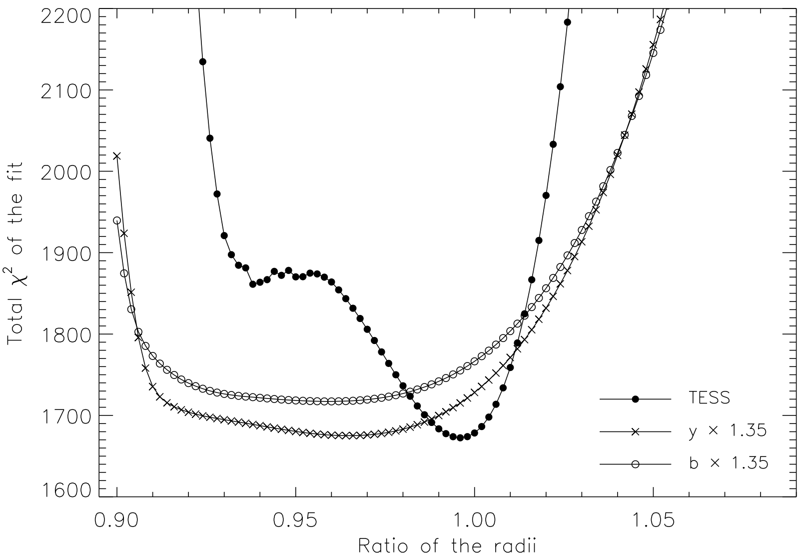

FIG. 4

The total χ^2 of the fit to the three available light-curves of KX Cnc, for a grid of values of the ratio of the radii. The results for each light-curve are shown with different symbols (see key). Each fit also included the RVs of the two stars from Sowell *et al.*[29]. The results for the *y* and *b* light-curves have been multiplied by a factor of 1·35 to give them approximately the same minimum χ^2 as the *TESS* data.

Fig. 4 shows the χ^2 of the fits *versus* the ratio of the radii in all three cases. For the *TESS* data there is a clear minimum around $k = 1$, whereas the *b* and *y* light-curves have a much broader minimum around $k = 0{\cdot}96$. The *TESS* data clearly provide a more tightly constrained solution, and we attribute this to the complete coverage of all eclipse phases (the ground-based data miss the first and last contact points of secondary eclipse). Out of curiosity we repeated this process without the RVs, and found a negligible difference. We conclude that e and ω are well defined by the photometry alone in this case.

With the results from the previous paragraph in mind, we proceeded to determine the physical parameters of KX Cnc using the *TESS* data and Sowell *et al.*[29] RVs, with error bars scaled so each dataset yielded a reduced χ^2 of unity. The systemic velocity was fitted separately for the two stars, but the values were found to be in good agreement. Uncertainties in the fitted parameters were calculated using Monte Carlo and residual-permutation algorithms[31]. The final best fit and uncertainties are given in Table II. Whilst the ratio of the radii is formally greater than unity, it is so by only an insignificant amount. The light ratio found in this solution agrees well with the spectroscopic value of 0·9685 found by Sowell *et al.*

Physical properties and distance

For a full picture of the properties of KX Cnc we required estimates of the $T_{\rm eff}$ values of the stars. We obtained them from Sowell *et al.*, and confirmed that their ratio was in good agreement with the central surface-brightness ratio

TABLE II

Best fit to the TESS light-curve and ground-based RVs of KX Cnc obtained with JKTEBOP. The 1σ uncertainties have been calculated using Monte Carlo and residual-permutation algorithms. The same limb-darkening coefficients were used for both stars. The uncertainties in the systemic velocities do not account for any transformations onto a standard system, which are likely much larger than the quoted error bars.

Parameter	*Value*
Fitted parameters:	
Primary eclipse time (BJD/TDB)	2458876·93684 ± 0·00002
Orbital period (d)	1·2198786 ± 0·0000006
Orbital inclination (°)	89·829 ± 0·001
Sum of the fractional radii	0·038580 ± 0·000014
Ratio of the radii	1·0060 ± 0·0039
Central surface-brightness ratio	0·9641 ± 0·0015
Linear limb-darkening coefficient	0·2946 ± 0·0047
Quadratic limb-darkening coefficient	0·21 (fixed)
$e \cos \omega$	0·20548 ± 0·00004
$e \sin \omega$	0·42267 ± 0·00042
Velocity amplitude of star A (km s^{-1})	50·021 ± 0·095
Velocity amplitude of star B (km s^{-1})	50·485 ± 0·053
Systemic velocity of star A (km s^{-1})	4·975 ± 0·005
Systemic velocity of star B (km s^{-1})	5·032 ± 0·004
Derived parameters:	
Fractional radius of star A	0·01923 ± 0·00010
Fractional radius of star B	0·01935 ± 0·00009
Orbital eccentricity	0·46997 ± 0·00036
Argument of periastron (°)	64·074 ± 0·027
Light ratio	0·9756 ± 0·0061

determined from the JKTEBOP solution of the *TESS* light-curve. The $T_{\rm eff}$ values, and the surface gravities, of the stars are consistent with spectral types of G0V and G1V using the calibration by Pecaut & Mamajek[43].

The $T_{\rm eff}$ values were augmented by the fractional radii, orbital inclination and eccentricity, period and velocity amplitude determined in the previous section, and provided to the JKTABSDIM code[44,21]. This yielded the physical properties of the system, with uncertainties propagated using a perturbation approach, given in Table III. The masses and radii are determined to precisions of 0·5% or better. The measured properties exhibit an inverted mass–radius relation — star B is less massive but larger than star A — which is not expected from stellar theory. However, this result is measured to only the 1·5σ level (see the ratio of the radii in Table II) so is not significant. The two stars are both physically very similar to our Sun.

The distance to KX Cnc was determined using the apparent magnitudes of the system in the *BV* and *JHK*s bands (see Table I) and the physical properties. This was done in two ways: the surface-brightness method[44] with the empirical surface-brightness calibration from Kervella *et al.*[46], and the bolometric correction method with the theoretical bolometric corrections from Girardi *et al.*[47]. The distances found for the *BV* bands are in good agreement with, but less precise than, the parallax distance of 49·30 ± 0·12 pc from *Gaia* DR2[24]. This agreement is evidence that the $T_{\rm eff}$ values of the stars are reliable, but it would be worthwhile in future to perform a detailed spectroscopic analysis in order to determine photospheric abundances and more precise $T_{\rm eff}$ values.

TABLE III

Physical properties of KX Cnc.
The T_{eff} values are from Sowell et al.[29].
Units superscripted with an 'N' are defined by IAU 2015 Resolution B3[45].

Parameter	*Star A*	*Star B*
Mass ratio	0.9908 ± 0.0021	
Semi-major axis ($R^{N}_{\odot}$)	54.744 ± 0.060	
Mass ($M^{N}_{\odot}$)	1.1345 ± 0.0032	1.1241 ± 0.0045
Radius ($R^{N}_{\odot}$)	1.0527 ± 0.0056	1.0593 ± 0.0051
Surface gravity (log[cgs])	4.4825 ± 0.0045	4.4388 ± 0.0041
Density ($\rho_{\odot}$)	0.972 ± 0.015	0.946 ± 0.013
Synchronous rotational velocity (kms^{-1})	1.706 ± 0.009	1.717 ± 0.008
$T_{\rm eff}$ (K)	5900 ± 100	5843 ± 100
Luminosity $\log(L/L^{N}_{\odot})$	0.083 ± 0.030	0.071 ± 0.030
$M_{\rm bol}$ (mag)	4.53 ± 0.07	4.57 ± 0.08

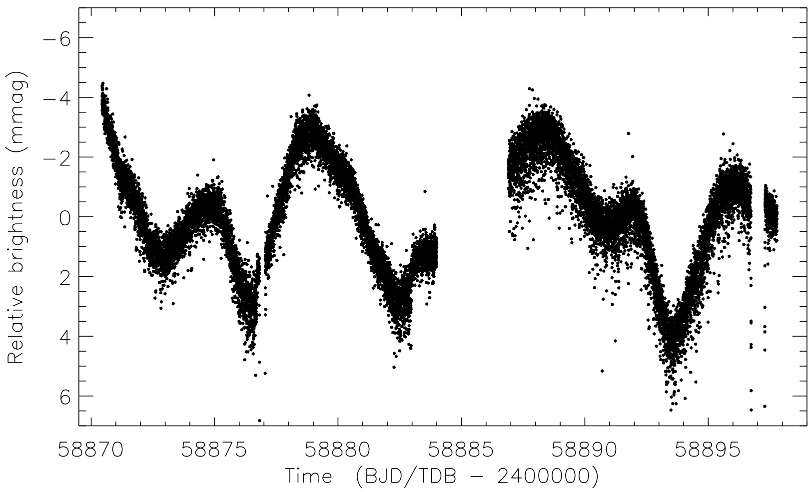

FIG. 5

The *TESS* light-curve of KX Cnc, with the *y*-axis limits chosen to show the out-of-eclipse variability due to starspots.

The distances obtained in the *JHK*s bands should be more reliable because of the tighter empirical calibration and lesser effect of interstellar extinction, but are anomalously large. On investigating this we found that the 2MASS observations of KX Cnc[26] were taken at an orbital phase of 0·6410, which is during secondary eclipse (see Fig. 3) when the light from the system is fainter than the combined light of the two stars.

Starspot activity and tidal effects

KX Cnc contains two solar-type stars so photometric variability due to starspots is a possibility[48,49]. Fig. 5 shows the *TESS* light-curve of KX Cnc with a magnified *y*-axis to make the out-of-eclipse variability easier to see. There are clear signatures of rotational variability in the light-curve, but evolution of the spots means that consecutive rotational periods of the star(s) do not repeat the same pattern of variability. A rotation period of $9{\cdot}0 \pm 0{\cdot}2$ d provides a plausible solution to the rotational modulation seen in the *TESS* light-curve of KX Cnc.

Sowell *et al.*[29] measured a rotational period of $8^{\rm d}{\cdot}49$ from photometric monitoring of the system over two observing seasons. This value is slightly shorter than suggested by the *TESS* light-curve, and is based on data that are sparser but with a much better temporal baseline. Sowell *et al.* measured rotational velocities $v \sin i$ of $6{\cdot}4 \pm 1{\cdot}0$ km s^{-1} and $6{\cdot}5 \pm 1{\cdot}0$ km s^{-1} for star A and star B, respectively, from their spectral line widths. With the radii measured in the previous section, these correspond to rotation periods of $8^{\rm d}{\cdot}3 \pm 0^{\rm d}{\cdot}1$ and $8^{\rm d}{\cdot}2 \pm 0^{\rm d}{\cdot}1$, respectively. The rotation of the stars is thus approximately consistent with the observed rotation periods, and is also greater than the synchronous and pseudosynchronous rotational velocities.

The system is therefore tidally unevolved: the orbit is not circularized and the stars are not rotating either synchronously or pseudosynchronously. This is not surprising due to the weakness of tidal effects at this orbital period. The theory of Zahn[50] gives the timescales of orbital circularization and rotational synchronization to be approximately 10 Gyr and 30 Tyr, respectively (Zahn's equations 6.1 and 6.2 for convective-envelope stars). These are both significantly longer than the age of KX Cnc, in agreement with its eccentric orbit and super-synchronous stellar rotation[51].

Conclusion

The eclipsing binary system KX Cnc contains two stars similar to the Sun on an eccentric 31-d orbit. We have determined the physical properties of the system based on published RVs[29] and the *TESS* light-curve, measuring masses and radii to precisions of 0·5% or better. The *TESS* light-curve is the first to have complete coverage of both eclipses, and leads to a ratio of the radii that is close to unity. It also shows clear brightness modulation due to starspots, and this modulation is consistent with the rotation period determined from ground-based light-curves[29] and the spectroscopic rotational velocities of the stars[29].

We have compared the masses, radii, and $T_{\rm eff}$ values of the two stars to the predictions of several theoretical models[52–54]. This is relatively uninformative because the two stars are very similar, but does allow an age and chemical composition to be inferred. All properties of the stars can be matched for an age of 1·0–1·5 Gyr and a metal abundance 1·5 times the solar value. This metal abundance matches the slightly super-solar metallicity inferred by Sowell *et al.*[29] from comparison between the spectra of KX Cnc and of standard stars.

Our understanding of KX Cnc would be improved by a detailed analysis of high-resolution spectra to obtain the $T_{\rm eff}$ values and photospheric chemical abundances of the stars. With this information, it will become a benchmark system capable of providing an important test of theoretical models of the evolution of solar-type stars.

Acknowledgements

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CORRESPONDENCE

To the Editors of 'The Observatory'

Not a Moribund Institution

When Dr. Richard Woolley arrived at the Royal Greenwich Observatory it has been claimed that he found a moribund institution; see these pages (**140**, 157, 2020). This may have been true of astrophysics, where deaths and career moves had taken a toll, but seems too harsh when the work on geodesy by the RGO and the Nautical Almanac Office combined is also taken into account. I had many car journeys with Woolley at that period to Donald Sadler's home and many conversations, mainly about bridge but sometimes touching on more technical matters that came up each working day: Did the time signals need to be changed? Dr. Robert d'Escourt Atkinson pointed out that they would automatically go in with the average of other time signals. Could the difference between Ephemeris Time and UT be determined with the Markovitz moon camera? Hopefully, yes.

The commissioning of a Photographic Zenith Tube at Herstmonceux (and other PZTs elsewhere) together with the invention of the Caesium clock and advances in satellite navigation meant, in the famous phrase, "you have reached your destination" to a precision of about 20 feet. And yes, it was sensible to move the Prime Meridian.

Charles II would have been surprised and very pleased.

Yours sincerely,
PHILLIP GETHING

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2020 August 10

REVIEWS

Einstein in Bohemia, by Michael D. Gordin (Princeton University Press), 2020. Pp. 360, 24 × 16 cm. Price £25 (hardbound; ISBN 978 0 691 17737 3).

Michael D. Gordin is a distinguished historian of modern physical sciences and Russian history at Princeton University. As an academic he is curious, creative, multi-talented, and a historian with an exceptional ability of writing for a general readership. He is a vivid writer who uses a biographical approach to bring the past and its people alive, taking great care with descriptions of the landscapes, contexts, and social interactions of the principal characters. The narrative pivots around the sixteen months, from Spring 1911, that Einstein, with his wife Mileva and their two sons, lived in Prague, after he had accepted the chair in theoretical physics at the German University. Modern biographers have looked at the period as an interlude between his 1905 *Annus Mirabilis* and his move, *via* ETH Zurich, to the Prussian Academy of Sciences in 1914. Apparently, nothing much happened in Prague, apart from the disintegration of Einstein's marriage and the completion of his paper on the gravitational deflection of light in 1911 June.

However, Gordin's forensic narrative recounts a more elaborate and absorbing story. By the end of the long 19th Century, Prague was a major hub of European science, with a proud history relating to astronomy: Tycho Brahe, Johannes Kepler, Christian Doppler, and Ernst Mach had lived there. Bohemia — the westernmost region of the Czech lands — was prosperous and modern, with a large chemical industry and highly productive agriculture. Prague had an electric-tram network by 1891, three years after Paris and a decade ahead of London. It hosted international conferences and was well connected with Germanophone universities throughout Central Europe. It was through this network that Einstein was recruited. Although this was less desirable than a position in Vienna or Berlin, Einstein perceived Prague as a well-paid staging post on his journey to towering fame. The negatives included strident nationalism concerning language issues. When Einstein arrived in the city the Germanophone population had declined to seven percent of the population. Einstein encountered hostility toward Germans and anti-Semitism. Within 16 months Einstein was on his way to Berlin. This account of his challenging interlude in Bohemia is at once informative, engaging, and enjoyable. — SIMON MITTON.

Decoding the Stars: A Biography of Angelo Secchi, Jesuit and Scientist, by Ileana Chinnici (Brill), 2019. Pp.367, 24 × 16 cm. Price $169 (about £128) (hardbound; ISBN 978 90 04 38729 4).

Jesuits have long been involved in education, as the first teaching order within the Catholic church, and this well-written and searching biography of Angelo Secchi (as part of Brill's *Jesuit Studies* series) nicely chronicles his life, his religious education and faith, his scientific work, his expeditions, and his controversies, and describes how he came to publish several very important educational and specialist works. The book is very well illustrated, and most of the illustrations were new to this reviewer.

Angelo Secchi lived in uncertain times. Science, including astronomy, was developing quickly in the mid-19th Century, at a time of important socio-political change throughout Europe. The process of consolidation of the various states of the Italian peninsula into what would become the Kingdom of Italy, catalysed by widespread revolutions in 1848, was completed in 1861. The Pope retained a French army garrison in Rome until Napoleon III withdrew it in 1870 when the Franco–Prussian War broke out, after which the Papal State enjoyed no further military protection, and Pius IX was stripped of much of his former power. It was against this background of tumultuous change and uncertainty that Secchi directed the Collegio Romano Observatory with distinction (and modest resources) from 1852 till his death in 1878, aged 59. Secchi's background in physics no doubt helped him greatly, in particular by suggesting new and original lines of research for his institution. He was a pragmatist and a hands-on scientist who preferred observation to theory. There is no doubt that Secchi was also a faithful Catholic who was devoted to Pius IX. The latter, who had a scientific background, held Secchi in high regard. Religious and political matters are naturally dealt with throughout the book, including the exile of the Jesuits from Rome during 1848–49, when Secchi stayed at Stonyhurst College.

I first studied Secchi's writings when writing a monograph about Martian dust storms, for his original drawings of the 1858 opposition (still preserved in Rome) provide an early example of the phenomenon. It was at once obvious that Secchi was a skilful observer who drew sensible conclusions from his data. Today, however, Secchi is best remembered for his pioneering work on the spectroscopic classification of stars.

A great deal of Secchi's observational work concerned solar prominences. By combining his 1860 photographic total-eclipse observations with those of Warren de la Rue taken at a different location, he could conclusively prove that the prominences were phenomena associated with the solar limb. Ileana Chinnici describes how Secchi and his younger friend and colleague Pietro Tacchini founded the Società Degli Spettroscopisti, and how its members pooled their data on solar prominences, and could thereby follow their daily and hourly changes. In the 1870s Secchi published a superb book about the Sun, in two volumes, which appeared in Italian, and later in German and French editions.

By publishing most of his work in Italian, there was always the danger that astronomers in Great Britain and America would not become aware of Secchi's discoveries. At the same time, the exchange of publications between Italy and the RAS was extremely slow, and the *Monthly Notices* could arrive up to two years late. And so it happened that Sir Norman Lockyer, founder editor of *Nature* and a bastion of the British scientific establishment — and coincidentally the author of a recent volume about the Sun — complained in a review of Secchi's book that the author did not appear to have read his recent papers. Chinnici provides compelling evidence that Lockyer used his influence to safeguard his own interests, and to prevent an English edition of Secchi. At least Secchi was correct — and Lockyer wrong — on the question of the Doppler effect and the Sun's rotation, and about the existence of a reversing layer. These and other controversies, including Secchi's long-running feud with the Italian astronomer Respighi, are fully dealt with in *Decoding the Stars*.

To summarize, this is an impressive and honest biography of Secchi, which fully brings out his personality and the importance of his contributions to science and astronomy in general, and to spectroscopy and stellar classification in particular. It is enriched by Chinnici's many fine (and often lively) translations of Secchi's voluminous correspondence. In some ways it is a timely biography two centuries after Secchi's birth, for His Holiness Pope Francis I is currently the first pope to have come from the Jesuit Order.

The only issue for libraries considering whether or not to purchase this fine biography will be its relatively high cost. — RICHARD MCKIM.

Tycho Brahe and the Measure of the Heavens, by John Robert Christianson (Reaktion Books), 2020. Pp. 287, 22·5 × 14·5 cm. Price £15·95 (hardbound; ISBN 978 1 78914 234 1).

When we consider modern astronomy with its multi-instrument observatories and its university departments well-staffed with collaborating academics, we can trace its origins back to the Danish nobleman Tycho Brahe (1546–1601) and his Uraniborg Castle on the island of Hven in the Öresund Strait between Scania (Sweden) and Zealand (Denmark). Brahe was a renaissance man, and he converted astronomy from being the pursuit of the lonely and somewhat isolated and underappreciated academic, into a prestigious team effort with the emphasis on repeated observations, innovative instruments, and accuracy. It helped that he was self-confident, extremely intelligent, demanding, competitive, and an effective teacher. He was also a gracious courtier and clearly got on well with his benefactors King Frederick II and Emperor Rudolf II, and with a host of other astronomers. Tycho believed that accurate data was the foundation stone of knowledge and progress, and that interpretation and hypothesis came well and truly second. His astronomical endeavours were stimulated by the appearance of the supernova of 1572 and the great comet of 1578, both of which he proved to be beyond the Moon, thus contradicting the prevalent Aristotelian mindset. He also realized that the woefully inaccurate predictions of future planetary positions could only be improved by observation and improved data.

Christianson, an emeritus professor of history at Luther College, Decorah, Iowa, has provided us with a concise, erudite, informative, well-illustrated, and well-referenced book that is an absolute joy to read. He revealed the heart of his subject and emphasized the humanity of Brahe. One was left with the impression of a great scientist, and also a great employer, instructor, and family man (Brahe had eight children). Brahe clearly had huge diplomatic skills; dealing with a dysfunctional genius like Johannes Kepler could not have been easy.

I enjoyed this book hugely. It is not only a first-class introduction to the life of Brahe it is also a first-class introduction to astronomy in the Renaissance. — DAVID W. HUGHES.

Astronomy of the Inca Empire: Use and Significance of the Sun and the Night Sky, by Steven R. Gullberg (Springer), 2020. Pp. 370, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 48365 4).

Dr Gullberg is an associate professor of Interdisciplinary Studies at the University of Oklahoma and has expanded his doctoral thesis and love of archaeology and astronomy into the present book. We are treated to a topographical tour of the historical ruins of the Machu Picchu, Cusco, and the Sacred Valley region of the ancient Inca Empire, enlivened with over 300 photographs, art works, and maps. The text abounds in shrines (*huaca*), sacred mountains (*apu*), observing platforms (*ushnus*), sight lines (*ceque*), and solar markers (*sucanca*). This area of western Peru and Bolivia looks delightful and the book is a great advert for its touristic potential.

The Inca Empire was built on previous cultures such as the Huari, Nasca, and Chavin. The heyday of the Inca Empire was the AD 1400s with leaders such as Pachacuti, Topa Inca, and Huayna Capac. It all came to a rather sudden end with the arrival of the Spanish Conquistadors in the 1530s. This saw the indigenous religion of solar worship being purged by Spanish Roman Catholicism. Anything relevant that could be easily dismantled or burnt was quickly destroyed.

The fascination of Inca astronomy is that it was uninfluenced by European ideas. The main problem is that Incas had no written language. Gullberg concludes that they believed that their royal ruler was the son of the Sun. The Moon was secondary and thought to be both the wife and sister of the Sun. Solar worship helped to reinforce the divine authority of the emperor. The main annual celebrations seemed to be at the solstices and the equinoxes, these being defined by specific solar rising and setting positions on the mountainous horizons. The use of these dates for agricultural purposes seemed to be rather secondary, as did observations of the heliacal rising of the Pleiades and the celestial position of the Milky Way. Nothing in the book indicates that the Incas were numerate or that any notice was taken of the planets. Astrological significance was not mentioned.

Certain features of Inca archaeology had cardinal alignments. Gullberg gives little indication as to how the east–west and north–south axes were established, or how accurate this process was. The reader is left with the impression that Inca astronomy was not up to much. So the title of the book is somewhat misleading, and out of the 370 pages only a very few percent are needed to summarize our scant knowledge of their apparently limited astronomical prowess. In all, the book was over long, repetitive, and greatly in need of an effective editor. — DAVID W. HUGHES.

The History of Celestial Navigation: Rise of the Royal Observatory and Nautical Almanacs, edited by P. Kenneth Seidelmann & Catherine Y. Hohenkerk (Springer), 2020. Pp. 332, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 43630 8).

The subject of the present book is not, today at least, the most ‘fashionable’ branch of astronomy, but in practical terms it is arguably the most important. From ancient times, the stability and/or regularity of the various components of the celestial sphere have offered a framework for human activity, from the provision of a time service on a range of scales to ways of establishing position on the globe for the more adventurous humans as they travelled ever further from their homes. But even today, celestial navigation is taught to mariners as a backup to the GPS and related services we all too readily take for granted. And the core of that ‘security blanket’ is the Nautical Almanac, a compendium of data showing times and positions of all manner of celestial bodies throughout the year for the benefit of navigators and astronomers alike.

The first chapter gives a whistle-stop tour of early efforts to catalogue celestial events, produce calendars, and the like, thoughtfully graced with sufficient references to follow-up those stories.

A very substantial Chapter 2, by Adam Perkins, gives a delightful and full account of the founding of the Royal Observatory at Greenwich by King Charles II in order that John Flamsteed “Our Astronomicall Observator, ... [shall] apply himself with the most exact care and diligence, to the rectifieing the Tables of the motions of the Heavens, and the places of the fixed stars, so as to find out the much desired Longitude of places for the perfecting the Art of Navigation”. This, however, did not immediately produce the desired results, and turning to Chapter 3, also by Perkins, we find Edmond Halley, with his crony, Isaac Newton, hassling Flamsteed for his measurements, and eventually becoming the second Astronomer Royal. But even then, nothing really satisfactory was produced, to the point where a number of serious losses at sea made the government of the day pass the Longitude Act in 1714 and offer a prize for the solution (which eventually depended on the wonderful clocks produced by John Harrison).

Chapter 4, by Jim Bennett, introduces the fifth Astronomer Royal, Nevil Maskelyne, and it was he who finally produced the *Nautical Almanac and Astronomical Ephemeris*. The following chapters show how astronomers, first in Britain and then, from the middle of the 19th Century, in the USA, built on that achievement and enhanced the methods of measurement, computation, and printing of the *Almanacs* and initiated the international collaboration which is a vital feature of the work today. These chapters, written by experts from the Nautical Almanac Offices of the UK and the USA, show just how complicated things have become, with continuous adjustments to the systems of reference frames and the measurement of time — on the grand scale still based upon the solar day but on the fine scale by the frequency of a transition within ^{133}Cs atoms.

It's just as well that there are experts in these somewhat arcane matters, although lacking the glamour of other branches of astronomy presents a risk that the funding agencies may not understand their significance. Indeed, in the UK, we might well have lost the expertise of the NAO with the destruction of the Royal Greenwich Observatory by the Particle Physics and Astronomy Research Council (at least I vaguely recall that's what the chameleon was called at the time) just before the end of the 20th Century. However, the NAO had a stay of execution with a move to Rutherford Appleton Laboratory, although it was hanging on there by its finger nails with just three staff. Fortunately, it was eventually rescued by the Royal Navy in the shape of the UK Hydrographic Office (HO), and now seems to have expanded and is being well supported, according to its present head, Steve Bell. Ironically, it was something of a homecoming, since the NAO first came under the charge of the HO in the 19th Century.

This is an important story which should be of interest and concern to all. — DAVID STICKLAND.

History of the Plurality of Worlds: The Myths of Extraterrestrials Through the Ages, by Pierre Connes and edited by James Lequeux (Springer), 2020. Pp. 406, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 030 41447 4).

Pierre Connes is better known to astronomers for his high-resolution infrared spectroscopy of stars and planets* and we learn from the Editor's Foreword that it was his resolution into individual lines of the IR CO_2 bands in the atmosphere of Venus in 1964 that triggered the author's interest in possible planets around other stars, extraterrestrial life, and the history of the plurality of worlds. This book was decades in the writing but not published in the author's lifetime. Before his death, he circulated copies to a number of astronomical friends in the hope that one of them would edit it for publication, which James Lequeux has done for us.

The book traces the development of ideas about the plurality of worlds from the ancient philosophers, through Church Fathers and medieval scholars to 17th Century astronomers, finishing with Christiaan Huygens. The editor has written a final chapter bringing the story up to date in the light of the discovery of exoplanets, and SETI. The book aims to show that there was no abrupt transition to the modern concept of plurality. We have a mix of metaphysics, theology, and science in varying proportions. And themes such as the Principle of Plenitude — that the Universe, being essentially complete, could not be empty or useless in any of its parts — and teleology keep recurring.

To put the ideas of plurality into context, the author covers the development of cosmological thinking in each period, with the result that this book could

*There were plans to install the latest version of his Michelson-type interferometer, suitably adapted by Michael Smyth, at *UKIRT* (*The Observatory*, **98**, 101, 1978), but it did not reach the telescope and was, in due course, superseded by cooled grating spectrometers using infrared arrays.

be considered a History of Cosmology, or even a History of Astronomy without planetary motions. Consequently, we are introduced to some historical figures less familiar to astronomers, while the works of the more familiar are considered only as they touch on the plurality of worlds. Amongst the earliest was Anaxagoras. The fall of a large meteorite on a river bank, regarded by his fellow citizens as a portent of a naval disaster (which did occur), prompted him to think that the Earth and heavens were one. He went on to teach that there were dwellings on the Moon, but this led to his banishment. Later, Democritus believed that there were worlds infinite in number, and Lucretius believed that, in other regions, "there are other Earths and various tribes of men and breeds of beasts", but between all those worlds "...there is a limitless abyss of space such as even the dazzling flashes of lightning cannot traverse it, racing through an interminable tract of time." A feature of this book is the extensive quotation from texts, well referenced in a bibliography.

The pendulum then swung. The Pythogoreans opposed the Ionian view of nature by bringing in mathematics and morals. The multiplicity of worlds was strongly rejected. This view persisted into the Middle Ages when the Bible, as interpreted by the Church Fathers, became the sole authority. From the 12th Century, the re-discovery of the works of Aristotle raised problems as his cosmic system was built out of necessity, and God could not by any means have made it different from what it is. This was condemned as heresy in one of Bishop Tempier's decrees of 1277 which, in effect, allowed plurality of worlds to the discretion of the Creator. A more familiar figure, Nicolaus Cusanus, was the first to write openly that the human vantage point was unremarkable because the Universe looked the same wherever you stood. He also believed stars and parts of the Heavens were inhabited, all owing their origin to God.

The Universe of Copernicus had a single centre, the Sun, with no reference to other stars or plurality. The ill-fated Bruno adopted Copernicanism and plurality. He located stars at infinite distances, probably influenced* by Thomas Digges, whom he may have met in England, and whose *Perfit Description of the Celestiall Orbes* included a translation of the first chapter of *De Revolutionibus* as well as his own speculation on the distances to stars. Bruno posited innumerable Suns and an infinite number of Earths revolving about them — and that the other worlds were inhabited. Whether it was for this or his other heresies he perished at the stake, we don't know — he had also written delirious praise of that abominable heretic, Queen Elizabeth!

We get more practical with the work of Galileo and Kepler, to whom two substantial chapters are devoted. Although Galileo's discoveries moved plurality from metaphysics to science, he remained cautious as to the possible inhabitants of the Moon or planets because of the absence of observational evidence. Kepler, on the other hand, expected Solar System planets to be inhabited — but rejected outright ideas that other stars might have planetary systems. Teleology is not dispensed with. With reference to the Galilean satellites of Jupiter, he wrote ".. these four planets were ordained not primarily for us who live on Earth, but undoubtedly for Jovian beings who dwell around Jupiter." Similarly, in the inhabited Solar System described by Fontenelle, disciple of Descartes, the satellites are there for illumination: Mercury and Venus do not require any because of their proximity to the Sun, while the need is greatest for Jupiter and Saturn. The final chapter written by Connes sets out the ideas of Christiaan Huygens, who brought together instrumental, observing, and mathematical expertise. Nevertheless, in his *Cosmotheros*, he provides his

*The author attributes (p. 192) this connection to Owen Gingerich, but the paper referred to (Gingerich 1975) is actually by Stillman Drake.

systematically constructed Solar System with inhabitants who have equalled (but not exceeded) our achievements — effectively, back to Plenitude! The Editor's final chapter is altogether more sober.

Altogether, I found this an engaging book, with a much wider scope than suggested by its title. The writing is lively and humorous, welcome when approaching some of the metaphysical and theological passages. The supporting apparatus, footnotes, two bibliographies, and index are thorough, and the production is good, with a only a few spelling mistakes. I am happy to recommend it, not just for specialists. — PEREDUR WILLIAMS.

Using Sequence Generator Pro and Friends: Imaging with SGP, PHD2, and Related Software, by Alex McConahay (Springer), 2019. Pp. 417, 23·5 × 15·5 cm. Price £24·99/$34·99 (paperback; ISBN 978 3 030 19718 6).

Forty years ago when I started to do astrophotography with a telescope it was a very manual affair. The telescope was pointed using setting circles, the detector was film, and guiding was done by eye and hand using an illuminated reticle guidescope. Things are much different now with Go-To telescope mounts, autoguiders, and digital-imaging cameras. This has led to a huge increase in productivity and, ultimately, the option to automate the entire process so that the observer can enjoy some sleep or go to the pub safe in the knowledge that their observatory is producing high-quality data in their absence.

In the Windows software world, all of the different elements of an imaging system tend to communicate *via* a standard, open protocol called ASCOM. This greatly simplifies the job of connecting together different system components from different manufacturers so that they can work together smoothly. The next step is to be able to write scripts which automatically control the system through the night. This could be, for instance, to image thousands of galaxies for a supernova search, or to take long sets of exposures with different filters to obtain yet another image of M 42. One of the most comprehensive scripting systems on Windows is SEQUENCE GENERATOR PRO (SGP) from Main Sequence Software.

This book is essentially a user manual for SGP and the supporting software and components which make up an automated imaging system. Since SGP is involved in all areas of the imaging process and it has a large amount of flexibility, the learning curve is steep so a book like this is welcome. The author has written a great deal of on-line material about SGP and he clearly has a lot of experience with the program and what can go wrong. There is much here which will help new and experienced users alike.

Unfortunately, like many recent books, there is little sign of any sub-editing and so what gets printed is pretty much what the author submitted. This seems an inevitable consequence of the current publishing climate of very low profit margins but it does mean that the book is rambling and repetitive in places. If you can get past that, and you are looking for a comprehensive guide and user manual for SGP, this is a good place to start. — NICK JAMES.

Night Sky Almanac: A Stargazer's Guide to 2021, by Storm Dunlop & Wil Tirion (Collins), 2020. Pp. 255, 19 × 11·5 cm. Price £9·99 (hardbound; ISBN 978 0 00 840360 7).

My trusty *Concise Oxford Dictionary* (1964 version) gives 'almanac' as an "Annual calendar of months & days, with astronomical & other data". The present example is perhaps the most charming of such publications I ever recall seeing, with its dark blue cover with astronomical and night-time scenes reminiscent of a Victorian book, which, of course, chimes perfectly with a guardian of what I have always regarded as a Victorian magazine — *The Observatory*; I'm sure Sir William Christie would have approved.

The first 38 pages carry introductory material, and include major events for the year, Moon maps, and explanations for the maps to follow, which benefit both northern- and southern-hemisphere observers. Then follow the 12 monthly chapters, with data on the Earth's location, occultations, the planets, sunrise and sunset times for nine major cities around the globe, phases of the Moon (and information on names given to the Full Moon, especially by Native North Americans), a calendar of events for the month — meteor showers, close approaches, *etc.* — with accompanying thumbnail sketches, and then the principal constellations and bright stars dominating the night sky. These chapters conclude with a 'special'; so for January the topic is Meteors, while for April the Occultation of Mars (for East Asia) is described. Thus through the year a number of interesting subjects are brought to the fore. The concluding 30 pages provide a list of dark-sky sites, twilight diagrams, and a glossary with tables of the constellations and prominent asterisms, a list of further reading and useful contacts, and an index.

Both delightful and useful. — DAVID STICKLAND.

Dark Skies: A Practical Guide to Astrotourism, by Valerie Stimac (Lonely Planet), 2019. Pp. 288, 21 × 17 cm. Price £14·99 (hardback; ISBN 978 1 788686198).

In recent years there has been a surge in 'Astrotourism', with tours and cruises devoted to archaeoastronomy, modern astronomical institutions, solar eclipses and, in particular, the aurora. This book aims to cover all of these types of activity, and succeeds reasonably well in describing the places and events that may be experienced. It starts with a section devoted to designated 'dark sky' sites worldwide and then goes on to describe observatories and other institutions that may be visited. Other chapters cover topics such as meteor showers, the aurora, eclipses, and launch sites, ending with an extremely optimistic summary of actual 'space tourism' ranging from suborbital flights to 'Solar System and Interstellar Tourism'.

It is a pity that Stimac is obviously not particularly well versed in practical astronomy. Her advice to complete beginners is a case in point. She suggests the use of a stellarscope — one of those things that look like a miniature telescope and pretend to show the sky at any particular date and time — when a common-or-garden planisphere would be more practical. Similarly, she advises beginners to start by looking at Polaris, Sirius, and Alpha Centauri, leaving it to readers to find out for themselves how to identify those stars. (A few simple charts would have helped.) It would be far better to advise them to start by identifying asterisms or constellations such as (say) the Plough (Big Dipper, if you will), Orion, and Crux.

There are colour photographs throughout the book, generally relevant, although the introduction to the section on meteors is marred by an image, supposedly of the Perseid meteor shower, that includes two fake meteors with curved trails, rather like miniature comets, that curve in from opposite sides of the image. The chapter on 'Astronomy in Action' opens with a double-page image of a particle detector at CERN. The lack of any other images is particularly felt in the section on eclipses, where all the total solar eclipses in the current decade are described. (But not annular or partial eclipses.)

Here, the omission of maps of the eclipse tracks is particularly inconvenient.

The book is obviously written for the North-American market, and this shows in some of the individual descriptions. Many of the photographs are of locations or even flora and fauna that have no direct connection to astronomy, but are close to sites of interest, and are suitable for excursions during the day. There are some odd terms that gave me pause for thought: 'shoulder season' was one that is not often used. Generally, unfortunately, the astronomical information is somewhat shaky, but as a summary of tourist locations the book is of interest and useful. — STORM DUNLOP.

Cosmology's Century: An Inside History of Our Modern Understanding of the Universe, by P. J. E. Peebles (Princeton University Press), 2020. Pp. 425, 24 × 16·5 cm. Price £30/$35 (hardbound; ISBM 978 0 691 19602 2).

[As readers will see from the reviews below, this book is seen to be an important addition to the astronomical library, and the Editors felt that they could usefully carry reviews from two of our most regular reviewers to discuss its contents.]

"Jim Peebles has surely contributed more to the history of our understanding of the large-scale structure and evolution of the Universe than anyone else still in a position to write about it; so written about it he has. And magnificently!" These words I assembled some months ago in response to a request from the publisher for a back-cover blurb based on the galley-proof version of the book. In fact Princeton University Press preferred to use other forms of praise from Robert Kirshner, Priyavada Natarajan, Janna Levin, and David Kaiser, but, honourable folks that they are, they sent the promised copy of the published book anyway. A careful search of the 'front matter' finds me between Michael Turner and Joseph Silk.

The author's page 1 begins "The story of how cosmology grew is fairly simple compared to what people have been doing in other branches of science", and page 354 ends "But there are still clouds over ΛCDM and dreams of completion that we may be sure will lead to something new and maybe transformative."

What comes in between? And how might it be used? If you are a cosmologist or a science historian, probably the first thing you will want to know is whether you are mentioned. The index has very few names, apart from eponyms. But there are 44 pages of references, from Aaronson to Zwicky (neither, as it happens, likely to be looking for themselves). You will have a good chance of finding out what Peebles thinks is important about your work, because each reference carries the page number where it is cited. There are also some folks mentioned without a reference (I happen to be one of them and will offer a glass of good wine to the first person who finds out where, if we are ever allowed again to drink together).

Uses? Alexander Szalay, who is multiply cited, mostly for his work on the cosmological significance of neutrino rest masses, is quoted (p. 281) saying that, when he was a student in Hungary, where nobody was interested in cosmology, he learned what it meant from Jim's earlier book, *Physical Cosmology*. A 21st-Century, equally isolated student, if such there be, could clearly do the same from *Cosmology's Century*.

Some topics are treated with enormous, careful detail, for instance, the lead up to the discovery of the cosmic microwave background and predictions thereof. Notable is that an early draft of one of the Princeton papers did credit the "Gamow team" (Ralph Alpher, Robert Herman, James Follin) for one or more of their predictions. This somehow disappeared from the published paper, leading to occasional criticisms. In contrast (p. 72) the shrinkage of Hubble's constant from *c.* 500 km/sec/Mpc to somewhere around 100 has only two steps, Baade at the Rome (1952) IAU not having seen the RR Lyrae stars in M31 (no credit to David Thackeray for the simultaneous confirmation of having seen the RR Lyraes in the Magellanic Clouds, 1·5 magnitudes fainter than he was expecting); and Allan Sandage (1958) recognizing that many of Hubble's "brightest stars" were actually whole H II regions, intrinsically a factor of four or so brighter and so twice as far away.

But that is a really good page to look at, because facing it (p. 72) is the text of a 1947 September 26 letter from Einstein to Lemaître, recognizing that there was then a time-scale problem and agreeing "It is true that the introduction of a λ term offers a possibility, it may even be that it is the right one." So, if this had been 'Einstein's biggest blunder' (it was not), he made it twice. But then you probably already know that Newton bought shares in the South Sea Bubble twice.

The history of dark matter?* Oort on the Milky Way, yes (1932); Jeans and Kapteyn (1922, separately), no. In other galaxies? Zwicky on the Coma cluster (1933), yes; Sinclair Smith on Virgo (1937), yes; Babcock (1939) on M31, yes; Vera Rubin and Ken Ford, multiple rotation curves (and a cute picture), yes; binary galaxies from either Holmberg (1937 or so) or Thornton Page (later), no. And my favourite 'missing person' is Knut Lundmark, although Peebles credits him with one of the versions of the 'pre-Hubble constant'. But in 1930, in the *Middelande från Lunds Observatoriums* No. 125 he reported *Über die Bestimmung der Entfernungen, Dimensionen, Massen, und Dichtigkeiten für die Nächstgelegenen Anagalaktischen Sternsysteme*. His Table 4 reports six ratios of "*Leuchtende + dunkle Materie / Leuchtende Materie*" for six galaxies as 6, 10, 10, 20, 30, 100. The paper was unearthed by Lars Bergstrom in Stockholm and brought to my attention by Robert Cumming of the Chalmers Institute in Sweden.

In some ways, the most interesting chapter is the last, very short 'The Ways of Research'. It includes 'Technology', 'Human Behaviour', 'Roads Not Taken', and 'The Social Construction of Science'. Near the end, the author distinguishes between the normal progress of science and attempts at revolution, in a somewhat Kuhnian sense. His four revolutionaries are Fred Hoyle (steady state, of course), Allan Sandage (attempting to measure the deceleration parameter by observing galaxies), Stirling Colgate (deceleration from supernovae), and his own thesis advisor and hero, Robert Dicke, who "dreamed of detection of the evolution of dimensionless parameters of physics". I completely agree about them all, and in particular am glad the American Astronomical Society voted its 1992 Tinsley Prize to Dicke, the year I chaired the committee and when Bob was still able to appreciate it, although all he could say, in a greatly softened voice at the podium, was "thank you". Annie (Currie) Dicke, whom he married in 1942, was there, and with him to the end in 1997.

Prof. Peebles has dedicated this volume "To Alison, my best friend for six decades". — VIRGINIA TRIMBLE.

*Actually Chapter 6 is not called dark matter or even missing mass, or sub-luminous mass or matter. It is "subluminal" mass. This of course made me think the opposite would be superluminal something, a word that was co-opted decades ago to describe the apparent motion on the sky of components of radio galaxies and quasars, if special relativistic effects were not taken properly into account.

The fact that Peebles received half of the 2019 Nobel Prize for physics (the other half was split* between two who had discovered extrasolar planets) might help the sales of this book, but it was certainly in the works before the announcement. In fact, it was expected: as John Peacock noted, "[r]oughly once every decade, an important event takes place in cosmology: Jim Peebles publishes a textbook"[1]. Actually, he did miss a couple of decades (about 20 and 10 years ago), but also published a book on quantum mechanics[2] in addition to his books on cosmology (refs. 3–5 and the one reviewed here). The subtitle is important; this is neither a cosmology book with obligatory historical references, nor a history-of-science book on cosmology, but rather tells the stories, from a historical and personal point of view, of several lines of investigation which converged on what is now known as the 'concordance model' or 'standard model' of cosmology; Peebles refers to that convergence as a revolution. He has played a large part in many of those, for well over half of cosmology's century (conveniently dated as starting with Einstein's first paper applying General Relativity to cosmology[6]), essentially all of that at Princeton, having arrived there in 1958 after undergraduate education at the University of Manitoba in Winnipeg, Canada.

After more than four pages of 'Preface and Acknowledgements' and a short introductory chapter, the book continues with a topic in which Peebles was not directly involved, namely a history of the concept of 'The Homogeneous Universe', considered in some detail because he had not found a full discussion elsewhere. As such, it is complementary to most discussions of the first few decades of cosmology, which are often restricted to homogeneous models, but provide little background as to why that was the case and how justified it was then, and to what extent it is more justified now. Of course, in the early days essentially only homogeneous models were considered, but the reasons for doing so and the extent to which that was an assumption rather than an observation, and how that changed with time, are interesting topics in themselves. The discussion of classical cosmology continues with the chapter on 'Cosmological Models'. That topic will be familiar material to many, but it is interesting to have Peebles' take on it along with the discussion of the other topics.

The second and third chapters are mainly about work done before the start of Peebles' career; the rest discuss work done during his career, by him and others. Chapters 4–7 cover the four lines of investigation: the CMB and Big Bang nucleosynthesis, growth of cosmic structure, subluminal mass, and nonbaryonic dark matter. The fact that there are two chapters on dark matter is due to the distinction, historically, between "the astronomers' subluminal matter", "the particle physicists' nonbaryonic matter", and "the cosmologists' dark matter". Chapter 8 discusses how the first two concepts of dark matter came together in what came to be known as sCDM, standard cold dark matter ('the cosmologists' dark matter'); as Peebles notes, it is 'standard' because it came first, not because it was established. It also discusses refinements introduced both to match better observations and because initial choices were often

*The possibilities for shared prizes are: two get a half each, one gets a half and two get a quarter each (as here), or three get a third each. While each year has a general theme (*e.g.*, astrophysics, nuclear physics), prizes which are split can be awarded for work on the same specific topic or for slightly different topics on the same theme, except that awards of a third each are always for the same specific topic, as are the two quarter awards. That says nothing about whether joint awards are for joint work; in this respect, all combinations are possible.

motivated by 'non-empirical assessment', as well as structure formation in those models. Chapter 9 is on 'The 1998–2003 Revolution'* and Chapter 10 offers thoughts on how science is done.

Conspicuous by its absence (though that absence is mentioned in a footnote) is the history of determinations of the Hubble constant, presumably because Peebles was not involved personally to any significant extent. Discussing that at the same level of detail would amount to enough material for another book. The main cosmological tests which cemented the case for ΛCDM — the magnitude–redshift relation for type-Ia supernovae, CMB anisotropies, and baryon acoustic oscillations — are discussed in some detail. Cosmological applications of gravitational lensing are mentioned briefly; those were important for a while, but the precision and accuracy of other tests have relegated them to a smaller role, though they provide an interesting additional consistency check.

As expected, the quality is top-notch; I noticed no obvious mistakes, though there are a few minor things which one might like to think about. Peebles disagrees with some contemporary evaluations of the 1919 eclipse expedition (see ref. 7 for a thorough account, reviewed recently in these pages[8]). I've often complained[9–12] that modern cosmology books usually ignore research into the flatness problem after its formulation by Dicke & Peebles[13]; that is also the case here. On other topics, he spends a lot of time discussing how the community opinion changed, works which were neglected for a long time which later became popular, and so on. (But also some dead ends (referring to another topic): "The idea is elegant, of historical interest, and worth considering, but wrong.") Similar to many other authors, his stance on the flatness problem is essentially the same as that of Dicke & Peebles, but he is perhaps a bit less adamant about it. Perhaps his opinion has softened somewhat, but I think it more likely that he is just recapping the history here (and the fact is that most people think that nothing much concerning that topic has happened since Dicke & Peebles) and also that it is not so important for him. The Dicke & Peebles article was perhaps mostly Dicke's work, and Peebles hasn't returned to that topic in any substantial form since then. The book doesn't even have an index entry for 'flatness problem'. On the positive side, although by his own admission weak on the literature ("I was never strong on the literature", "[s]till am not strong on the literature", "I have never been as diligent as I should be about following the literature"[14] — admittedly the quotations are several decades old), there are copious references here. Not only that, but in the case of exact quotations the page of the work cited is mentioned, and the reference list mentions the page(s) in this book where the reference occurs. (Not only with regard to references, the book is somewhat like a long review article.)

Looking towards the future, like Lord Kelvin more than a hundred years ago, Peebles identifies two clouds which might result in a precipitation of game-changing ideas. Kelvin's were 'Relative Motion of Ether and Ponderable Bodies' and 'the Maxwell–Boltzmann doctrine regarding the partition of energy'[15]. Peebles' are "the issue of what happened in the very early universe

*Note that he doesn't mean a revolution in the sense of a paradigm shift; rather, the term here is used to denote a significant increase in the accuracy and precision of observations which confirmed what had already become the leading paradigm (ΛCDM) in the eyes of many. Peebles himself had often played devil's advocate, a valuable role necessary to test the robustness of a model, but stopped doing so once the evidence for ΛCDM became overwhelming. The story of cosmology's century as told in the book essentially ends after that revolution.

which replaces the extrapolation of ΛCDM back to a singularity" and "the enigmatic simplicity of the dark sector of ΛCDM". Kelvin's famously led to Special Relativity and quantum mechanics. Certainly Peebles' first puzzle, and perhaps also the second, would, if resolved, lead to a similar revision of our understanding of the Universe.*

There are few actual typos (though there is a minus sign missing in the definition of the deceleration parameter q_0) and about the average number of phrases and so on which I would have edited differently (about one per page), though some are arguably matters of taste. A few black-and-white diagrams are scattered throughout the text, and eight pages of plates towards the end of the book containing diagrams as well as pictures of people and items of historical interest such as detectors and postcards. There are no end-notes but rather the better option, occasional footnotes in the main text. At 44 pages, the reference list, including titles of articles, is extensive. The book ends with a four-and-one-half-page index. Especially considering the length of the book and the fact that it contains colour plates, the price is more than reasonable.

There are equations, but the book is not overly technical and thus suitable as an overview of the topics it covers, even for non-experts, while copious references allow one easily to find more-detailed descriptions. (While it is an inside story, it is a story of science, with few details of Peebles' own life, though I was happy to read that the only programming language he knows is Fortran.) It is also very well written. The book is essential reading for anyone interested in the first hundred years of modern cosmology. — PHILLIP HELBIG.

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*One often reads that Kelvin's view was that those two clouds were relatively minor problems, the understanding of which would essentially bring physics to an end; that is probably exaggerated — there would be no need to write forty pages about such unimportant things — and the opposite might be closer to the truth.

FROM THE LIBRARY

Through My Telescope: Astronomy For All, by William Thomson Hay (J. Murray, London & E. P. Dutton, USA), 1935. Pp. 141, 19 × 13 cm. Currently unavailable. (Hardbound.)

Will Hay (1888–1949) is not well remembered today in either the entertainment or astronomical communities. In the 1930s, however, Mr. Hay was the equivalent of what we would now call a superstar — and very active and quite well known and respected in both the BAA and the RAS. In his acting career he made dozens of movies presenting himself as a bumbling professor, schoolteacher, fireman, or some other character, and was very popularly received by the cinema-going crowd. Between radio, motion pictures, and the stage, he was the third-highest-grossing performer of his time. With major studios such as Gainsborough and Ealing, the United Kingdom possessed the second-largest movie industry after Hollywood in the USA. They produced thousands of films, and I was very fortunate many years ago to attend an auction in Beverly Hills at which I purchased several thousand VHS tapes for an extremely low price, which I still have not thoroughly explored. They were recorded on high-quality equipment by a Hollywood producer who had lived many years in the UK. Apparently nobody wanted them because DVDs had just hit the market and it was yesterday's technology. There were many films of Will Hay in the lot.

In real life Will Hay was quite the opposite of his screen portrayals — a dedicated and serious individual who for a time produced a magazine dealing with the different aspects of comedy. Also, like the current Brian May of Queen, he spent much of his professional earnings on astronomy. Hay was fluent in several languages and travelled the world performing on stage before settling down to a movie career in England. He owned a light plane and cabin cruiser, piloting them both. His early interest in engineering served him in good stead: he designed and built several chronographs after making accurate drawings of them, and also a blink microscope that he donated to the BAA. Using a chronograph and micrometer he designed, Hay made accurate determinations of cometary positions. He kept a detailed journal during his observing career from 1932 to 1944. In this journal are very good sketches of various Solar System objects. The first part is dominated by drawings he made of Saturn on which he discovered the White Spot in 1933 (which we now know was a storm in the planet's atmosphere). He owned many large telescopes far beyond the financial reach of the average citizen of his time. I only mention the foregoing items as an introduction to my review of his book. A detailed biography may be found in the 1978 book *Good Morning Boys* by Seaton and Martin (published by Barrie & Jenkins); and there is detailed information about his telescopes in an article entitled 'Will Hay (1888–1949) and his telescopes' (*JBAA*, **119**, 2, 2009).

Now to the book. His book is organized into a table of contents, a list of illustrations, and an introduction, followed by 19 chapters designated by Roman numerals. Although the date of publication is given as 1935, it was written earlier but he was reluctant to publish it then because he did not want to capitalize on his celebrity status and wanted the book to be accepted on its merits. It was only at the urging of friends that he published it under the name W. T. Hay, hoping he would not be recognized. Of course just the opposite occurred and it caused a jump in his fame.

Will Hay was primarily interested in the Solar System, as confirmed by his observing career and notebook, but he covered other topics in the final chapters of his book. After expressing his philosophy in the first chapter, pointing out that we are "citizens of the universe", Chapters II to X detail the contemporary knowledge of the Solar System starting with the Sun and, including the asteroids, ending with the then recently discovered Pluto. Chapter XI covers comets, and XII, which is titled by the popular but erroneous name 'shooting stars', describes meteors. Nebulae within our galaxy and other galaxies are explained in Chapter XIV, while XV treats the spectroscopy of the day. A brief description of astronomical distance in Chapter XVI is titled 'The Astronomer's Tape Measure'. Chapter XVII, 'Navigating in Space', describes measuring angles on the celestial sphere and the refraction of starlight in the atmosphere. The last two chapters, XVIII and XIX, describe the construction of the telescope and its use.

The book would thus have given the novice amateur astronomer of the day an effective overview of the subject as it was understood at the time. It contains 24 black-and-white pictures and diagrams. They are well presented, and since there is no credit given for them anywhere in the book, I assume that they are from the pen of Will Hay, who was a talented illustrator; the book is well worth keeping as an historical document for Hay's drawings alone, but I would not give it to a beginner of today because of the enormous advances in knowledge made since Hay's passing. The book was published at a time when Edwin Hubble and others were beginning to detail the expansion of the Universe and astronomy was going through the long transition from the mostly positional astronomy of the 19th Century to the dynamic and encompassing astronomy of the second half of the 20th. — LEONARD MATULA.

OBITUARY

Iain Kenneth McKinnon Nicolson (*1945–2020*)

Iain Nicolson was suddenly and unexpectedly taken very seriously ill whilst at home in Alloa and died the next day on 2020 September 3. He had been born on 1945 April 20 to John and Caroline Nicolson a hundred miles further north, at Keith in what was then Banffshire. Between those dates, though, he lived in Hertfordshire for several decades and had travelled to many parts of the world.

Iain will have been known to a legion of readers of *The Observatory* and to countless members of the general public for his brilliant and numerous public lectures on all aspects of astronomy and for his many appearances on TV and radio discussing topical astronomical news items. He will also have been known to thousands of cruise-liner passengers whom he guided through the night sky in remote and exotic locations around the world. Tens more thousands of people will have been fascinated by his numerous books, such as *Unfolding our Universe* (I once asked him who had folded it in the first place, but he replied that "he was reserving that for another book"). If queried about how many books he had written, in typically modest fashion, he would confess only to having written "more than twenty" — but it was *many* more.

Iain also imparted his love of astronomy to the thousands of students who attended his lectures, saw him during tutorials, and were guided by him during their observing sessions throughout his twenty-five years as a lecturer and principal lecturer at the University of Hertfordshire (formerly the Hatfield Polytechnic) — many of those students going on to careers in astronomy themselves.

Iain's fascination with astronomy began early: whilst still at school, he borrowed a telescope from the BAA to use at home, then in Tillicoultry just four miles from Alloa. The year 1963, when he was 18, was very auspicious for him — he toured observatories and planetaria in Germany with Patrick Moore (a life-time friend), started his degree in Physics and Astronomy at the University of St. Andrews, and met his future wife, Jean, during a night hike. Iain and Jean were to marry six years later. After his graduation, he became the first person to be employed specifically to teach astronomy at the then newly formed Hatfield Polytechnic. He played a major part in the development of its and the succeeding University of Hertfordshire's astronomy courses and teaching observatory, until he took early retirement in 1995.

Also, from early in his life, Iain developed a passion for boats and the sea. From cadging lifts on small boats on the River Tay, he went on to have a succession of boats of his own. With Jean and later with their children, Alastair and Shona, they sailed to most of the islands around the West Coast of Scotland. Alastair recalls "… being dangled over the edge of the bow to unhook a fouled anchor …" and that there "… were times when we could barely hold the tiller, but we always knew we were safe with … [Iain] on board".

All of us who ever met Iain will know he was a most friendly, unassuming, and out-going person. He was devoted to his family: his wife of over fifty years, Jean, his children, and his grandchild, Oliver. He also maintained very close ties throughout his life with his brother, Donald, his sister-in law, Deborah, and nephew and niece, Andrew and Kathryn. His death leaves an un-fillable hole in their and our lives, ameliorated somewhat by happy memories of him and the numerous times we are reminded of him to think "Iain would have loved that".

Iain was honoured for his achievements during his lifetime by being awarded the Eric Zucker Award of the Federation of Astronomical Societies, a visiting fellowship at the University of Hertfordshire, the naming of the *Iain Nicolson* telescope at the University's observatory, and an *Astronomy Now* Lifetime Achievement Award.

At Iain's funeral, his brother, Donald, read a poem written by his mother, Caroline, entitled '*Hebridian Island*', the final lines of which read appropriately,

No longer will I roam,

My Island,

I am coming home.

— C. R. Kitchin.

Here and There

PLANETARY MIGRATION?

In astronomy, the passage of a planet across the face of the Sun or the Moon. — Crossword clue for 'Transit' from *The Telegraph* book of *General Knowledge Crosswords 5*.