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SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 264: HD 174123

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HD 174123 is shown to be a double-lined spectroscopic binary system consisting of practically equal components of near-solar type, in a low-eccentricity orbit with a period of 13 years and an inclination of about 60°.

Introduction

HD 174123 is an 8^m star of *HD* type G5, to be found in the constellation Draco at a declination of almost 70°, about 3° north-preceding the third-magnitude star δ Dra. It was mentioned in Paper 239[1] of this series of papers as being the only object remaining without a published orbit among the stars divined by Suchkov & McMaster[2] as being metal-deficient and at the same time 'over-luminous' inasmuch as their parallaxes showed them to be brighter than they 'ought' to be according to a luminosity-sensitive photometric parameter derived from *ubvyβ* photometry. The magnitude and colour index of HD 174123 have always been found close to $V = 8^{m}{\cdot}01$, $(B-V) = 0^{m}{\cdot}52$; the latter is considerably bluer than the $0^{m}{\cdot}70$ that normally[3] corresponds to the G5 spectral type, but the difference might be occasioned by the star's metal deficiency, or it could arise at least in part from a minor error of classification.

The parallax of HD 174123 has been measured both by *Hipparcos* and by *Gaia*, and in both cases an initial value has been superseded by another one. The whole spread of the four values is, however, very small, ranging from 13·31 to 13·76 milliseconds of arc, corresponding to distances of about 75–73 parsecs or a distance modulus of about 4·3 magnitudes. The implied absolute magnitude of about $+3^{m}{\cdot}7$ is that expected for a mid-F main-sequence star, rather than the G5 that is the classification of HD 174123 in the *HD Catalogue*. Such a discrepancy could normally be attributed to metal-deficiency and/or mis-classification, but in this case it evidently results mainly from the fact that HD 174123 consists of two stars that are very similar to one another and therefore has double the luminosity that would correspond to their spectral type (an absolute magnitude $0^{m}\cdot75$ brighter). Duplicity also neatly explains the finding by Suchkov & McMaster[2] that HD 174123 is 'over-luminous' in the sense mentioned in the preceding paragraph.

Radial velocities of HD 174123

Simbad reports three papers relating to radial velocities of HD 174123. One of them is only a catalogue, which notes that its entry stems from just one publication; the other two[4,5] give mean velocities that are noted as being derived respectively from two, and an unspecified number, of measurements, which unfortunately do not seem to be retrievable individually and thus cannot contribute to the orbit derived in this present paper.

The star was placed on the programme of the Cambridge *Coravel* radial-velocity programme in late 2002. The trace appeared to be single-lined; it still did so on two occasions in the following year, and no change in velocity was apparent. The writer's interest in the star accordingly lapsed, until a fresh observation in 2006 showed it to be double-lined. Fairly systematic measurements, 43 in total, were then made with the Cambridge *Coravel* in the ensuing ten years, which proved to be most of an orbital cycle. All the radial velocities are listed in Table I, and readily lead to the results that are shown in the informal table of orbital elements below and in the diagram of the corresponding velocity curves that appears as Fig. 1. The component that gives the marginally bigger dip in the radial-velocity traces is found to have a mass that appears to be slightly smaller than that of its companion. The differences, both in dip area and in radial-velocity amplitude, are, however, not statistically significant, so HD 174123 can be considered to be an equal-component binary.

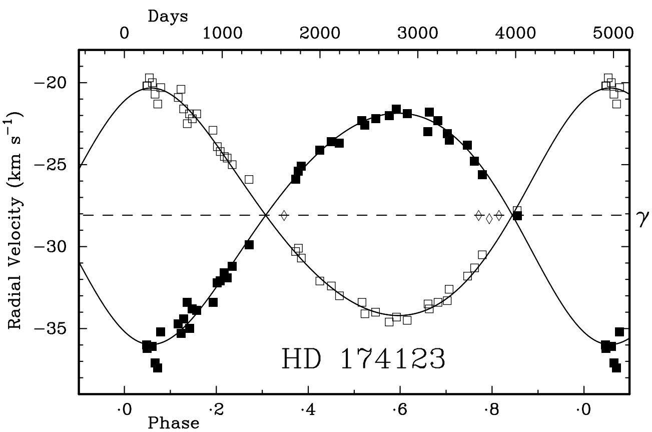

FIG. 1

The observed radial velocities of HD 174123 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All the observations were made with the Cambridge *Coravel*. The filled symbols represent measurements of the primary star, open ones those of the secondary. Open diamonds plot measurements that were reduced as if the object were single-lined; they were not taken into account in the derivation of the orbit.

TABLE I

Radial-velocity observations of HD 174123

Heliocentric Date			*HMJD*	*Velocity* Prim. km s^{-1}	*Velocity* Sec. km s^{-1}	*Phase*	*(O–C)* Prim. km s^{-1}	*(O–C)* Sec. km s^{-1}
2002	Dec.	19·75	52627·75	−28·1		0·771	–	–
2003	Apr.	8·10	52737·10	−28·3		0·794	–	–
	July	15·99	835·99	−28·1		·816	–	–
2006	July	13·06	53929·06	−36·0	−20·2	1·048	0·0	+0·1
		18·04	934·04	−36·2	−20·2	·049	−0·2	+0·1
	Aug.	8·00	955·00	−36·1	−19·7	·054	−0·1	+0·6
	Sept.	7·97	985·97	−36·1	−20·0	·060	−0·1	+0·3
	Oct.	4·93	54012·93	−37·1	−20·7	·066	−1·1	−0·4
	Nov.	1·85	040·85	−37·4	−21·3	·072	−1·5	−0·9
	Dec.	2·78	071·78	−35·2	−20·3	·079	+0·7	+0·1
2007	May	30·09	54250·09	−34·7	−20·9	1·116	+0·5	+0·1
	June	28·04	279·04	−35·3	−20·4	·123	−0·2	+0·8
	July	24·96	305·96	−34·4	−21·6	·128	+0·5	−0·3
	Aug.	31·03	343·03	−33·4	−22·5	·136	+1·3	−0·9
	Sept.	22·90	365·90	−35·0	−21·9	·141	−0·4	−0·2
	Oct.	21·90	394·90	−33·8	−22·2	·147	+0·6	−0·3
	Dec.	5·79	439·79	−33·9	−21·9	·157	+0·2	+0·3
2008	May	20·07	54606·07	−33·4	−22·9	1·192	−0·6	+0·6
	July	4·05	651·05	−32·2	−23·9	·202	+0·2	0·0
	Aug.	3·03	681·03	−32·1	−24·2	·208	0·0	−0·1
	Sept.	13·91	722·91	−31·6	−24·5	·217	+0·2	0·0
	Oct.	12·87	751·87	−31·9	−24·6	·223	−0·4	+0·1
	Dec.	2·76	802·76	−31·2	−25·0	·234	−0·1	+0·2
2009	May	24·08	54975·08	−29·9	−25·9	1·271	−0·4	+0·8
2010	May	18·11	55334·11	−28·1		1·347	–	–
	Sept.	12·96	451·96	−25·9	−30·3	·372	−0·1	+0·1
	Oct.	11·85	480·85	−25·4	−30·1	·378	+0·2	+0·5
	Nov.	10·80	510·80	−25·1	−30·7	·385	+0·3	+0·1
2011	May	19·09	55700·09	−24·1	−32·1	1·425	+0·1	−0·2
	Sept.	13·93	817·93	−23·6	−32·4	·450	0·0	+0·1
	Dec.	5·80	900·80	−23·7	−33·0	·468	−0·5	−0·1
2012	July	24·02	56132·02	−22·3	−33·4	1·517	+0·1	+0·3
	Aug.	22·92	161·92	−22·6	−34·1	·523	−0·3	−0·3
	Dec.	9·73	270·73	−22·2	−34·0	·547	−0·1	0·0
2013	Apr.	28·14	56410·14	−22·0	−34·6	1·576	−0·1	−0·4
	July	12·02	485·02	−21·6	−34·3	·592	+0·3	−0·1
	Oct.	29·76	594·76	−21·9	−34·5	·615	0·0	−0·3
2014	May	31·10	56808·10	−23·0	−33·5	1·661	−0·8	+0·3
	June	13·09	821·09	−21·8	−33·8	·664	+0·5	0·0
	Sept.	9·97	909·97	−22·3	−33·4	·683	+0·3	+0·1
	Dec.	13·75	57004·75	−23·1	−33·3	·703	−0·2	−0·2
2015	Jan.	2·72	57024·72	−23·5	−32·6	1·707	−0·5	+0·5
	July	10·01	213·01	−23·8	−31·8	·747	+0·3	+0·2
	Sept.	19·90	284·90	−24·8	−31·3	·762	−0·2	+0·2
	Dec.	7·75	363·75	−25·6	−30·5	·779	−0·4	+0·4
2016	Nov.	28·78	57720·78	−28·1	−27·8	1·855	+0·5	−0·2

The averages of the four quantities that are specified separately for each of the components in the informal table below could well be attributed to both components. If the masses of the components are judged from the spectral type to be slightly sub-solar, the $m \sin^3 i$ values indicate an orbital inclination of about 60°.

P	$= 4699 \pm 54$ days	T_1	$=$ MJD 53702 ± 67
γ	$= -28{\cdot}08 \pm 0{\cdot}05$ km s^{-1}	$a_1 \sin i$	$= 452 \pm 8$ Gm
K_1	$= 7{\cdot}06 \pm 0{\cdot}10$ km s^{-1}	$a_2 \sin i$	$= 445 \pm 8$ Gm
K_2	$= 6{\cdot}94 \pm 0{\cdot}10$ km s^{-1}	$f(m_1)$	$= 0{\cdot}167 \pm 0{\cdot}007\ M_\odot$
q	$= 0{\cdot}983 \pm 0{\cdot}019\ (= m_1/m_2)$	$f(m_2)$	$= 0{\cdot}159 \pm 0{\cdot}007\ M_\odot$
e	$= 0{\cdot}133 \pm 0{\cdot}013$	$m_1 \sin^3 i$	$= 0{\cdot}646 \pm 0{\cdot}023\ M_\odot$
ω	$= 153 \pm 6$ degrees	$m_2 \sin^3 i$	$= 0{\cdot}657 \pm 0{\cdot}024\ M_\odot$

R.m.s. residual for unit weight $= 0{\cdot}43$ km s^{-1}

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CORRESPONDENCE

To the Editors of 'The Observatory'

Historical Observations of STEVE and the Solar Cycle

I read with great interest the article recently published on the historical observations of the phenomenon known as 'Steve' (Strong Thermal Emission Velocity Enhancement)[1]. It presented a list of Steve events that could be very useful for statistical studies, which are impossible to perform with the (few) available 'modern' observations[2,3]. In particular, the relationship between the Steve events and the phase of the solar cycle can be studied using these historical observations.

I have computed the number of historical Steve events with respect to the phase of the solar cycle. The distribution of the number of historical Steve events with respect to the solar-cycle maximum covers all possible lags between the year of observation and the year of the solar-cycle maximum. However, this distribution shows an exceptional and intriguing peak for the third year after the year of the solar-cycle maximum. Thus, Steve events occurred in 1764, 1781, 1819, 1833, 1863, and 1896 (with the maximum of the solar cycle in 1761, 1778, 1816, 1830, 1860, and 1893, respectively[4]).

Obviously, this peak of the distribution could be the result of chance. Despite the fine compilation work of Bailey *et al.*[1], we still have relatively few events and some of them could be dubious. In particular, the set of Steve events listed in the cited article does not represent a complete sample. In any case, I think that it is a result worthy of being pointed out, and that it could be a clue to establish the true physical nature of this rare type of atmospheric phenomenon.

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Further Discussion of the Speeds of Light, Gravitational Waves, and Gravity

Taylor[1] asked the question whether the fact that $c = c_g$, where c is the speed of light and c_g the speed of gravitational waves (GWs), is an assumption of General Relativity (GR) or whether there is some deeper justification, and suggested a *gedanken* experiment which he claimed proves that $c = c_g$. Thornburg[2] showed that there is a logical error in Taylor's argument: assuming that that which he wishes to prove is true. (Although it is true that Taylor excluded "material particles", *e.g.*, neutrinos, from his argument, Thornburg's claim that c_g could be replaced by the speed of neutrinos doesn't change the logical structure of the argument. While it is true that we now know that neutrinos have mass, for a long time it was assumed that they did not, and the argument could have been made then, its validity to be determined experimentally, as in the case of the question whether $c = c_g$.) As pointed out by Thornburg, $c = c_g$ holds strictly in GR but not necessarily in some other relativistic gravity theories, and there is now strong observational evidence[3] that $c = c_g$, a point not disputed by Taylor[4], who then emphasized that he is concerned with finding an *explanation* of why $c = c_g$ in GR.

Whether an obvious explanation for the equivalence of c and c_g exists within the context of GR is a valid question, though of course what is obvious depends on the observer, so to speak. It is certainly the case that not all accounts of relativity, especially Special Relativity, are easy to follow; a common mistake is not to distinguish between purely relative effects (A sees B's clock run slow and *vice versa*), real effects (B's clock is behind A's when the two are compared at rest after B travels away and returns, this depending only on the length and speed of the journey and not on the acceleration and is explicable within the context of Special Relativity), and effects, such as the appearance of moving objects, which depend on the finite velocity of light[5–7]. However, one must distinguish between clear predictions of a theory as understood by experts, about which there is no debate, and confusion in popular-science depictions.

Taylor[4] then suggested that $c = c_g$ might follow from quantum gravity. While it is true that in quantum field theory the photon is massless, and hence propagates at c, this does not follow from first principles, but is an assumption, shored up by much observational evidence[8,9]. (For that matter, neutrinos are massless in the Standard Model[10], essentially because all neutrinos are left-handed, their masses thus indicating that the Standard Model is not complete; although the evidence for massless photons is much stronger, in the end this question must also be decided experimentally, as long as no-one has shown from first principles that photons *must* be massless.) Thus, similar arguments from a quantum theory of gravity would no more prove the masslessness of the graviton than quantum field theory proves the masslessness of the photon; in fact, 'massive gravity', *i.e.*, theories in which the graviton has a finite mass, is an active area of research[11].

Taylor then asks whether the speed of propagation of *gravity itself* (say, c_G) must necessarily be the same as the speed of propagation of *gravitational waves*. In this case as well, the question is more whether an obvious explanation exists than whether this is a genuine puzzle within the context of GR. One thing which is clear, however, is that a black hole cannot swallow its own gravitational field nor, in the case of a Kerr–Newman (or, with no angular momentum, a Reissner–Nordström) black hole, its electric field[12]. This can be understood intuitively as follows. First, since GR is not a quantum theory, gravitons are a red herring. The gravitational field outside of the horizon can be calculated from the mass before collapse to a black hole; indeed, a distant observer never sees anything cross the horizon, because it is infinitely redshifted. Nevertheless, there *is* a quantum theory of electromagnetism, and the standard result is that the electric field can 'escape' from the black hole. Classically, the answer to this puzzle is the same as in the case of the gravitational field. With regard to photons (and gravitons), since the field is mediated by *virtual* particles, these are not constrained to be interior to light cones (*i.e.*, can 'travel faster than light', though not, of course, carry information), so there is no problem.

There are also more observational tests which have bearing on this issue. Will pointed out that the precession of the perihelion of the planets can be used to provide upper limits on the mass of the graviton (a massive graviton would imply that $c_g < c$, though in general the converse is not true) and hence constraints on alternative theories of gravity, the effect increasing with the distance from the Sun, in contrast to the case in GR; constraints also depend on the quality of observations, the best constraints being provided by the orbit of Mars[13,14]. Will also pointed out that a 'massive graviton' would lead to differences in arrival times between GWs of different frequencies; the fact that these are not observed implies that gravitons are massless (or, strictly speaking, puts strong upper limits on their mass)[14,15]. At present, the Solar System bounds are stricter than those from GWs, but this might change when the space-based gravitational-wave observatory *LISA* becomes operational[14,16]. (Note that these Solar System constraints do not directly test whether $c = c_g$, but rather, by constraining alternative theories, increase our confidence that GR is correct, in which case $c = c_g$.) Some modified-gravity theories predict different Shapiro delays for photons and GWs; this would lead to differences in arrival times on the order of several hundred days in the case of GW170817[17,18]. The extremely small difference in arrival times[3], compatible with zero, rules those out. That is independent of the constraint, based on the same difference in arrival times, which rules out theories in which the speeds of photons and GWs differ.

In summary, the speed of light is the same as the speed of gravitational waves: $c = c_g$ follows from GR and is also verified experimentally, since the arrival times of electromagnetic and gravitational waves are essentially the same (this conclusion is supported by the lack of observed dispersion in GWs). The same observation also rules out some modified-gravity theories which predict different Shapiro delays for photons and GWs. Like Solar System dynamics, while not testing directly whether $c = c_g$, this increases our confidence that GR is correct, in which case $c = c_g$. The speed of light is also the same as the 'speed of gravity': $c = c_G$ is also built in to GR (there are, however, theories where this is not the case[19]). In both cases, the sole remaining, but subjective, question is whether there is an 'obvious' explanation[20].

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Further Discussion on the Velocity of Gravitational Waves

Taylor[1] suggested a *gedanken* experiment which he claimed demonstrates that the speed of propagation of (weak) gravitational waves (GWs), c_g, must equal the speed of light, c. I replied[2] noting a logical flaw in Taylor's analysis, and argued that his *gedanken* experiment does not in and of itself establish the value of c_g. Taylor[3] responded with further observations, as did Trimble[4], and Helbig[5]. A few further points may be of interest.

As Taylor noted, 'strong' GWs (those in which the metric perturbations are not small compared to the metric components) need not have a propagation speed of c even in General Relativity (GR). In order to define GWs, we must also be able to distinguish them from the overall 'background' space–time curvature, *i.e.*, GWs must have wavelengths much shorter than the scale on which the 'background' space–time curvature varies (*e.g.*, the Hubble radius). Henceforth I'll consider only weak, short-wavelength GWs; with these assumptions, we can usefully model GWs as small perturbations of the space–time metric.

Taylor asked for "a clear, first-principles *explanation*" [italics in original] of why $c_g = c$. This question can be approached from several different perspectives. It is important to realize that the question "does $c_g = c$?" is actually comprised of several distinct sub-questions. The first sub-question is a *mathematics* question: does a certain equation or system of equations (for GR, this would be the Einstein equations) have wave-like solutions which we can reasonably interpret as GWs, and if so, with what velocity or velocities do these waves propagate? The second sub-question is a *physics* question: does this equation or system of equations accurately describe gravitation in the physical Universe (to within the finite limits of our observational/experimental accuracy)? And there is a third sub-question, one of *astronomy*: do GW sources actually exist in the Universe?

Focussing now on the mathematics sub-question, we see that in order to proceed we must assume a specific theory of gravity (*e.g.*, GR, a scalar-tensor theory, Rosen's bimetric theory, *etc.*) and its governing equations.

Focussing on GR, consider small, short-wavelength perturbations of the Einstein equations about a fixed 'background' space–time. (The analysis is simplest if the background is assumed to be flat, *i.e.*, Minkowski space–time, but this is not essential.) It's fairly easy to show that if we adopt a suitable coordinate condition for the perturbations (the 'Lorenz gauge'*), then the coordinate components of the metric perturbation do indeed satisfy a wave equation, with propagation along null geodesics. We can identify these propagating-wave solutions as GWs. Massless particles such as photons also propagate along null geodesics (which for this reason we often refer to as 'light cones'), so we have that $c_g = c$.

As is often the case in GR, some further analysis is then required in order to verify that these propagating waves are in fact physically real (assuming favourable answers to the 'physics' and 'astronomy' sub-questions) and are not an artefact of the coordinate choice. The problem here is that in GR the coordinates are not unique; rather, they may be freely chosen. It is possible to have propagating waves of coordinate perturbations (which imply corresponding perturbations in the coordinate components of the metric and other tensors) even if the 'perturbed' space–time is in fact identical to the background space–time, *i.e.*, even if there are no actual physical effects. However, a direct calculation shows that the GW metric perturbations described in the previous paragraph do in fact have a non-zero Riemann tensor, implying that they are physically real (and at least *gedanken* measurable) and are not purely coordinate effects. There was some controversy about this point in the early development of the theory of GWs in GR, but the classic 1957 Feynman–Bondi 'two beads on a stick' *gedanken* experiment (ref. 7, exercise 18.1) resolved this controversy by demonstrating that GWs can impart energy to a (*gedanken*) GW detector and thus must be physically real.

The mathematical analysis leading to $c_g = c$ in GR, and to the physical reality of GWs, is nicely explained in (for example) the introductory textbooks

*Note that the gauge is named for Ludwig Lorenz (1829–1891), and not Hendrik Lorentz (1853–1920), for whom Lorentz invariance and the Lorentz transformation are named. See Jackson & Okun[6] for an extensive discussion of the historical roots of gauge invariance.

by Schutz (ref. 8, Chapter 9), d'Inverno (ref. 9, Chapter 20), Hartle (ref. 10, section 21.5 and Chapter 16), and Carroll (ref. 11, sections 7.4 through 7.7). At a more advanced level, Misner, Thorne and Wheeler's classic textbook (ref. 7, chapters 18 and 35) gives an extensive discussion.

Returning to Taylor's request for a "first-principles *explanation*" for why $c_g = c$, the analysis outlined above makes it clear that in GR the existence of GWs and their propagation along null geodesics ('light cones') is built deeply into the mathematical structure of the Einstein equations. c and c_g are not independent quantities; rather, they are both manifestations of the same null-geodesic structure of space–time. Whether or not this mathematical analysis qualifies as an "explanation" is perhaps in the eye of the beholder.

Alternatively, if we do *not* assume the validity of GR but instead consider other gravity theories, the situation changes substantially. While almost all modern relativistic gravity theories have GW solutions, it is not necessarily the case that these GWs have only two linearly independent polarizations, that their propagation velocity is $c_g = c$, or even that this velocity is unique. Will (ref. 12, Chapter 10) discusses this in some detail for a number of non-GR relativistic gravity theories. For example, in Rosen's bimetric theory c_g "depends on both cosmological parameters and on the local distribution of matter", while in Rastall's theory there are "three independent polarizations for [GWs], one having a different velocity than the other two". (This doesn't contradict Taylor's argument that c_g must be locally unique since Taylor's argument assumes the validity of Special Relativity (including Lorentz invariance) in a local reference frame, whereas Rosen's and Rastall's theories both violate local Lorentz invariance.)

Returning to questions of mathematics within GR, Taylor[3] also alludes to the velocity-aberration effect first noted by Laplace: if gravitational effects propagate at a finite speed, then we might expect the instantaneous gravitational force on a test mass due to a moving source to point 'backwards' by $\mathcal{O}(v/c)$ to the retarded position of the source mass at the time of emission. However, in General Relativity the situation is actually rather more complicated than it might appear. A careful analysis by Carlip[13] shows that this velocity aberration is almost exactly cancelled by velocity-dependent interactions, with the leading-order effects of a moving source not appearing until $\mathcal{O}[(v/c)^5]$. I do not know whether or not anyone has generalized this analysis to non-GR gravity theories.

In conclusion, since different gravity theories predict significantly different GW speeds and other properties, we see that in addition to the mathematical analyses described above, the question of whether or not $c_g = c$ in the physical Universe also requires an investigation of the 'physics' subquestion of what equation(s) accurately describes gravitation in the physical Universe. In GR, c_g and c are necessarily equal as a mathematical consequence of the Einstein equations. But in other gravity theories c_g may differ from c, may vary from one place in space–time to another, and may vary between different GW polarizations.

Fortunately, we now have extensive observational and experimental evidence bearing on the 'physics' subquestion[12,14]. At this time we have no good evidence to reject the 'null hypothesis' that GR accurately describes classical (non-quantum) gravitation. We also now have strong astronomical evidence that GW sources actually exist with properties consistent with GR predictions[15], including that c_g and c are identical to within very tight experimental limits[16].

GW observations can provide many useful constraints on Lorentz violation[17] and other deviations from GR.

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REVIEWS

Galileo Galilei, The Tuscan Artist, by Pietro Greco (Springer), 2018. Pp. 383, 24 × 16 cm. Price £24/$44·99 (hardbound; ISBN 978 3 319 72031 9).

One of the 'must read' books of my youth was *The Sleepwalkers: A History of Man's Changing Vision of the Universe*, by Arthur Koestler (Hutchinson of London, 1959). Koestler had very trenchant views about Galileo. Words like rebellious, confrontational, mocking, sarcastic, quarrelsome, and disputational sprang from the pages. "Galileo had a rare gift of provoking enmity … which genius plus arrogance minus humility creates, among the mediocrities in his audience." (p. 368). The picture painted of Galileo was that of an archetypical academic loudmouth.

This new biography by Pietro Greco, an influential, well-known Italian science journalist and writer, emphasizes Galileo's literary, musical, artistic, and poetic side, attributes that are usually bypassed. The result is a most enjoyable book, extremely thought-provoking and revealing, and offering a refreshingly new insight into Galileo's character. We read of the student who starts by following his father's wishes by studying medicine, but falls in love with mathematics and physics. Greco stresses Galileo's literary skills, his abilities as an engineer and instrument maker, and his success as an experimentalist. He also underlines the stresses of Galileo's private life and his continual financial problems. He relates how the appearance of the supernova of 1604 encouraged Galileo's astronomical endeavours, a new interest that culminated in Galileo's great improvements to the image quality and magnification of the then new-fangled telescope. Galileo's discovery of the satellites of Jupiter, the rotation of the Sun, the phases of Venus, lunar mountains, and the starry nature of the Milky Way are also covered. Then we come to Galileo's 'problem'. As a scientist, it is one thing to discover new things for yourself, to have opinions about their interpretation and significance, and publish these in a reputable scientific way. It is an entirely different thing to try and force these views on others (members of the public, politicians, church-goers) many of whom are less willing to accept your conclusions. And this is where Galileo got into trouble. Galileo 'took on' the Roman Catholic church and especially the conservative embittered Jesuit faction and tried to drag it into the blossoming scientific age.

Greco's text shows a most impressive knowledge of the contemporary correspondence and literature concerning Galileo and much is quoted in full. However, like many biographies of historic figures, even though we learn a great deal about *what* the person did, we learn much less about *who* they were and *why* they did it. Also the translation of the original Italian text is indelicate to say the least, the proof-reading of the text is slipshod, and the index is derisory. I was also surprised that considering the author's stress on the artistic nature of his subject he decided to produce a tome that contained absolutely no illustrations. The form of Galileo's military compass, telescope, book illustrations, and frontispieces are left to the reader's imagination. — DAVID W. HUGHES.

François Félix Tisserand: Forgotten Genius of Celestial Mechanics, by Janet Hyde & Neil Taylor (Observatoire Solaire), 2018. Pp. 85, 21 × 15 cm. Price £6·99 (paperback; ISBN 978 19999 044 1).

This is only a short book, but it truly brings to life not only Félix Tisserand (1845–1896) himself, but also the world of French astronomy in the late 19th Century. It is clearly and elegantly written, and packs a great deal of information into a total of 85 pages, including colour plates, appendices, and diagrams. Janet Hyde & Neil Taylor provide a clear sense of time, place, and personality, and set this illustrious celestial mechanician, the true successor to Laplace, into his historical context.

What comes over particularly strongly is Tisserand's humorous, genial personality, plus his gifts as an inspiring teacher and fair-minded Director of both the Toulouse and Paris Observatories. And what a contrast to the arrogant and high-handed Urbain Le Verrier, who fell out with most people, yet with whom Tisserand found a way of working. The quotations from the travel diary of Charles Piazzi Smyth bring this contrast out clearly.

A mathematical genius from his schooldays in Burgundy, where his cooper father made barrels for the wine trade, Tisserand's scientific career focussed upon celestial mechanics. As a young man, he travelled on several astronomical expeditions, most notably to Japan with Jules Janssen to observe the 1874 Venus Transit, and excelled in the making of meticulous observations.

He is perhaps chiefly remembered today for the 'Tisserand Criterion', and the identification of returning periodic comets from their measured orbital criteria. Hyde & Taylor conclude by posing the question of why this eminent man is not better known. They suggest three possible reasons. Firstly, he was overshadowed by the reputation of the long-dead (1827) Laplace; yet Tisserand's publications advanced celestial mechanics well beyond Laplace. Secondly, he was a modest, un-pushy man. And thirdly, 'bad timing' was a contributory factor, for by the time of Tisserand's sudden death — probably from a stroke in his sleep at the age of 51 — physics was rapidly moving into new realms, beyond that of celestial mechanics: indeed, into the 'New Physics' realm of Einstein, Bohr, Lorentz, and others, making celestial mechanics seem somewhat dated.

The main text requires 'no prior knowledge of astronomy' to read and enjoy, but detailed technical appendices are provided, especially on the Tisserand Criterion.

The book is well produced and illustrated, and the smiling bust of Tisserand at his birthplace, Nuits-Saint-Georges, on the front cover gives one a sense of the man who will be encountered inside. — ALLAN CHAPMAN.

Making Stars Physical. The Astronomy of Sir John Herschel, by Stephen Case (University of Pittsburgh), 2018. Pp. 328, 23·5 × 16 cm. Price $39·95 (about £30) (hardbound; ISBN 978 0 8229 4530 7).

Thanks to a very generous gift from a long-time astronomical friend, I have on my office shelf a copy of *Results of Astronomical Observations at the Cape of Good Hope Made During the Years 1834,5,6,7,8 at the Cape of Good Hope, being the completion of a telescopic survey of the whole surface of the visible heavens, commenced in 1825* by Sir John F. W. Herschel, to give its full title, and which was published in London in 1847. A recent project has had me delving into this book regularly and it never fails to impress both by the remarkable scope of the work done and the author's considerable descriptive powers. Herschel observed the Sun and planets, comets, variable stars, double stars, and nebulae.

It is with double stars that much of Case's text is concerned, and which most aptly 'makes the stars physical'. During Herschel's career the stars went from being points of positional data to bodies of physical knowledge. Herschel made significant advances in the mathematics of calculating binary-star orbits in the 1830s, and although not the first to produce an apparent orbit (that was done by Savary in 1830), he refined the method and followed it up by assiduously observing binary stars, especially from the southern hemisphere. He also produced designs for a new type of micrometer which the reviewer was not aware of, and it appears that he had made an attempt to determine stellar masses from binary-star orbits before F. W. Bessel.

Towards the end of the book the author assesses the influence which Herschel had on Victorian Society and his fellow scientists and researchers, and discusses the activities, amongst others, of Mary Somerville, T. W. Webb, and Agnes Clerke. He notes that the historian Walter Cannon claimed that "it was from Herschel's writings primarily, or from books based on his writings, that intelligent Victorians learned their astronomy, and suggests that *Treatise of Astronomy* and *Outlines of Astronomy* did for sidereal astronomy what Pierre-Simon Laplace's *Méchanique céleste* did for the Solar System". This seems a fair statement — but Herschel's polymathic interests also embraced photography, optics, and chemistry.

The author has done a signal service by compressing what Sir John Herschel did into an accessibly small volume. Herschel's output was prodigious and apart from about 55 original papers and books, Dr. Case has also consulted several-hundred primary and secondary sources which appear in the bibliography. He does not dwell too long on the work of William Herschel, whose own work was certainly influential on the young John, but shows how Herschel developed, on his own merit, into a scientist of great repute. The text is beautifully written and deeply researched and the volume is recommended. — ROBERT ARGYLE.

Kew Observatory and the Evolution of Victorian Science 1840–1910, by Lee T. Macdonald (University of Pittsburgh Press), 2018. Pp. 308, 22·5 × 16 cm. Price $45 (about £34) (hardbound; ISBN 978 0 8229 4526 0).

I've always had a somewhat higher regard for King George III than most of my fellow countrymen (the Prince of Wales excepted). He was the first really 'English' of the Hanoverian monarchs, had a keen interest in many things such as farming and science, and clearly had a passion for astronomy. And this led to the construction of the King's Observatory in Old Deer Park at Kew near Richmond just in time for His Majesty to observe the transit of Venus on 1769 June 3. His devotion to the subject might have led to the naming by William Herschel of a planet *Georgium Sidus* after him, but alas the poor object ended up with the moniker Uranus, which does require careful pronunciation.

After George III, astronomy at Kew went into something of a decline, such that the start of Victoria's reign found the Observatory in a rather sorry state. But other sciences were to step in and save the day: meteorology and geomagnetism. With the enormous reach of the British Empire, the time was ripe for scientists to think seriously about global observations of meteorological conditions and the variations of the magnetic field across the Earth; this was not just in the interests of pure research but also because of their importance for navigation, trade, and other aspects of value to the imperial adventure.

One of the most influential of the drivers on the geomagnetic side was Edward Sabine, who envisaged a 'Magnetic Crusade' to study the Earth's field by combining observations from across the Empire with those made locally, and the Kew Observatory became the nerve centre of it. Meteorology followed a similar path, along with complementary studies of atmospheric electricity. Initially the Royal Society was involved, but funding was always an issue and eventually the British Association for the Advancement of Science and private donors became essential. One such donor was Warren de la Rue, whose interest in photography led to a programme of daily photography of the Sun, which was soon taken on board at Kew where it thrived as a component of the work of a 'Physical Observatory'.

Needless to say, it was not long before the reasonably flourishing Kew Observatory came under the steely purview of the Astronomer Royal, George Airy, who felt that there were some activities that might more properly be carried out by the Royal Observatory at Greenwich. And so for several years we can imagine heated arguments going on in smoke-filled rooms! Ultimately the photoheliographic programme was wrested from Kew and re-established at Greenwich, ultimately to be transferred to Herstmonceux, by then the Royal Greenwich Observatory. I was privileged (or fated) to be the last to run that operation, and was very reluctantly obliged to attend the IAU General Assembly in Grenoble in 1976 and announce the closure of the service.

Meanwhile, at Kew, another project had started very successfully: the standardization of scientific equipment, particularly thermometers but also barometers, sextants, *etc*. This eventually became a 'nice little earner' for Kew, and it did no harm to their reputation across the world, with the stamp 'KO' carrying great prestige.

This diversity of interest kept Kew going throughout the Victorian age until it eventually outgrew the 'King's Observatory' and the available space in Old Deer Park, particularly for the standardization work but also other aspects of physical science that could be seen going on in the Physicalisch-Technische Reichsanstalt in Berlin (and by then, Germany was a serious competitor in many areas). A 'National Physical Laboratory' was required and was ultimately set up in Teddington, not far from Kew. Little by little, work left Kew, with the magnetic operation transferred to Eskdalemuir, and the meteorological coordination moved to the Met Office. Now we find Kew Observatory again asleep in the middle of a golf course.

The story of Kew's rise and fall throughout the Victorian age is told in great depth by Lee Macdonald in this fascinating book from the University of Pittsburgh Press. It demonstrates an enormous amount of detailed research, and provides copious notes (36 pages), an extensive bibliography, and a good index. It will be a treasure trove for historians of science, and is a very welcome addition to the literature. — DAVID STICKLAND.

Imagining Other Worlds: Explorations in Astronomy and Culture, edited by Nicholas Campion & Chris Impey (Sophia Centre Press), 2018. Pp. 351, 23·5 × 15·5 cm. Price £29 (paperback; ISBN 978 1 907767 11 1).

This book arises from the ninth INSAP (Inspiration of Astronomical Phenomena) conference, held in Gresham College in 2015. The INSAP conference series "celebrates our shared experience of the starry sky", to quote Martin Rees in the Introduction to his lucid and wide-ranging public lecture at the beginning of this volume. The lecture was followed by a panel discussion, in which five of the Gresham Professors took questions from the audience.

Like its predecessors, the conference brought together astronomers and artists, anthropologists and historians, to address the cultural interests of astronomy, leading to a very diverse set of topics, reported here in 22 contributions. The 'Other Worlds' in the title are catered for by Chris Impey, who gives us a fine survey of the long history of the idea of the plurality of worlds, from classical times to the present. Like most contributions, it is thoroughly referenced for those wanting to follow up any topic.

Examples of astronomically related artworks range over the centuries, from Bevis's *Uranographica Britannica* (Jay Pasachoff and Kevin Kilburn), *via* the symbolism of Galileo's tomb (Liana De Girolami Cheney), the *Salvator Mundi* Mosaic in Saint Isaac's Cathedral (Michael Mendillo and Ethan Pollock), and Giacomo Balla's paintings inspired by the 1914 transit of Mercury (Gary Wells), to contemporary artworks by Annette Lee inspired by Ojibwe and D(L)akota astronomical lore, which she and colleagues are working to save. Her chapter concludes with tables of Ojibwe and D(L)akota celestial vocabularies. These contributions are all well illustrated and the authors have had enough space to discuss the works, their sources, and inspiration.

The interplay of astronomy and art is demonstrated by the work at the Royal Museums Greenwich, which incorporates the old Royal Observatory (ROG), the National Maritime Museum, and the Queen's House art gallery (and the Cutty Sark), well described by Melanie Vandenbrouck and Marek Kukula. The Astronomical Photographer of the Year competitions have been greatly expanded over the years, increasing community engagement and attracting commercial sponsorship. In parallel, their sequence of art exhibitions included astronomical themes and latterly led to the acquisition of contemporary art works by the Museums. It is interesting to compare this with Michael Geffert's account of the similar use of old astronomical plates and other historical material from the Observatorium Hoher List in exhibitions of modern art.

In her account of Christopher Wren's re-building of St. Paul's Cathedral, Valerie Shrimplin reminds us that Wren was an astronomer before he was an architect, and discusses the orientation of the rebuilt St. Paul's Cathedral and the use of the South West Tower for astronomical work. In a rare departure from the high standard of production in the volume, two of the figures (21.9 and 21.10, The Monument and St. Stephen Walbrook) in this chapter got interchanged.

There are many more, varied contributions. We are also given an 'About the Contributors' section — more than usually valuable given their very diverse backgrounds. I am happy to recommend this book to anyone interested in the fascinating offshoots and byways of astronomy, especially to those involved in outreach. — PEREDUR WILLIAMS.

The Secret Life of Science: How It Really Works and Why It Really Matters, by Jeremy J. Baumberg (Princeton University Press), 2018. Pp. 236, 24 × 16 cm. Price £24·95/$29·95 (hardbound; ISBN 978 0 691 17435 8).

If only the author, Baumberg, had the same easy writing style as the unacknowledged scribe who produced the blurb on the flyleaf, which clearly describes what the book is about, then this book would have been much easier to read and this review more of a pleasure to write.

I have no doubt that there is an interesting and possibly important book within these pages but I found it quite a trial to dig out the meaning from frequent awkward sentence constructions — but maybe that is a matter of personal taste. Baumberg sets up the problem quite straightforwardly in the brief Acknowledgements section — "Why the scientists that I come into daily contact with do things in certain ways". He also says that his writing was motivated by his "disquiet … about the typical view most people have about how science works, and what scientists do". Thereafter in the main chapters the sentences meander and seem to lose focus with the occasional negative placed at the end of a sentence which disrupts easy reading — as in the slang that was in vogue a few years ago in which something or somebody is described in glowing terms only to be discounted by adding "not" at the end of the sentence.

I have a friend who samples books by reading a sentence at random from page 164, always page 164 — for this book on page 164 I read; "Because funding science fills a market failure to deliver a common good of society, we could say that all science is an ecosystem service". I don't know about you but I have no idea what that sentence is telling me.

Baumberg sets himself the task of describing how science is actually done in the present day, and the pressures and influences acting upon the scientists in carrying out their work: who are scientists and who becomes a scientist, what do they actually do, and where do they work? His overarching belief is that the pressure to work, and report, in a particular way, in specific journals is leading to a standardization and homogeneity in science, and that this uniformity is detrimental to scientific progress and the lives of scientists.

There have been several books lately dealing with the sociology of science, written by sociologists, often about large collaborations or institutes such as CERN. Baumberg's remit is larger, dealing with the overall worldwide generality of doing science. So it is a book about science and the sociological environment in which it operates, rather than the sociology of scientists themselves.

He starts with collecting some basic data such as who scientists are, how many there are, what they do, and to some extent why they do it. He divides scientists into two camps, and rather than use the traditional labels of theoretical and applied, Baumberg prefers to use the names 'Simplifiers' and 'Constructors'. He justifies this as a means to get away from the rigidity implied in the traditional descriptions. A cartoon illustrating the two types shows Simplifiers as cutting slices from what looks like a pumpkin, and Constructors as planting trees. This illustration, like many of the drawings in the book, serves to confuse rather than illuminate — why a pumpkin? And is a slice simpler than a whole pumpkin? Perhaps the cartoon trees stand for all plants and the pumpkin for all fruit, and thus we see Simplifiers feeding off the fruit of the Constructors' hard work — or maybe I am reading too much into it. He also distinguishes between academic scientists, *i.e.*, those working in universities, and industry-based scientists, *i.e.*, those working in commercial organizations. The career trajectories and pressures on the two are clearly different, says Baumberg — the need to publish in high-impact journals being paramount in the academic case and the need to solve the immediate technical problem in the case of industry-based scientists. Fortunately there is no accompanying illustration.

So this book is basically descriptive, using information gleaned from several sources in many countries, including his own tenure in the US, Japan, Spain, and the UK, in both university and industry. The author has collected interesting data in terms of the numbers of scientists and the sort of work they do, and then attempts to analyse what these data mean for the state of science both in the present and for the future. The arguments are illustrated graphically by making use of a basic foundation diagram described as the 'Science Ecosystem'; and I have already mentioned the difficulty of interpreting the diagrams. The Ecosystem chart first appears in Chapter 2, 'What is Science', as a five-lobed Venn-like diagram, the lobes being People, Translation, Knowledge, Funding, and Media, all set in a grey shaded rectangle described as Public. The lobes contain various 'actors' — PhDs, Institutes, Research Councils, Newspapers, *etc.*, *etc.* — there are 24 separate component parts. As each new topic or chapter is introduced the diagram is repeated with arrows of varying thickness illustrating the linkage between these components. By the time we get to the penultimate chapter (9) the diagram is so thick with overlapping arrows of varying thickness and shading that it is difficult to deduce anything — other than perhaps complexity; and that may have been the point as in this case the diagram represents the flows and tensions within the Scio-spheres (me neither) at the present time. Fortunately, in the last chapter the clear potential future of the Science Ecosystem is illustrated with the diagram now free of arrows, and the actors have been renamed with punchy modern sounding names — science curators, new metrics, professional postdocs, ecosystem services. So the illustrative diagrams progressed from a simple and uncluttered naming of parts through the chaos and mayhem of a black-arrow-scribbled present, onward to a potentially uncluttered future. Is that what the text is also telling us?

There is an interesting section on science reporting as journalism, which serves as a useful summary of the process by which science becomes a news story. Baumberg notes that all of the world's science output is reported in the UK by fewer than 100 science journalists. He then goes on to describe the deadlines and influences that constrain such a journalist in the selection of which items to cover. Journalists believe that there is a hierarchy of topics that make suitable popular stories, and this belief is supported by their reading figures. There are only four such themes and they are: origins (prehistory or planetary), microbiology and genetics in relation to health, the environment (climate, flora, and fauna), and fundamental things particularly in physics — and what gets missed is pretty much all of materials science, engineering, chemistry, mathematics, and astronomy that is not related to fundamental physics or planets. Bad news, then, or rather no news, for most of astronomy.

In spite of some difficulty that I found in the writing — and I resented every sentence that I had to re-read multiple times — Baumberg has collected some useful information and made interesting comments. There are occasional gems such as "… doctors and lawyers gain respect by doing the same things very well [over and over again], … [whereas] scientists are always having to do something for the first time". Or the realization of the new PhD student who, having aced his fact-based undergraduate course, is suddenly struck by the thought that not only does he not know the answer to a particular problem but nobody does. Baumberg also has some comments about the necessity of diversity in science, by which he means the different styles or approaches to problem-solving, but he has nothing to say about human diversity such as the gender, ethnic, and class bias in science and science institutions. (Baumberg is a professor at Cambridge University, an institution with an undergraduate intake of about 40% from private schools.) As Bob Dylan has long since noted, "money doesn't talk, it swears", and what it swears about is privilege rather than equality of opportunity and diversity.

So *The Secret Life of Science* is a challenging, interesting, but very time-consuming read. I could have used a well-written summary, or a concluding overview, about what we have learned from this comprehensive gathering of data. Instead Baumberg invites us to join the discussion at his blog www.thesciencemonster.com. If you want to join in or just take a look then make sure that you use the correct address, as in the book it is wrong in all but two instances. — BARRY KENT.

The History of Physics: A Very Short Introduction, by J. L. Heilbron (Oxford University Press), 2018. Pp. 175, 17·5 × 11 cm. Price £7·99/$11·95 (paperback; ISBN 978 0 19 968412 0).

Heilbron's short history begins with Ptolemy and other Greek universes, praises the elegance and utility of astrolabes, and ends with dark energy and dark matter. It is, therefore, as much a history of astronomy as of physics. The volume is one of almost 600 short introductions from Oxford University Press, other members of the inventory including Astrophysics (by James Binney), Black Holes (Katherine Blundell), Cosmology (Peter Coles), Galileo (Stillman Drake), History of Astronomy (Michael Hoskin), and Relativity (Russell Stannard). Most authors are recognizably British, and Heilbron, though long professor at University of California Berkeley, is now resident in Oxford.

The author mentions that cosmology and cosmogony are lasting concerns of humanity; is of the opinion that Copernicus knew of the Tusi couple rather than inventing it independently; adopts a firmly secular view by considering a Bungling Demiurge as an alternative to an Intelligent Creator to explain the non-detections by SETI; and puts Edwin Hubble at Caltech rather than Mt. Wilson and Palomar Mountain Observatories. Mesons are called Yukons (for Hideo Yukawa), and Cesare Lattes comes out Giulio (one of his middle names).

But the remarks that stick in a sensitive mind are cultural rather than scientific: (*i*) "The US had learned to produce not only theorists of the Jewish-cosmopolitan-extrovert type like Oppenheimer, Feynman, and Schwinger, but also of an introverted, unassuming, gentile type. John Bardeen …" ; (*ii*) "The House of Wisdom established in Baghdad by al-Mamun incorporated the library of his father Harun al-Rashid, the Caliph of the Thousand and One Nights, and an observatory for other nocturnal activities."; (*iii*) "As the new universities assimilated their Greek–Muslim inheritance, other important material arrived with people fleeing a Byzantium wrecked by crusaders and threatened by other barbarians."

Heilbron places the beginning of the Scientific Revolution in 1654, with the invention of the air pump (Wootton, in *The Invention of Science*★, chose Tycho's *nova stella*) and provides a very nice description of how Descartes's vortices flowing between Earth and Moon produce tides. Newton's version is more familiar, though one still has to understand "the establishment of the port" (the constant time interval by which high tide lags meridian passage of the Moon, supposedly a discovery of the Venerable Bede and the only western contribution to science in 800 years).

This is, in summary, a curious and interesting book, in which you will easily find astronomical and other remarks to arouse anger! My copy was a review one, sent to Another Journal. — VIRGINIA TRIMBLE.

★ See review in these pages, **137**, 315, 2018.

Conjuring the Universe: the Origins of the Laws of Nature, by Peter Atkins (Oxford University Press), 2018. Pp. 197, 22 × 14 cm. Price £14·95/$24·95 (hardbound; ISBN 978 0 19 881337 8).

Atkins, the author of several technical and several popular-science books, is probably best known for his *Physical Chemistry* (also from OUP). This book focusses on the laws of Nature and their origin. Although the material is familiar, in contrast to most popular-science books it is presented in a somewhat idiosyncratic way, with respect to both content and presentation (the "evolution of folk" does not refer to Dylan picking up an electric guitar). After a general discussion on various types of laws of Nature (probably only Atkins refers to them as "inlaws" and "outlaws"), conservation laws, and the least-action principle, Atkins' explication of temperature and the laws of thermodynamics leads into an example of his theme that laws arise from indolence and anarchy (on the part of the constituents of matter), coupled with our ignorance of details: individual molecules do their own thing in a gas, and our description of them due to Boyle, Mariotte, and Charles is due to our ignorance of the details. That is applicable not just to ideal gases. The somewhat different topic of the laws of electricity and magnetism is discussed in similar terms, the concepts of anarchy and ignorance emphasized in Feynman's explanation of the least-action principle. The book ends with a discussion of the constants of Nature and musings on why mathematics works so well in science (here mentioning Max Tegmark's similar ideas[1], reviewed[2] in this *Magazine*).

Atkins is fond of the concept that the Universe arose from nothing, without describing in detail what that nothing was, though postulating that "nothing much happened". The mechanism is necessarily vague, but he sees that as a possible explanation for the initial low entropy of the cosmos. "With no chaotic disorder, the initial entropy would have been zero." (Without gravity, perfect uniformity is a high-entropy state, but since entropy increases due to gravitational clumping and gravitation is important in cosmology, especially in the dense early Universe, a smooth initial state is a relatively low-entropy one.) The explanation of the low entropy at the Big Bang is still a topic of debate, but probably needs a better explanation than what Atkins offers. (To be fair, he admits that this and other speculations are lacking in detail and perhaps not convincing.)

The discussion of constants of Nature is interesting and presented a bit differently than most such, especially with regard to the question of which constants are truly fundamental. The main conclusion, that only dimensionless constants need to be considered, is correct, but comes at the end of a long series of explanations. Some readers thus might overlook that main idea, while others might think more deeply about the concepts, especially because Atkins presents them in a somewhat roundabout way. Most readers will probably be aware that the historical concept of the mechanical equivalent of heat is merely an artefact of using different units for mechanical and thermal energy, and see an analogy with Boltzmann's constant. That Planck's constant is in the same category might surprise some; surely we can imagine a world with a different value for Planck's constant, and not due just to a different system of units. The same goes for the speed of light, but is that still possible if the speed of light is defined to be constant and that assumption used to define the metre in terms of the second? It is, but ultimately one must compare dimensionless constants constructed out of combinations of others. A bit more detail would have been nice here. While the rest of the book makes things easier to understand, after reading this penultimate chapter some might be left feeling like Fermi: still confused, but on a higher level.

There are neither figures nor footnotes; endnotes are mostly mathematical details (sometimes quite complicated, in contrast to the main text, which contains no equations) or commented references; the small-print index is a bit more than four pages. Although a bit quirky in some ways, the main text is easy to follow, and though it makes use of metaphors and so on, the mathematical details in the notes are there for those who want a more scientific description. There are only a few minor typos and other small mistakes, though unfortunately in some cases the intended meaning will not be obvious to all readers. I enjoyed reading the book, not only for the main themes but also for several asides on history, etymology, and so on. — PHILLIP HELBIG.

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A Student's Guide to Atomic Physics, by Mark Fox (Cambridge University Press), 2018. Pp. 275, 23 × 15 cm. Price £17·99/$24·99 (paperback; ISBN 978 1 108 44631 0).

Incorporation of experimental and theoretical knowledge of atoms and molecules into astronomy distinguishes astrophysics from astronomy. Today, a thorough understanding of atomic and molecular physics is surely a prerequisite for a career in astrophysics, especially now that the entire electromagnetic spectrum of many astronomical objects may be open to quantitative examination. Given the need for a sound understanding, the question becomes how are students to develop a serious interest in atomic and molecular physics? This book by Mark Fox deserves consideration for an atomic-physics course taken by physics (and other) students in the second half of their undergraduate career.

Fox has divided his book two parts. Part I headed 'Fundamental Principles' introduces the expected array of topics in eight chapters beginning with 'Preliminary Concepts', continuing through 'The Shell Model and Alkali Spectra' in Chapter 4, to 'External Fields: The Zeeman and Stark Effects' in the concluding Chapter 8. Four chapters in Part II on 'Applications of Atomic Physics' cover 'Stimulated Emission and Lasers', 'Cold Atoms', 'Atomic Physics Applied to the Solid State', and 'Atomic Physics in Astronomy'.

For today's undergraduate with laptop on the classroom desk, cell phone to hand, and ears plugged up and blasted with 'music', Part I is likely to seem too heavily weighted towards mathematics. Too bad! But I would sympathize with those young people in that this part might have provided a more representative set of real spectra. Topics in Part II should engage some of today's undergraduates.

It is vital, I feel, to capture a few science undergraduates early in their careers with the beauty of astrophysics and, in particular, with examples of astronomical detective work which demand knowledge of atomic and molecular physics. In this regard, the chapter 'Atomic Physics in Astronomy' may not be terribly successful. Closer coupling of the astronomical object (*i.e.*, stars, gaseous nebulae, *etc.*) with illustrations of atomic astronomical spectra ending with discussion of information gained would have helped. Then, this information should have been linked to fundamental questions about, for example, the origins of the Universe, the life of stars, and origins of planets.

In conclusion, I welcome this book for its clear exposition of the basic ideas on atomic structure and spectra. When a second edition is prepared, I would hope the changes will include an expanded discussion of theoretical and experimental determinations of line intensities (*e.g.*, Einstein A-values, *gf*-values) so critical to spectroscopic astrophysics. But more crucially, I would like to see a more-enticing and ordered discussion of how knowledge of atomic spectra advances astrophysics. The health of spectroscopic astrophysics demands that young bright minds are brought into the field in every generation. Texts like that by Mark Fox have a crucial role to play in this context. — DAVID L. LAMBERT.

Bayesian Astrophysics, edited by Andrés Asensio Ramos & Iñigo Arregui (Cambridge University Press), 2018. Pp. 194, 25 × 18 cm. Price £110/$140 (hardbound; ISBN 978 1 107 10213 2).

The Canary Islands Winter School of Astrophysics has run annually since 1989. The format is successful enough that it has scarcely changed over three decades: a handful of experts delivering graduate-level lectures to a few dozen participants on a subject of topical interest over the course of a week or so. Both lecturers and students (who can themselves contribute short poster-based presentations) are drawn from the wide international community, and the lectures are published by CUP.

The 2014 School, on 'Bayesian Astrophysics', was delivered by seven lecturers, of whom five have submitted written contributions to this volume. The opening review, 'Bayesian Inference and Computations: A Beginner's Guide', was easily the most useful for me. Written by Brendon Brewer (an astrophysicist now working in the Dept. of Statistics at Auckland), it's clear and full of useful practical tips — exactly the sort of introduction that I wish I'd had when I started on my tentative exploration of Markov-Chain Monte-Carlo methods (and that I'm still glad to have now).

There follow essays on three more-specialized astro-applications: 'Inverse Problems in Astronomy' (Jean-Luc Starck, heavily focussed on image reconstruction/deconvolution), 'Bayesian Inference in Extrasolar Planet Searches' (Phil Gregory on Keplerian periodograms), and 'Bayesian Cosmology' (Roberto Trotta's review of modern cosmology, with a relatively brief Bayesian afterword). Finally, José Bernardo, a full-blooded Bayesian statistician with no direct astro connections, offers a rigorous, mathematical 'Introduction to Objective Bayesian Statistics'.

As is customary with CUP 'Proceedings' volumes (which is how this one is categorized), the printed book is in bleak monochrome, although as usual a number of inappropriate figure captions suggest that contributors must've expected colour; that alone would be enough to deter me, on principle, from considering a personal purchase, even if the heavy toll of more than £1 per sheet of B5 paper didn't. There is a pdf version (available for separate, not bundled, purchase); unfortunately, in this case it is, inexplicably, also monochrome (though a full-colour version of Brewer's contribution is freely available on his website as I write this). Interested parties with university affiliations may well find that, like me, they have free ('at the point of use') access to the pdf through an institutional subscription. I therefore suppose that some may consider the budget option of printing off a pdf chapter or two as an alternative to purchasing the book, at least until such time as CUP Proceedings volumes match the production standards and value for money of their textbooks (print runs notwithstanding). — IAN D. HOWARTH.

Jets and Winds in Pulsar Wind Nebulae, Gamma-Ray Bursts and Blazars, edited by Andrei Bykov *et al.* (Springer), 2018. Pp. 360, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 94 024 1291 8).

Editors Bykov *et al.*, Springer, and the International Space Science Institute (Bern) have chosen to favour us with nine chapters that originally appeared in *Space Science Reviews* between 2016 December and 2017 June. The conference of which these are the proceedings took place in 2015 November 16–20. There is, of course, no index, but each of the chapters does deal with either observations or theoretical interpretation of one of the categories of astronomical source mentioned in the title.

The articles were reviewed, but this did not prevent the same *Chandra* image of the trilobite-like SNR G292.0+1.8 from appearing twice in one of the pulsar-wind-nebula chapters, nor correct a figure caption proclaiming that "the pulsar is highly piled up" (overexposed, would seem to be intended).

No participant list appears. The editors mention "about forty leading experts"; 33 people appear in the conference photograph; and addresses on the chapters indicate that they came from at least 11 countries. Near-full lists of team members of *HESS*, *NuSTAR*, *Planck*, and *XIPE* appear as the authors of some cited papers, and I can imagine using these as sources for something in the future; the ageing chapters perhaps not so much so.

The chapter in which Yajiey Yuan is communicating (though not first) author introduces the word 'magnetoluminescence' to describe "dramatic flaring activity where the electromagnetic energy distributed over large volumes appears to be converted efficiently into high-energy particles and gamma-rays". The first author is Roger Blandford, and I suspect any conference where he, editor Jonathan Arons, and author Steve Reynolds were participants must have been a valuable experience for the younger astrophysicists there.

At press time, the editors contemplated two more similarly-structured ISSI workshops, on supernovae and clusters of galaxies. If these have not already taken place, I recommend that you try to wangle yourself an invitation to one or both, but don't sit up nights waiting for the proceedings to appear.

Conflict-of-interest statement: I asked for the review copy of this volume because of a commitment to write a chapter on the history of astrophysical jets later this year (2018). One chapter, by Gustavo Romero, Markus Boettcher, *et al.*, honourably begins with Curtis 1918, who does not use the word 'jet'. — VIRGINIA TRIMBLE.

Cosmic Magnetic Fields, edited by Jorge Sánchez Almeida & María Jesús Martínez González (Cambridge University Press), 2018. Pp. 202, 25·5 × 18 cm. Price £110/$140 (hardbound; ISBN 978 1 107 09781 0).

This 2013 graduate school was organized on the premise that cosmic magnetism should be studied as a unified whole: a strangely common attitude, although no-one would apply the same logic to, say, gravitation. The contents demonstrate that to become an expert in every aspect of cosmic magnetism one would have to understand the whole of astrophysics. Despite the promise of a 'complete' review, there are startling omissions: no neutron stars, white dwarfs, or contact binaries, only cursory comments on magnetic fields in star formation, and the lectures on galaxy clusters were never written up. What remains, after a brief summary of MHD by the editors, are compact reviews of magnetic fields in the Sun (P. G. Judge), main-sequence stars (O. Kochukhov), AGN and feedback (R. Keppens, O. Porth and J. P. Goedbloed), late-type galaxies (R. Beck), and the early Universe (F. Finelli and D. Paoletti).

Most of the lectures are in a tutorial style, with emphasis on observational techniques, phenomenology, and the theoretical building blocks; so the delay in publication hardly affects their usefulness. The chapters on solar and stellar magnetic fields are nicely complementary. Judge's sceptical review starts with Eugene Parker's unanswered question, "why, according to the basic laws of physics, is the Sun obliged to form a sunspot?", while Kochukhov shows that many stars are under no such obligation. A highlight is the description of the amazing variety of stellar magnetic-field configurations, much of which has recently been revealed by new techniques such as full-Stokes Zeeman Doppler Imaging. Beck's masterly review of spiral galaxies emphasizes the many open questions, and is copiously illustrated with observed field patterns. In contrast, Keppens *et al.* approach AGN largely as an exercise in applied maths: their primary focus is the accretion disc and the jet-launching process, which remains out of reach to direct observation, although now visualized by 3-D General-Relativistic MHD simulations. Linear stability analysis of idealized (non-turbulent) discs receives, perhaps, undue attention. Finelli & Paoletti's chapter seems even more theoretical, but only to predict the signature of primordial fields on the CMB, sadly yielding only upper limits. Familiarity with cosmological perturbation theory is assumed, especially as the standard notation goes undefined.

This book is too abbreviated and fragmented to serve as a stand-alone text. It provides useful entry-points to the literature, but few students will need to study more than one chapter. — J. P. Leahy.

Magnetic Fields in the Solar System: Planets, Moons and Solar Wind Interactions, edited by Herman Lühr, Johannes Wicht, Stuart A. Gilder & Matthias Holschneider (Springer), 2018. Pp. 413, 24 × 16 cm. Price £131·50/$189 (hardbound; ISBN 978 3 319 64291 8).

This book summarizes work done in the programme 'PlanetMag', sponsored by a German research foundation. It discusses observation and modelling of magnetic fields, or processes strongly influenced by magnetism, within different environments in the Solar System.

Chapter 3, for example, describes the nature of magnetic dynamos operating at Jupiter and Saturn. There is also a nice discussion as to why Saturn's observed internal magnetic field should be axisymmetric (coincident rotational and magnetic poles).

Chapter 4 develops the link between dynamics of the Earth's outer core and the time dependence of the magnetic field which it generates. Chapter 5 is a useful description of the role of magnetic fields in destabilizing rotational flows in different astrophysical environments — it rewards repeated examination.

Chapter 6 takes us to the outer Solar System, and provides an excellent overview of the various sources of magnetic field in Jupiter's magnetosphere, the coupling between the planet's ionosphere and magnetosphere, and the interaction between the various icy moons — including Ganymede — and the ambient, variable field of their parent planet. This is a chapter of relevance for those involved in missions such as *Juno* and *JUICE*.

Chapter 8 takes us much closer to the Sun, and examines particle acceleration in the magnetosphere of Mercury — emphasizing the much stronger 'driving' of the system by the process of magnetic merging/reconnection, compared to the case of the Earth. Chapter 9 draws our attention to the unique environment of Saturn's moon Enceladus, and the now-famous (thanks to *Cassini*) water plume of that moon. This plume constitutes a true 'dusty plasma' — that is, the dust grains form an additional component with 'collective behaviour'.

Chapter 10 takes us back to our own planet, and is a well-written treatise on modelling magnetic signatures of Earth's ionospheric current system. Magnetosphere–ionosphere coupling at the Earth is emphasized in the following Chapter 11, which explores viable related mechanisms for the phenomenon of vertical plasma and upper-atmospheric flow. This chapter makes use of various satellite databases for estimating the relevant physical parameters of the atmosphere and ionosphere. Elsewhere in the book, we have a good illustration of how accurate modelling of Mars' crustal field can guide our thinking regarding the past activity of its dynamo (Chapter 12), and a study of the magnetic signatures of terrestrial impact craters (Chapter 13).

There is yet more good useful material in the book — the overall impression is of the importance of combining theory, observation, laboratory experiment, and new methods of modelling and data analysis. I would recommend this book as a well-referenced and up-to-date summary of research related to planetary magnetism and magnetospheres. — NICK ACHILLEOS.

Wacky and Wonderful Misconceptions About Our Universe, by Geoffrey Kirby (Springer), 2018. Pp. 258, 23·5 × 15·5 cm. Price £19·50/$34·99 (paperback; ISBN 978 3 319 73021 9).

This book sets out to describe 'wacky' ideas in astronomy, defining them as "Funny or amusing in an odd or peculiar way." The author casts his net wide. Included are the works of capable scientists along with those ignorant or contemptuous of science, the people Augustus de Morgan would call 'paradoxers'. Including hoaxes and outright fiction seems to go beyond the title; surely an idea must actually be *believed* in order for it to be a misconception?

Still, I suppose one might consider this an old-fashioned curio box, with contents one could examine just to say, 'how strange'. Unfortunately it includes a great deal that is inaccurate or simply wrong. Sir John Herschel believed the Sun to be inhabited in spite of a temperature of 10 000° F (p. 6)? Well, no, the temperature was not determined until after Herschel's time. John D. Hooker ground the mirror of the telescope that bears his name (p. 213)? No, it was a team effort, led by Ritchey. Examples could be multiplied. The result is a confused mixture of fact, mistake, speculation, and rumour. How did this come about?

There is a big clue in the chapter end-notes. A quick count gives 222 of these as references. Of these, 56 are to books, some of them from 'paradoxers' (*Worlds in Collision* and the like), some are collections with titles like *Space Oddities* and *Weird Science*. Only eight are scientific journal references. (I checked two of these: W. Herschel, *Phil. Trans. Roy. Soc.*, **91**, 265, 1801, does not contain the quote attributed to it; and contrary to Kirby's text, Whipple & Menzel, *PASP*, **67**, 161, 1955, has no speculation about life on Venus.) Of 158 notes, the great majority, are links to world-wide-web pages (including YouTube videos). If you depend on web pages for your information, you'll often be wrong.

I would have liked to see the source of several assertions, including the fact that there is 'a hard core of anomalous images' that could be alien artifacts on the Moon (pp. 117–8) and the theory that the Earth had once been a 'six-faced tetrahedron' (p. 87; what sort of topology does that imply?). Unfortunately, there are no references at all for these.

I do not recommend this book. — ALAN WHITING.

Serendipities in the Solar System and Beyond (ASP Conference Series, Vol 513) edited by Chung-Ming Ko, Chan-Kao Chang & Po-Chieh Yu (Astronomical Society of the Pacific, San Francisco), 2018. Pp. 309, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 910 4).

Born 1947 in Nanjing, China, Professor Wing-Huen Ip was an undergraduate in Hong Kong, did his PhD in the USA, spent twenty years at the Max-Planck-Institute for Aeronomy, Katlenburg-Lindau, West Germany, and then moved to the Institutes of Astronomy and Space Science, National Central University, Taiwan. Scientifically he concentrated on comets, planets, Solar System evolution, exoplanets, and the *Cassini–Huygens* mission to Titan. The book under review is his *Festschrift*, the thirty-one papers originating at the 2017 July 10–13 symposium at his Taiwan university which celebrated his seventieth birthday.

We are presented with a feast that underlines the importance and productivity of international and interdisciplinary astronomy and space science. Topics such as the surface of comet 67P/Churyumov–Gerasimenko, the spin rate of asteroids, the possibilities of the existence of transplutonic planets, solar wind, grain charging in Saturn's rings, and the origin and evolution of Titan vie for your attention. What I loved especially were the photographs of the participants, presenting papers, listening to talks, sitting in their offices, eating lunches, and being generally scientific.

The word 'serendipity' in the title of this book is associated with chance and accident. Like many astronomical planetary folk Wing was lucky to be born in the space age, and to have Comet Halley visit the inner Solar System at the height of his career. But the papers presented in this superb volume underline that added to chance and accident was a huge amount of dedication, cleverness, hard work, and making the most of the opportunities presented. — DAVID W. HUGHES.

Life on Mars: What to Know Before We Go, by David A. Weintraub (Princeton University Press), 2018. Pp. 302, 24 × 16·5 cm. Price £24·95/$29·95 (hardbound; ISBN 978 0 691 18053 3).

Life on Mars is not just a book about Mars; it is a chronicle of humankind's obsession with the Red Planet, the evolution of 'Mars-mania', our hopes for life beyond Earth, and a cautionary warning about the ethical implications of Mars exploration.

In this book, Weintraub narrates the story of our love affair with Mars from the moment we set our eyes on it. He guides us through the fascination and obsession of the many scientists who were convinced of the existence of life on Mars, and the lengths they went to prove to the world what they believed was true. He tells us of their disappointments, and explains how humans had to keep lowering their expectations of our planetary neighbour as we discovered that the advanced civilizations, canals, algae and lichens observed by scientists, were nothing but the product of obsession, imagination, and hope. Yet, hope persists.

We continue to look for life on Mars, but we do it with a healthy scepticism. The fact that Mars might once have been habitable does not mean that life existed there, but the possibility is enough to keep us looking for it, as evidenced by the missions dedicated to finding it. As Weintraub explains, the answer to this question is important for a number of reasons, and its implications profound, whether we find life (past or present) on Mars or not. With plans to send humans to Mars in the future, we have a responsibility to consider the possibility of Martian life, and to think carefully about what our exploration and colonization of this planet would mean for such life, should it exist.

Well-written without using jargon, this is a must read for any Mars enthusiast, as well as a great educational book that shows how humanity's fixation with life on the Red Planet has contributed to the refinement of planetary science, and of how it is done and communicated. — REBECA BARCENILLA GARCIA.

Further Adventures of the Celestial Sleuth: Using Astronomy to Solve More Mysteries in Art, History, and Literature, by Donald W. Olson (Springer), 2018, Pp. 334, 24 × 17 cm. Price £22·50/$39·99 (paperback; ISBN 978 3 319 70319 0).

I enjoyed Donald Olson's first *Celestial Sleuth* when it came out four years ago, so when I saw that another book in a similar vein had been published, I was keen to see what it offered. Like its predecessor, the *Further Adventures of the Celestial Sleuth* is split into three parts. The first part is 'Astronomy in Art', the second is 'Astronomy in History', and the third is 'Astronomy in Literature'. There is also a fourth section which is called the 'Terrestrial Sleuth'.

The skills and techniques used in the book are broadly similar to those of its predecessor and include the determination of the positions of planets and stars, the appearance of comets and meteors, the calculation of the phases of the Moon, the identification of specific celestial objects in various works of art and telling time using the stars. Other information plays a significant part in the author's investigations such as cartography, meteorology, tidal information, historical accounts, and military records. Olson also makes use of the work of other experts as he progresses through the cases he has chosen to investigate.

These cases include works by artists such as Turner, van Gogh, Monet, and Manet, the writings of authors such as Chaucer, Cervantes, Shakespeare, Byron, and Poe, and historical events such as the battle of Stirling Bridge where William Wallace overcame the English forces of Edward the First in 1297, all the way through to battles fought during World War II and the Korean War, including the sinking of the Royal Oak in Scapa Flow and the Chosin Reservoir Campaign, respectively. It even looks at aspects of the iconic photograph of a sailor kissing a dental nurse in Times Square on VJ day photographed by Alfred Eisenstaedt.

The section labelled 'Terrestrial Sleuth' involves work done on the origin of J. M. W. Turner's painting *Rain, Steam and Speed — The Great Western Railway*, based on the account of a journey made by Lady Jane Simon in 1843 June. The second painting to be studied in this section is one of the works of John Everett Millais, his iconic pre-Raphaelite painting *The Proscribed Royalist, 1651*. The question to be answered here is the location of Millais's Oak depicted in this painting.

I thoroughly enjoyed this book as much as I enjoyed the original *Celestial Sleuth*, partly because some of my own work involves answering astronomical queries posed by other scientists, historians, and the general public. It is very satisfying to be able to use your knowledge of astronomy and physics to help people answer their questions and gain an understanding of their problem. At £22·50, this book is well worth the cover price and the time it takes to read it. — STEVE BELL.

The Universe Explained: A Cosmic Q&A, by Heather Couper & Nigel Henbest (Firefly), 2018. Pp. 288, 23·5 × 19 cm. Price £16·95 (paperback; ISBN 978 0 2281 0082 9).

This book has been inspired by nearly 200 questions that the authors have been asked at their international presentations and lectures. Those questions are grouped into 14 sections, though it is often necessary to use the index if looking for a specific subject or person. There is also a useful glossary of terms. Each chosen question is answered on a single- or double-page spread with an appropriate illustration — a recent image, historical picture, artist's impression, or cartoon-like drawing. This approach has led to a wide variety of subject matter being covered, from the pressing questions of today ("What is dark energy?") to the more speculative ("Should we reply?").

The language used is 'upbeat', humorous, and in American English — perhaps not surprising as the publishers are American/Canadian — though, fortunately, units are quoted in metric. This means that the book is designed to appeal mostly to older children and younger teenagers on both sides of the Atlantic. There is plenty of well-illustrated information to fire a nascent interest in astronomy yet not so much in the way of explanatory science. It is an attractive book for youngsters to dip into rather than read straight through. If they feel they need deeper explanations, they can then consult other sources.

It is good to see that the content and images are up-to-date, especially in the sections covering exoplanets and gravitational waves. The authors have clearly been able to access recent ideas and information.

In summary, this is a good introduction to most aspects of astronomy, written and presented in a style designed to appeal to the young, but don't expect any 'hard science' here. — DEBRA HOLTON.

OTHER BOOKS RECEIVED

Multiple Messengers and Challenges in Astroparticle Physics, edited by Roberto Aloisio, Eugenio Coccia & Francesco Vissani (Springer), 2018. Pp. 552, 24 × 16 cm. Price £165·50/$229 (hardbound; ISBN 978 3 319 65423 2).

This is the era of gravitational-wave and neutrino astrophysics, where the first distant cosmic sources have been found. The book contains six review chapters which are comprehensive and well-illustrated, plus one short chapter on the first gravitational-wave detection (GW 170817) of a binary neutron-star merger which occurred in 2017 August. The reviews show the links between traditional astronomy and the new 'multiple messengers', while the GW 170817 chapter shows what can be done by combining those with more electromagnetic data.

The Cosmological Singularity, by Vladimir Belinski & Marc Henneaux (Cambridge University Press), 2017. Pp. 263, 25·5 × 18 cm. Price £110 (hardbound; ISBN 978 1 107 04747 1).

This monograph discusses the structure of cosmological singularities in General Relativity. Part I presents theory following the original approach of Belinski, Khalatnikov and Lifshitz. Part II describes the 'cosmological billiards' reformulation, illuminating the behaviour of solutions near singularities. Four appendices provide additional mathematical details.

From the Library

Things you may have missed along the way: A review of books on astronomy and telescope construction that were published long ago and the last two generations of readers of this publication might have missed.

Journeyman Machinist en route to the Stars: Stellafane to Palomar, by Oscar Seth Marshall, as published posthumously by his daughter Eva Marshall Douglas (Wm. S. Sullwold, Taunton, Massachussetts), 1979. Pp. 163, 20 × 15·5 cm. Price: from £29·99 *via* Amazon (hardbound; ISBN 0 88492 025 9).

This book was written over several years in the form of a journal by Oscar Seth Marshall. There is no question he intended to publish it because he wrote a foreword to it, but sadly he passed away in 1953 before that could be done. Many years later his youngest daughter Eva found the manuscript and a treasure trove of photographs, edited it, and succeeded in having it published in 1979. That was a very opportune occurrence, or one of the most interesting aspects of the construction of one of the greatest instruments in the history of astronomy would have been lost!

Born in Vermont, the son of a Methodist minister who later became a doctor, Oscar chose to become a journeyman machinist, and was fortunate enough to be accepted in a three-year apprenticeship with the Gilman and Son Machine Shop. While there he helped design and build lathes for shoe manufacturers. After finishing his apprenticeship he enrolled at Syracuse University in New York, but did not finish his last semester because his former employer asked him to come back to work. The state of Vermont and its neighbours were a hotbed of machine-tool development and contributed greatly to America's rise as an industrial giant. The first chapters deal with this very well.

At some point Marshall obtained a used, 40-power telescope and became interested in astronomy and surveying. He used this telescope and a level to make a commercial map of the township of Springfield, Vermont. It was through this map that James Hartness introduced him to Russell W. Porter. James Hartness, a machinist also, would one day be governor of Vermont and the designer of the Hartness Turret Telescope. Porter had surveyed in Alaska and worked for the Bureau of Standards Optical Branch in Washington D.C. He checked Marshall's map and was surprised by how accurate it was, having been made with simple instruments. This all resulted in an article appearing in the magazine *Popular Astronomy* in 1922 March entitled 'The Telescope as a Measuring Instrument'. Porter, Marshall, and 15 others, mostly machinists and including one pioneering woman, founded in 1920 the Springfield Telescope Makers. This became the seed group which led to the large amateur telescope-making community which exists to this day almost 100 years later.

The remainder of the chapters describe how George Ellery Hale brought Porter to the California Institute of Technology to design the 200-inch, and subsequently Porter brought Marshall to do the precision machining required to construct the mounting. This was a monumental task. Chapter XV is especially interesting because it details how the instrument was mechanically improved with lessons learned from building the 100-inch. Also to be noted is the photograph on page 117 of the 1/10 scale model of the 200-inch. There are 126 photographs in the book, many of which this reviewer has seen nowhere else. It is a very good read with almost no typographical errors. It is refreshing to learn about the blue-collar side of constructing that great instrument. According to an original advertising sheet, I am fortunate to possess a copy, as only 1000 copies of the first edition were printed.

Anyone interested in the history of astronomy, telescope making, and this great instrument should read this book. Perhaps Springer or Cambridge can obtain rights to it and republish it. I am sure it would be well received. A footnote about Russell W. Porter: Porter literally designed the 200-inch and in the process made some wonderful drawings of it. When the great American artist Maxwell Parrish examined them he said that they should be in a special museum. He had the highest professional respect for Porter's work.

Russell W. Porter worked for the War Department during the Second World War when work on the 200-inch was suspended because of the emergency. His influence was subtle but monumental. If military manuals produced before the Second World War and those that came during and after are examined, great differences can be observed in the drawings. While still retaining the engineering drawings, he added what is called the exploded view: an oblique three-quarter view depicting all the various parts floating in space but separated by very small distances from the other parts to which they must be attached. Anyone looking at this drawing, novice or expert, can immediately see how the device is assembled. This resulted in great time savings in training the myriad of new workers required to run the vastly and rapidly expanding war industries. The full impact of the 'exploded view' on the war effort and industry to this day can probably never be calculated. This technique is still utilized by virtually every industry in the world from the production of automobiles, electronic equipment, and model airplanes to furniture by IKEA. It is truly one of the least-known unsung inventions of the 20th Century. — LEONARD MATULA.

Here and There

THE POLLUTION OF SPACE

… the DustPedia collaboration, a project funded … to exploit observations of dust emission from the Herschel Space Observatory … .— *Il Colle di Galileo* (Florence University Press), 2016, p. 33.

IT'S A PRE-COPERNICAN UNIVERSE AFTER ALL!

… [3D] technology is coming to astronomical imaging, with 360° images of the centre of the universe … — *A&G*, **59**, 2.4, 2018.