THE OBSERVATORY

Vol. 142 — 2022 FEBRUARY — No. 1286

THE TRANSITING PLANETARY SYSTEM WASP-86/KELT-12: *TESS* PROVIDES THE CASTING VOTE

By John Southworth[1] *and Francesca Faedi*[2,3]

1. *Astrophysics Group, Keele University*
2. *Università degli Studi di Urbino "Carlo Bo", Italy*
3. *INFN, Sezione di Firenze, Italy*

A transiting planetary system was discovered independently by two groups, under the names WASP-86 (Faedi *et al.*[1]) and KELT-12 (Stevens *et al.*[2]). The properties of the system determined in these works were very different, most tellingly a variation of a factor of three in the measured radius of the planet. We suggest that the system be named WASP-86/KELT-12 better to apportion the credit for discovery between the two groups. We analyse the light-curve of this system from the *Transiting Exoplanet Survey Satellite*, which observed it in two sectors, following the Homogeneous Studies approach. We find properties intermediate between the two previous studies: the star has a mass of $1{\cdot}278 \pm 0{\cdot}039\ M_{\odot}$ and a radius of $2{\cdot}02 \pm 0{\cdot}12\ R_{\odot}$, and the planet has a mass of $0{\cdot}833 \pm 0{\cdot}049\ M_{\rm Jup}$ and a radius of $1{\cdot}382 \pm 0{\cdot}089\ R_{\rm Jup}$. The discrepancy in the two previous sets of measured properties of the system arises from a disagreement over the transit depth and duration, caused by the transit being long and shallow so not well suited to follow-up photometry from ground-based telescopes. We also update the orbital ephemeris to aid future work on this system, which is a good candidate for characterizing the atmosphere of a planet through transmission spectroscopy.

Introduction

Transiting extrasolar planetary systems (TEPs) are the only systems beyond our own for which we can measure precisely the radii of planets, and thus their surface gravities and average densities. The first was discovered in late 1999[3,4] and over 4000 are currently known. Apart from the scientific prospects, the study of TEPs has the procedural advantage that thousands of stars can be searched simultaneously to find transits, using telescopes with large fields of view. The downside to this approach is that only a small fraction of planets are transiting, and that many transits turn out to be due to false positives rather than real planets. This makes it necessary to survey a large number of stars in order to find a useful number of TEPs.

The first large source of TEP detections was small ground-based telescopes such as *TrES*[5], *HAT*[6], *SuperWASP*[7], *KELT*[8], and *HATSouth*[9]. Although there were a variety of approaches, all of these projects converged on the idea of using small telescopes (often commercially-available telephoto lenses) to survey large fractions of the available sky[10]. An inevitable consequence was that some TEPs were independently detected by multiple groups, for example, HAT-P-10[11] is identical to WASP-11[12]. Although this might seem inefficient due to the duplication of effort, it does have two advantages: it holds information on the completeness of the surveys and it allows a cross-check on the reliability of the properties measured for the TEPs discovered (*e.g.* ref. 13).

In this work we revisit a planetary system that was announced almost simultaneously by two groups, under the names WASP-86 (Faedi *et al.*[1]) and KELT-12 (Stevens *et al.*[2]). The *SuperWASP* paper[1] included a small number of follow-up light-curves which did not cover the end of the transit well, plus a set of high-precision radial velocities (RVs) which yielded a clear detection of the planet and a tentative detection of an additional trend likely due to a third body on a wider orbit. The *KELT* paper[2] presented extensive photometry from small telescopes which, when combined, fully covered the transit. High-resolution speckle and adaptive-optics imaging was also obtained, as well as high-precision RVs that confirmed the additional trend at the $2{\cdot}4\sigma$ level.

Our interest in this object was recently revived in the course of a study of the suitability of the known TEPs for atmospheric characterization. The *TEPCat* database* listed the object as WASP-86, giving priority to the *SuperWASP* announcement as it predates the *KELT* announcement† whereas the NASA Exoplanet Archive‡ lists the properties from *KELT* and omits any mention of WASP-86. We found WASP-86 to be a poor target, but KELT-12 to be a very good target, for atmospheric characterization.

Closer inspection revealed a huge difference in the properties of the TEP in the two discovery papers, which we illustrate in Table I. Although many quantities vary significantly, some in particular stand out. The transit depth (which depends on the ratio of the radii) and duration (which depends on the sum of the radii divided by the semi-major axis of the relative orbit) are very discrepant. This is due to the shallow and long transit which makes it poorly suited to photometry from ground-based telescopes, and implies that high-precision photometry from a space-based observatory would be helpful. The masses and radii of the star are rather different, although the $T_{\rm eff}$ and [Fe/H] measurements are consistent. Most strikingly, the planetary-radius measurements differ by almost a factor of three.

We have therefore used data from the NASA *Transiting Exoplanet Survey Satellite* (*TESS*; ref. 15) to establish robust properties for this system. For the rest

* *TEPCat* is the *Transiting Extrasolar Planet Catalogue* (Southworth[14]) at https://www.astro.keele.ac.uk/jkt/tepcat/.

†The discovery paper of WASP-86 is date-stamped 2016 August 16 on the arXiv.org preprint server, whereas the *KELT* paper is date-stamped 2016 September 2.

‡https://exoplanetarchive.ipac.caltech.edu

TABLE I

Physical properties of WASP-86/KELT-12 from the two discovery papers. Some quantities were not given directly in the papers so have been calculated from other quantities which were.

Property	*Faedi et al.*[1]	*Stevens et al.*[2]
Stellar mass ($M_\odot$)	1·239 ± 0·018	$1{\cdot}591^{+0{\cdot}070}_{-0{\cdot}093}$
Stellar radius ($R_\odot$)	$1{\cdot}291^{+0{\cdot}014}_{-0{\cdot}013}$	2·37 ± 0·17
Stellar log g (c.g.s.)	4·309 ± 0·006	$3{\cdot}889^{+0{\cdot}051}_{-0{\cdot}050}$
Stellar density ($\rho_\odot$)	0·57 ± 0·01	$0{\cdot}119^{+0{\cdot}025}_{-0{\cdot}020}$
Stellar $T_{\rm eff}$ (K)	6330 ± 110	6279 ± 51
Stellar [Fe/H] (dex)	+0·23 ± 0·14	$+0{\cdot}190^{+0{\cdot}084}_{-0{\cdot}085}$
Orbital period (d)	5·031555 ± 0·000002	$5{\cdot}031623^{+0{\cdot}000032}_{-0{\cdot}000031}$
Velocity amplitude (m s^{-1})	84 ± 5	82 ± 12
Orbital eccentricity	0·0 (fixed)	0·0 (fixed)
Ratio of the radii	0·0503 ± 0·0008	$0{\cdot}0772^{+0{\cdot}0019}_{-0{\cdot}0018}$
Fractional stellar radius	0·0973	0·165 ± 0·010
Planet mass ($M_{\rm Jup}$)	0·821 ± 0·056	0·95 ± 0·14
Planet radius ($R_{\rm Jup}$)	$0{\cdot}632^{+0{\cdot}014}_{-0{\cdot}013}$	$1{\cdot}78^{+0{\cdot}017}_{-0{\cdot}016}$
Surface gravity (m s^{-2})	$46{\cdot}8^{+3{\cdot}3}_{-3{\cdot}1}$	$7{\cdot}45^{+1{\cdot}8}_{-1{\cdot}5}$
Planet density ($\rho_{\rm Jup}$)	$3{\cdot}24^{+0{\cdot}31}_{-0{\cdot}26}$	$0{\cdot}158^{+0{\cdot}054}_{-0{\cdot}040}$
Equilibrium temperature (K)	1415 ± 22	1800 ± 57
Semi-major axis (AU)	0·0617 ± 0·0005	$0{\cdot}06708^{+0{\cdot}00097}_{-0{\cdot}0013}$

of the current work we refer to the object under analysis as WASP-86/KELT-12 and suggest that this be adopted in the literature to ensure an equitable credit for the discovery of this planetary system.

Very little work has been published on WASP-86/KELT-12 since the discovery papers[1,2]. Coker *et al.*[16] presented high-resolution speckle imaging. They found no evidence for faint nearby companions, with limiting magnitude differences of 4·40 and 4·23 mag at 1·0″ separation, at wavelengths of 692 and 880 nm, respectively. The system is also listed under the name WASP-86 in the SWEETCat catalogue of stellar parameters⋆ (Santos *et al.*[17]), where the host star is assigned the properties $T_{\rm eff}$ = 6278 ± 51 K, log g = 3·89 ± 0·05, and [Fe/H] = +0·19 ± 0·08.

Observational material

WASP-86/KELT-12 was observed using the NASA *TESS* satellite[15] in sectors 25 (2020/05/13 to 2020/06/08) and 26 (2020/06/08 to 2020/07/04). The light-curves comprise 18 489 and 17 909 data points obtained in short-cadence mode[18], respectively, which were downloaded from the MAST archive† and converted to relative magnitude. All data points whose QUALITY flag was not zero were rejected, leaving a total of 34 188 observations.

⋆http://sweetcat.iastro.pt

†Mikulski Archive for Space Telescopes, https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

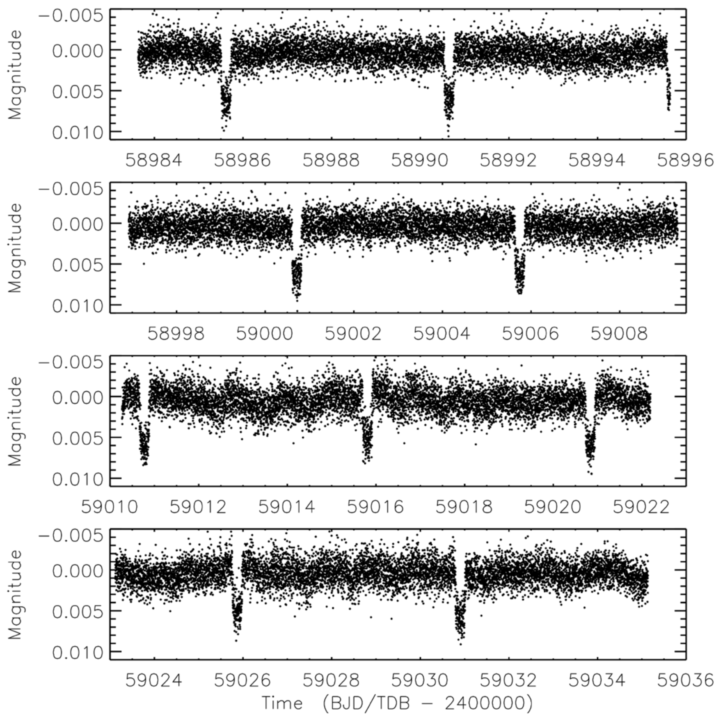

FIG. 1

TESS short-cadence PDCSAP photometry of WASP-86/KELT-12. The top two panels show the data for sector 25 and the bottom two panels show the data for sector 26.

The *TESS* simple aperture photometry (SAP) had several instrumental trends which have been removed from the Pre-search Data Conditioning (PDCSAP) data, so we used the latter in our analysis (Fig. 1). These data contain ten transits, of which one is only partially covered so was ignored. We selected the data during and close to each transit for further analysis, and fitted low-order polynomials to them to rectify them to zero differential magnitude. We rejected the data away from transit as they contain no useful information so merely slow down the computation of the best fit, leaving 4317 data points for our analysis.

Further data are planned* to be obtained in *TESS* sectors 40 (2021/06/24 to 2021/07/23) and 52–53 (2022/05/18 to 2022/07/09). It will be worthwhile to revisit the system at a later date to include these data in an updated analysis.

Analysis of the TESS light-curve

We analysed the *TESS* light-curve of WASP-86/KELT-12 using the approach developed in the first author's Homogeneous Studies papers (see ref. 19 and

*https://heasarc.gsfc.nasa.gov/cgi-bin/tess/webtess/wtv.py?Entry=wasp-86 subsequent works). This is briefly described below. The error bars were rescaled to force the reduced χ^2 of the best fit to be unity.

The light-curve was modelled using version 41 of the JKTEBOP* code[20,21]. The fitted parameters were a reference time of mid-transit (T_0), the orbital period (P) and inclination (i), and the sum and ratio of the fractional radii ($r_A + r_b$ and $k = r_b/r_A$ where $r_A = R_A/a$ and $r_b = R_b/a$, R_A is the radius of the star, R_b is the radius of the planet and a is the semi-major axis of the relative orbit). In the current work we subscript properties of the star with an 'A' and of the planet with a 'b'. We also fitted the coefficients of a straight line to normalize each transit to unit flux.

A circular orbit was assumed based on previous work[1,2] and third light was assumed to be zero because the star appears to be isolated in the sky and no close companions have been found using high-resolution imaging[2,16]. The relatively modest upper limits from the speckle imaging are not problematic because Southworth *et al.*[22] found that any stars more than 3 mag. fainter than the planet host star have a negligible effect on the transit fit.

Limb darkening was included using four biparametric laws: quadratic, square-root, logarithmic, and cubic[19]. The data were fitted using two approaches for each law: both limb-darkening coefficients fixed; and the linear coefficient fitted but the nonlinear coefficient fixed. There is no advantage in fitting for both limb-darkening coefficients as they are strongly correlated[23] so primarily cause the minimization process to be less stable. The values of the limb-darkening coefficients were obtained from Claret[24] for solar metallicity. The best fit is shown in Fig. 2.

We specified as the reference time of minimum light one of the transit mid-points near the middle of the *TESS* dataset. The *TESS* data alone constrain the orbital period well, but we included the quoted time of inferior conjunction from Stevens *et al.*[2] to improve the measurement further. This time is 383 cycles earlier than our reference time and improves the precision of the period measurement by a factor of 55.

The uncertainties in the parameters of the fit were obtained in two ways: using Monte Carlo and residual-permutation algorithms[19]. To this was added a contribution to the variation between fits with different treatment of limb-darkening coefficients, which was small. The Monte Carlo error bars are larger than the residual-permutation error bars in this case, indicating that red noise in the *TESS* light-curve is not significant. The fitted parameters and error bars are given in Table II.

Physical properties of WASP-86/KELT-12

Although TEPs are a special case of eclipsing-binary-star system, they have the disadvantage that one piece of information is missing: the planet is not (normally) identifiable in spectra so its RVs are not measurable. An additional constraint is needed, and is usually obtained by forcing the properties of the host star to match expectations for normal stars. This can be done using empirical calibrations of stellar properties[13,25,26] or by interpolating in the predictions of theoretical stellar models[25,27,28].

The theoretical-model approach is the more widely used because it yields high-precision results. The fractional radius of the star — as measured from the transit light-curve — is very closely related to its density[29]. High-resolution spectroscopy can be used to determine the $T_{\rm eff}$ and [Fe/H] of the star to high

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

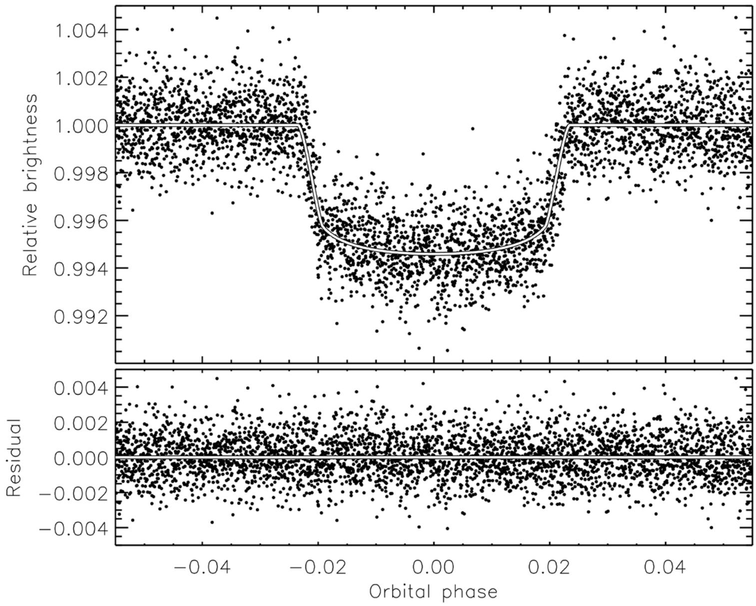

FIG. 2

The *TESS* light-curve of WASP-86/KELT-12 (filled circles) around the times of transit compared to the best fit (white line). The residuals of the fit are shown in the lower panel.

TABLE II

Results of the JKTEBOP analysis of the TESS light-curve of WASP-86/KELT-12. The error bars are 1σ.

Quantity	*Symbol*	*Value*
Orbital period (d)	P	5·0316331 ± 0·0000025
Time of minimum light (BJD/TDB)	T_0	2459010·77580 ± 0·00035
Sum of the fractional radii	$r_A + r_b$	0·1611 ± 0·0086
Ratio of the radii	k	0·07037 ± 0·00081
Orbital inclination (°)	i	85·9 ± 1·2
Fractional radius of the star	r_A	0·1505 ± 0·0080
Fractional radius of the planet	r_b	0·01059 ± 0·00067

precision. Armed with these measurements, the mass, radius, and age of the star follow from a comparison with theoretical predictions.

For the T_{eff} and [Fe/H] of the host star in WASP-86/KELT-12 we used the values from Stevens *et al.*[2]. For the velocity amplitude of the star we took the weighted mean of the values from the two discovery papers (Table I): $K_A = 83{\cdot}7 \pm 4{\cdot}6$ m s^{-1}.

We continued to follow the Homogeneous Studies approach[13] and use tabulated predictions from theoretical stellar-evolutionary models. We first estimated an initial value of the velocity amplitude of the *planet*, K_b, and used that plus K_A, r_A, r_b, i, and P to determine the full properties of both components using standard formulae[30]. We then iterated the value of K_b to find the best match between the measured r_A and T_{eff} and the values of R_A/a and T_{eff} obtained by interpolation in the theoretical models. This was done for a range of ages *via* a grid search to arrive at a single best set of physical properties for the system. Finally, this was performed for five different sets of theoretical models[13] to obtain five different estimates of the system properties. The uncertainties in all input values were propagated by re-running the analysis for every input parameter plus and minus its uncertainty. We also obtained a systematic error for each parameter, which we took to be the largest difference between the mean and individual values for each parameter across the results from the five different sets of theoretical models.

The final parameters and uncertainties are given in Table III. Random and systematic errors are given for all measured quantities, with the exception of those which do not depend on stellar theory thus have no systematic error. A comparison between Tables II and III and Table I shows that our results are intermediate between those from the discovery papers, but are closer to those from Stevens *et al.*[2] than Faedi *et al.*[1]. This is further illustrated in Figs. 3 and 4, which compare the sets of results in mass–radius diagrams for the two components of the system. We find the star to be moderately evolved and the planet to have an inflated radius as often seen in gas giants (*e.g.*, ref. 32).

It is clear that there are major differences in the three sets of physical properties measured for the WASP-86/KELT-12 system. We expect our new measurements to be the most reliable as they are based on much better light-curves (courtesy of *TESS*) than previously available. Interestingly, the differences do not arise from spectroscopic measurements because the T_{eff}, [Fe/H], and K_A values measured for the host star are very consistent across previous works[1,2]. The discrepancy therefore must come from the density of the star, which is calculated almost directly from r_A, which itself depends on the transit duration. Faedi *et al.*[1] significantly underestimated the transit duration, whereas Stevens *et al.*[2] slightly overestimated it. Both issues can be attributed to the difficulty of measuring the transit shape reliably using ground-based observations when the transit is this long (5·6 hours) and shallow (0·5%). Stevens *et al.* did indeed note that their

TABLE III

Physical properties of WASP-86/KELT-12 obtained in this work. Where one error bar is given this is the random error. Where two sets of error bars are given the first is the random and the second is the systematic error.

Parameter	*Value*
Stellar mass ($M_\odot$)	1·278 ± 0·034 ± 0·019
Stellar radius ($R_\odot$)	2·02 ± 0·12 ± 0·01
Stellar log g (c.g.s.)	3·934 ± 0·050 ± 0·002
Stellar density ($\rho_\odot$)	0·155 ± 0·027
Planet mass (M_{Jup})	0·833 ± 0·048 ± 0·008
Planet radius (R_{Jup})	1·382 ± 0·089 ± 0·007
Surface gravity (m s^{-2})	10·8 ± 1·5
Planet density (ρ_{Jup})	0·295 ± 0·059 ± 0·001
Equilibrium temperature (K)	1722 ± 51
Semimajor axis (AU)	0·06237 ± 0·00054 ± 0·00031
Age of system (Gyr)	$1{\cdot}5^{+0{\cdot}4+0{\cdot}4}_{-0{\cdot}5-0{\cdot}4}$

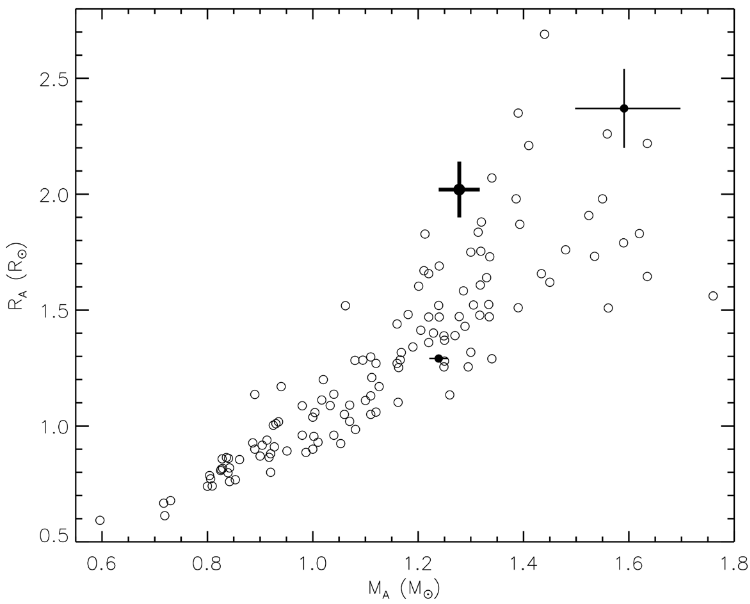

FIG. 3

Plot of the mass and radius measurements of the star in the WASP-86/KELT-12 system. The results from Faedi *et al.*[1] and Stevens *et al.*[2] are shown with filled points and error bars. The measurements from the current work are shown with a larger filled circle and thicker lines for the error bars. For context, the mass and radius measurements for the other stars discovered by the *SuperWASP* and *KELT* consortia are shown with open circles (error bars omitted for clarity). Data taken from *TEPCat*[31] on 2021/08/24.

results "can be heavily influenced by our choice of detrending parameters" (see their section 4.1).

In the discussion above we have assumed that the *TESS* light-curve, and our model of it, are both reliable. Whilst this assumption appears safe, it is possible that a small amount of contaminating light exists which would have the effect of making the transit shallower and thus causing us to underestimate the radius of the planet. It is unfortunately not possible to determine the amount of contaminating light directly from the *TESS* light-curve (see discussion in Southworth[13]) so we are unable to remove this caveat from our analysis.

Summary

The transiting planetary system WASP-86/KELT-12 was discovered independently by the *SuperWASP*[1] and *KELT*[2] groups, the two announcements occurring within a few weeks of each other. However, the properties of the system measured by the two groups were in poor agreement, the most obvious being a factor of three difference in the radius of the planetary component.

The main problem was the difficulty of obtaining suitable light-curves of the transit, which is 5·6 hours long and only 0·5% deep. We have therefore sought to establish reliable properties of the system using the light-curve obtained by

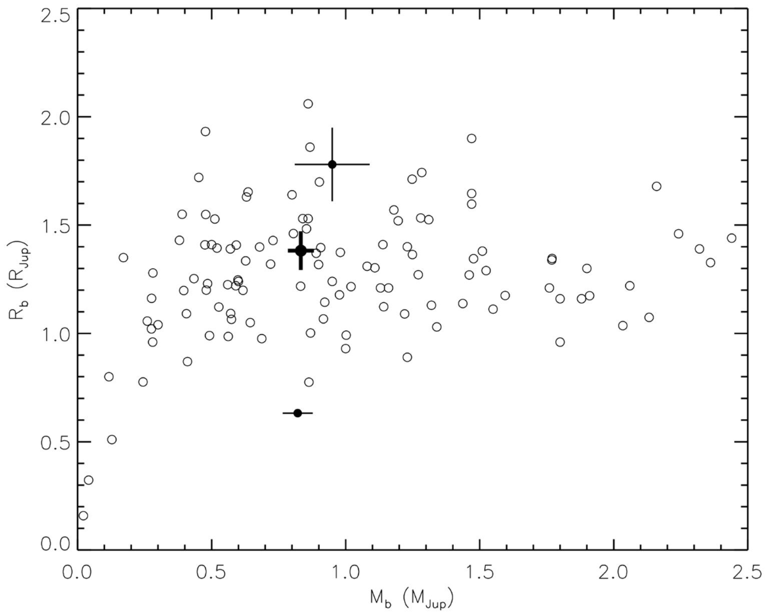

Fig. 4

Plot of the mass and radius measurements of the planet in the WASP-86/KELT-12 system. Other comments are the same as for Fig. 3.

the *TESS* mission, which observed ten consecutive transits over the course of 51·5 d. We used the Homogeneous Studies approach to analyses these data: we first modelled the *TESS* light-curve then deduced the properties of the system by requiring the host star to match tabulated predictions from several sets of theoretical stellar models.

We find system properties that are midway between those in the discovery papers[1,2]. The *SuperWASP* analysis yielded a transit duration that was too small, leading to an overestimate of the stellar density and an underestimate of the radii of both components. The *KELT* analysis was closer to our results, but had a slightly over-long transit duration and thus an overestimate of the two radii. These issues underline the difficulty of obtaining good light-curves of transits like these from ground-based telescopes. From our analysis of the *TESS* light-curve we find that the host star is moderately evolved and that the planet is one of the class of inflated hot Jupiters[33].

Other quasi-simultaneous independent discoveries have also occurred in the past, for example, HAT-P-10[11] and WASP-11[12], HAT-P-27[34] and WASP-40[35], MASCARA-2[36] and KELT-20[37]. Several independent announcements of new TEPs have also occurred based on separate groups following up the same *TESS* light-curves. Whilst most sets of analyses are in mutual agreement, there are examples of strong disagreement on the physical properties (*e.g.*, the subject of the current work) or even how many planets are needed to produce a set of observed transit events (*e.g.*, TOI-561; refs. 38,39). These instances can serve as informative cross-checks on the veracity of the properties measured for TEPs.

Acknowledgements

We thank Jake Morgan for accidentally triggering this work, and Andrew Cameron and Don Pollacco for helpful comments. This paper includes data collected by the *TESS* mission. Funding for the *TESS* mission is provided by the NASA's Science Mission Directorate. The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arχiv scientific paper preprint service operated by Cornell University.

References

(1) F. Faedi *et al.*, arXiv:1608.04225, 2016.
(2) D. J. Stevens *et al.*, *AJ*, **153**, 178, 2017.
(3) G. W. Henry *et al.*, *ApJ*, **529**, L41, 2000.
(4) D. Charbonneau *et al.*, *ApJ*, **529**, L45, 2000.
(5) R. Alonso *et al.*, *ApJ*, **613**, L153, 2004.
(6) G. Á. Bakos *et al.*, *PASP*, **114**, 974, 2002.
(7) D. L. Pollacco *et al.*, *PASP*, **118**, 1407, 2006.
(8) J. Pepper *et al.*, *PASP*, **119**, 923, 2007.
(9) G. Á. Bakos *et al.*, *PASP*, **125**, 154, 2013.
(10) J. Pepper, A. Gould & D. L. Depoy, *AcA*, **53**, 213, 2003.
(11) G. Á. Bakos *et al.*, *ApJ*, **696**, 1950, 2009.
(12) R. G. West *et al.*, *A&A*, **502**, 395, 2009.
(13) J. Southworth, *MNRAS*, **408**, 1689, 2010.
(14) J. Southworth, *MNRAS*, **417**, 2166, 2011.
(15) G. R. Ricker *et al.*, *Journal of Astronomical Telescopes, Instruments, and Systems*, **1**, 014003, 2015.
(16) C. T. Coker *et al.*, *AJ*, **155**, 27, 2018.
(17) N. C. Santos *et al.*, *A&A*, **556**, A150, 2013.
(18) J. M. Jenkins *et al.*, in *Proc. SPIE*, 2016, *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, vol. 9913, p. 99133E.
(19) J. Southworth, *MNRAS*, **386**, 1644, 2008.
(20) J. Southworth, P. F. L. Maxted & B. Smalley, *MNRAS*, **351**, 1277, 2004.
(21) J. Southworth, *A&A*, **557**, A119, 2013.
(22) J. Southworth *et al.*, *A&A*, **635**, A74, 2020.
(23) J. Southworth, H. Bruntt & D. L. Buzasi, *A&A*, **467**, 1215, 2007.
(24) A. Claret, *A&A*, **600**, A30, 2017.
(25) J. Southworth, *MNRAS*, **394**, 272, 2009.
(26) B. Enoch *et al.*, *A&A*, **516**, A33, 2010.
(27) A. Sozzetti *et al.*, *ApJ*, **664**, 1190, 2007.
(28) P. F. L. Maxted, A. M. Serenelli & J. Southworth, *A&A*, **575**, A36, 2015.
(29) S. Seager & G. Mallén-Ornelas, *ApJ*, **585**, 1038, 2003.
(30) R. W. Hilditch, *An Introduction to Close Binary Stars* (Cambridge University Press), 2001.
(31) J. Southworth, in *Living Together: Planets, Host Stars and Binaries* (S. M. Rucinski, G. Torres & M. Zejda, eds.), 2015, *Astronomical Society of the Pacific Conference Series*, vol. 496, p. 321.
(32) J. Southworth *et al.*, *MNRAS*, **426**, 1338, 2012.
(33) J. J. Fortney, M. S. Marley & J. W. Barnes, *ApJ*, **659**, 1661, 2007.
(34) B. Béky *et al.*, *ApJ*, **734**, 109, 2011.
(35) D. R. Anderson *et al.*, *PASP*, **123**, 555, 2011.
(36) G. J. J. Talens *et al.*, *A&A*, **612**, A57, 2018.
(37) M. B. Lund *et al.*, *AJ*, **154**, 194, 2017.
(38) G. Lacedelli *et al.*, *MNRAS*, **501**, 4148, 2021.
(39) L. M. Weiss *et al.*, *AJ*, **161**, 56, 2021.

CORRESPONDENCE

To the Editors of 'The Observatory'

Can Satellite Mega-Constellations Justify Their Impact on Astronomy?

In their latest paper, L. Rawls *et al.*[1] drew attention to the impacts of satellite constellations on astronomy. Near-earth space is being increasingly commercialized by private space companies. This has many consequences for science, particularly, astronomy. Some estimates show that more than 100 000 satellites may orbit the Earth by 2030. This is an exponential increase from the approximately 4000 operational satellites in orbit today. Satellite mega-constellations for satellite internet connectivity are one of the main drivers behind the explosion in the number of satellites. The largest of these private space companies alone is hoping to send more than 42 000 satellites into orbit.

Many researchers have raised concerns about the impact that these satellites may have on observational astronomy. The situation is particularly bad for very-wide-field imaging observations performed with large telescopes. In a recent study, the researchers estimated that approximately 30% of the exposures of very-wide-field imaging observations performed with large telescopes can be ruined at the beginning and end of the night[2]. An independent study published by the *Rubin* observatory indicated a 40% impact during the twilight observing time[3].

The researchers discovered that wide-field imaging and spectroscopic surveys will be affected at a much lower level; up to 15% of the exposures recorded during the beginning and end of the night will be ruined. Moreover, up to 0·5% of medium-duration exposures with traditional fields of view will be ruined during twilight. By contrast, brief telescopic observations will largely remain unaffected.

The two most affected types of observations (*i.e.*, very-wide-field and wide-field imaging) are the backbone of astronomy and the main tools for discovery. Hence, the adverse impact that satellite mega-constellations can have on key surveys is deeply worrying.

Proponents of satellite mega-constellations often cite the connectivity benefits these systems could offer in order to justify the impact on astronomy. There is no denying that affordable internet access is strongly needed. However, we must ask ourselves if these satellite mega-constellations will be able to meet the demand. The estimated set-up and maintenance costs of satellite internet connectivity are prohibitively expensive for all countries in greatest need of internet access. A recently published dataset[4] has shown that the population that needs and can afford satellite internet connectivity is very small.

Considering the low utility of satellite internet connectivity to those who need it most, the current proposals of tens of thousands of satellites orbiting the Earth do not justify the impact they will have on the night sky and astronomy. The choice between protecting our night sky and satellite internet connectivity is not a binary one. Considering the current circumstances, it is impractical to call for the complete abandonment of all satellite mega-constellation projects. Greatly reducing the proposed number of satellites and regulating satellites more tightly would be more feasible.

Yours faithfully,
SAI CHARAN PETCHETTI

301, VSM Bhavan
Hyderabad
Telangana
India, 500073

saicharan@astronomy.org.in

2021 September 6

References

(1) M. L. Rawls *et al.*, *RNAAS*, **4**, 189, 2020.
(2) O. R. Hainaut & A. P. Williams, *A&A*, **636**, A121, 2020.
(3) Rubin Observatory Project Science Team, Technical Report: *Rubin Observatory Legacy Survey of Space and Time* (Document 33805), 2020.
(4) https://doi.org/10.5281/zenodo.4133884

On the Absence of Flat Star Clusters

Taylor[1] has asked the question (which had never occurred to me, but is obvious in hindsight) why there are no flat star clusters. Even though the question is now obvious to me, the answer is not. However, a useful starting point might be a paper by the late, great Donald Lynden-Bell, 'Can Spherical Clusters Rotate?'[2], in which he breaks with the tradition that the answer is always 'no' if there is a question mark in the title, and points out that a spherical cluster of mass points may rotate without becoming oblate. To be sure, he considers an *unrelaxed* system, while Taylor seems to be thinking of a relaxed system and assuming that rotation will lead to flattening. On the other hand, *Gaia* results indicate that at least some globular clusters rotate[3], but with no evidence of a link between rotation and flattening. ADS lists 51 citations for Lynden-Bell's paper — 12 after 2018, 28 after 2006, and none between 1964 and 1979; thus it appears to have remained relevant, especially in recent times. Lynden-Bell also remarks on "how little is the relief granted to a rotating cluster when it flattens".

Perhaps another reader knows the answer to Taylor's question, which might also be found in Lynden-Bell's rather technical paper, or in papers which cite it (or papers which cite those papers, *etc.*). His paper was written before I was born, and the topic is rather far from my main interests. I learned of its existence because, a couple of years ago, I had obtained a complete set of the sadly defunct *Quarterly Journal of the Royal Astronomical Society*. Apart from revisiting some classic papers read in observatory libraries over the years, I'm currently browsing all issues, looking for items which pique my interest. The older issues of the *QJRAS* contain abstracts of papers published in *MNRAS*. In particular, the first issue contains the abstract[4] of Lynden-Bell's paper.

Yours faithfully,
PHILLIP HELBIG

Institut d'Astrophysique et de Géophysique
Université de Liège
Quartier Agora
Allée du 6 août
B-4000 Liège 1 (Sart-Tilman)
Belgium

helbig@astro.multivax.de

2021 September 14

References

(1) C. Taylor, *The Observatory*, **141**, 246, 2021.
(2) D. Lynden-Bell, *MNRAS*, **120**, 204, 1960.
(3) A. Sollima, H. Barmgardt & M. Hilker, *MNRAS*, **485**, 1460, 2019.
(4) *QJRAS*, **1**, 117, 1960.

REVIEWS

A Stellar Life, by Helmut A. Abt (Palmetto Publishing, Charleston, SC), 2020. Pp. 241, 22·5 × 15 cm. Price $27·99 (about £20) (hardbound; ISBN 978 1 64990 518 5).

Helmut Arthur Abt is a most unusual astronomer, indeed a most unusual human being, and he has written a most unusual autobiography! First some basic biographical details, before going on to what is in (and what is not in) the volume in question. Abt was born on 1925 May 26 in Helmstedt, Germany, and moved with his parents Karl A. and Margaret S. and elder brother Karl W. Abt to the United States in 1927. He earned a BS in mathematics from Northwestern University in 1946, an MS in physics there in 1948, and the very first PhD in astronomy from the new programme at the California Institute of Technology in 1952, with a thesis under its director, Jesse L. Greenstein, on the prototype Type II Cepheid, W Virginis. After a year at Lick Observatory, and about six at the University of Chicago and McDonald Observatory, he settled in at the nearly-new KPNO (later NOAO, in the surveying for whose Kitt Peak site he had participated), where he remains to this day. On 1971 April 1, he took over the managing editorship of the *Astrophysical Journal* from S. Chandrasekhar, holding it until 1999, and officially retiring in 2000.

Now, what is in these 239 pages? The cover is a now-well-known colour image of the Crab Nebula, the frontispiece is a John Irwin 1970 or 1971 colour photo of Helmut, just after his return from Easter Island. There are 41 chapters, ranging from a single page up to 11 or 12, about six pages of references (including 71 to his own work, of the 403 that appear on the Astrophysics Data System, about which he has written), 25 pages of anecdotes about astronomers (ranging alphabetically from Abt to Zwicky), and an 11-page index. The chapters include discussions of Abt's own astronomical contributions, particularly on the properties and causes of Am, Ap, and normal A-type stars, with rotation, magnetic fields, and age all important. Another territory has been the fraction of solar-type stars with stellar companions — at least half, no matter how you look at his, and others', statistics. There is a firm conviction that the 1054 supernova was reported only in April and May from Europe and the Near East, but only in July and later from China, Japan, and Korea, while there may be Navajo pictographs of the supernova–crescent-moon configuration from both time frames.

Some of the later astronomical topics have included blue stragglers (he favours enhanced mixing over binary-star mergers and such), the origins of many exoplanets as independent formations and captures by their host stars, rather than formation in proto-stellar discs, and the structure and origin of the low-density region of interstellar material ('Local Bubble') in which the Solar System now finds itself.

The author mentions that he has, in recent years, sometimes had difficulty in getting his papers accepted for publication, and indeed many of the items appear only as AAS abstracts or in non-mainstream journals. Chapter 22 concerns how the *ApJ* developed (from about 200 papers per year to 2000) under his editorship, what changes were essential, what improvements made, and so forth. There are also mentions of how to referee usefully, 'best practices' for editing (he did not agree with Chandrasekhar about consulting firm opponents!), and for that matter how to write a successful paper. Abt is also an expert on successful papers, because he has produced a large number of analyses of 'productivity and impact' of telescopes, astronomers, wavebands, and so forth. Some of the surprises have been that small telescopes can be very productive and that outstanding astronomers are not finished at 35 (though mathematicians may be) nor at 45, or 55, but keep doing interesting, important things through their entire careers. He is an example!

Others of the chapters are near-travelogues, of the places Helmut has loved, including the deserts, canyons, and national parks of the American Southwest, China (you might want to disagree with him about what has happened in Tibet), Thailand, and Japan. Also Fiji, Easter Island, and the Galapagos. He seems to have made friends wherever he went — some astronomers, but lots of other people as well.

A few of the chapters reveal glimpses of Helmut as a human being. He had enormous admiration for Aden Meinel, a fabulously intelligent and creative designer of astronomical instrumentation, and regards Sidney Wolff as the best-ever director of KPNO/NOAO (as well as its longest-term one). There is a brief appearance by a foster or adopted son, Daniel Conaway, who was there when Helmut's 21-year-old cat had to be put to sleep just before Abt left for the 1997 IAU General Assembly in Kyoto, Japan. And we learn that the best 20 years of the author's life were 1996–2016 when John Fountain lived with him in Tucson and travelled with him to a number of meetings and on holidays.

There are some funny bits, as when Abt says that living for eternity would not be attractive: "what does one do ... after you have mastered all of the harp literature?" Some of the typos are accidentally funny, for instance, as in part, their departure from Germany was economically motivated because "people could not save up to bury furniture". (Probably a portmanteau of "buy baby furniture.")

Errors and omissions? Yes, there are some. You will look in vain for the names of the perpetrators of the trick played on Fritz Zwicky by having a non-existent student who got all the homework right, as well as for the name of the student (these are also missing in the oral-history version of Abt's autobiography)[1]. The mythical student was Hjalmar Sciatti and William A. (Willy) Fowler among the perpetrators. Fowler's Nobel Prize (p. 104) was not precisely for his "understanding of the evolution of stars." But it really is true that, in 1928, Edwin Hubble suggested that the Crab Nebula is the remnant of the Chinese guest star of 1054. Unfortunately, the reference is missing from the list (it was an ASP Leaflet, number 14 in the series, which in turn has no references, so just how Hubble had heard about the Chinese records remains a mystery). And the index of the present volume mentions Hubble in another context, but does not include his appearance on p. 4.

Conflicts of interest? Two, actually. But I don't have to tell you about the first because the book assigns no names to the first two associate editors added to the *ApJ* team in 1989. (Hint: Yervant Terzian was the other one.) The second conflict? Well, after ordering a copy of *A Stellar Life* (at full price, from Thrift Books), I asked Helmut if it was OK for me to review it. "Yes," he replied, "after you read it." The parcel arrived yesterday around 11 a.m., I started it during lunch, and turned the last page of text (the Zwicky anecdote), just before quitting time and darkness. — Virginia Trimble.

Reference

(1) Interview of Helmut A. Abt by Patrick McCray, on 1999 October 28–29. Niels Bohr Library and Archives, American Institute of Physics, College Park, MD. (And reading that took most of this morning.)

The Optical Papers of Isaac Newton, edited by Alan E. Shapiro. **Vol. 1: The Optical Lectures 1670–1672** (Cambridge University Press), 2010. Pp. 627, 25·5 × 18 cm. Price £38·99/$50·99 (paperback; ISBN 978 0 521 15509 0); **Vol. 2: The *Opticks* (1704) and Related Papers *ca.* 1688–1717** (Cambridge University Press), 2021. Pp. 423, 25 × 18 cm. Price £150/$195 (hardbound; ISBN 978 1 521 30218 0).

These two volumes are the fruit of a formidable body of meticulous scholarly research into Newton's surviving optical writings by Alan Shapiro, extending back over many years. They include, in Volume 1, the lectures delivered by Newton in Cambridge following his election to the Lucasian Professorship in 1669, and, in Volume 2, the manuscript and further annotations of The *Opticks*, that were eventually published in 1704 following the death of Newton's rival and fellow-analyst of sunlight, Dr. Robert Hooke. The lectures were delivered in Latin, as was the custom in most British and European universities in 1669. The original Latin texts are printed on each left-hand page, along with drawings and diagrams, with a modern English translation on the right-hand page.

Newton's fundamental discoveries in the nature of light and colours had already been made by 1670, when he succeeded Isaac Barrow as Lucasian Professor, and his *Lectiones Opticae* and *Optica* take his readership systematically through them. Newton makes it clear from the outset, however, that contemporary interest in light, optics, and colours had largely come about in the wake of the invention of the telescope, and attempts to improve telescopic images by means of lenses ground and polished into particular geometrical curves.

Volume 1, on the *Optical Lectures*, breaks into two sections, or sets of lectures, dealing respectively with refraction and the origin of colours. Newton systematically outlines those subsequently-famous experiments where he passed narrow beams of light through glass prisms, to produce a spectrum. Of course, it had been known since the Middle Ages that refraction through a transparent medium produced colours, although instead of attributing this to a corruption of pure light by contact with an earthy medium, Newton follows this observation by the classic experiments whereby he demonstrates experimentally that the colours must be real, in nature, by showing how they can be re-assembled into white light. Of course, Newton had already published this work before the Royal Society, but it is fascinating to see how, in the lectures, he communicates this as part of a developing optical discourse.

Volume II is devoted to the *Opticks*, and Alan Shapiro makes an exhaustive examination of the composition process of this work, and the stages through which it passed. Originally intending the *Opticks* to be in Latin, like *Principia*, Newton went on to write it in English. Shapiro takes us through these compositional stages in great detail, making it clear how this masterpiece evolved in Newton's mind. In the switch to English, moreover, *Opticks* is in some ways an indicator of the emergence of English as a language suitable for the presentation of major scientific ideas, especially as so much innovation in science was taking place outside the universities. The *Philosophical Transactions* of the Royal Society were in English, but the editors accepted papers in Latin, as well as French, the other great vernacular language of the age, and Latin papers were frequently published.

I warmly congratulate Professor Shapiro on his splendid achievement, over many years, in finally laying before us the contents of Newton's Optical Papers. — Allan Chapman.

Ten Patterns that Explain the Universe, by Brian Clegg (MIT Press), 2021. Pp. 224, 23·5 × 16 cm. Price $29·95 (about £22) (paperback; ISBN 978 0 262 54286 9).

Numerous commentators have noted that History is just one damn thing after another — nothing can be explained, there is no unifying principle — unlike, for example, Physics, with its laws and particles and forces. Events happen in time and space because of the interaction of these forces and particles obeying specific laws — albeit with probabilistic overtones. So in Brian Clegg's ten patterns I was anticipating a linked coherent story that demonstrated such unifying principles. But an initial reading seems to show that Clegg doesn't mean that — he means ten separate subjects covering a wide range of science and mathematics that he feels can each be explained by their own underlying pattern. And by patterns Clegg means something like rules, systems, or principles that underlie a particular aspect of the physical Universe.

The book is presented as a sort of schools' introductory text to science — brightly coloured pages interleaved with standard black text on white pages, lots of images, and boxes with explanatory captions, and a photograph of the relevant scientist to head each chapter. The design is generally clear and unfussy but I found the occasional page of small grey text on black background particularly irksome — for goodness sake, if you are aiming at clarity at least make the text readable. But having said that, the majority of the explanations are clear and concise with some nice ideas on how to think about certain subjects. The section on the quantum behaviour of particles and photons is rather good and particular care also seems to have been taken to ensure that illustrations and diagrams are adjacent to the relevant text.

It is reasonable to ask why these particular ten patterns, and why are they presented in the order chosen? Is there a pattern to the patterns? The ten topics are: 'The Cosmic Microwave Background' (CMB), 'Minkowski Diagrams', 'Particle Tracks', 'Feynman Diagrams', 'The Periodic Table', 'The Weather', 'Number Lines', 'Cladograms', 'DNA', and 'Symmetries', presented in that order, and Clegg lays out his reasons for this scheme in the introduction.

Whether these ten brief chapters go quite as far as explaining the Universe or even these specific topics is debatable. In almost every chapter there comes a point at which you have read through the introduction — checked out the photograph of the notable scientist, have understood the two or three pages of basics — then Clegg starts to discuss some interesting stuff that might make the subject useful in explaining some aspect of the Universe. He gives a name to the extension topic, maybe mentions another scientist or two, and you eagerly turn the page to find ... no more. Instead you have a new chapter and a new topic. For example, in the very first chapter on the cosmic microwave background, Clegg explains what it is, how it was discovered, and the satellite observations that have enabled a detailed description of the Universe — but he doesn't explain how. How exactly do you get from a map of very tiny temperature variations to a description of the Universe in which every-day matter is such a small component? So our appetite having been whetted is left gasping. Also there are the occasional throw-away lines, such as when the Universe was initially formed full of high-energy photons and particles, the Universe was opaque because the particles mopped up the photons. How exactly isn't explained. And one final example, perhaps one of the simplest, in the section on Number Lines: Clegg introduces the concept of negative numbers — simply march back along the number line to beyond zero. Now what about the square root of these negative numbers? And so he introduces imaginary and complex numbers. These are very useful, he explains, and shows the standard coordinate system of representing complex numbers as points on the complex plane with real and imaginary components. This representation is very useful in calculating many physical phenomena, he states, and you eagerly turn the page. Nope — that's it — there is no more about that; in this case we move on to an interesting discussion of the Fibonacci series.

So after my initial reading I was thinking, who is this book for? It might be useful for grabbing a few sentences to appear knowledgeable about a subject before quickly saying "of course, it is much more complicated than that". I could not imagine that it would satisfy anyone genuinely interested in the topics covered.

Then I read it a second time — more carefully — and although there is indeed a glitch at the end of each chapter in which you are left wanting more information, you are also rewarded with little snippets of background information. For example, we find out the fate of the pigeons in Penzias and Wilson's horn antenna that delayed the initial discovery of the CMB; and invariably each chapter does contain a nugget of knowledge that gives a key idea to enable clear thinking about a subject. For instance, particles can be thought of as moving intensity spikes in fields, or the mass of protons and neutrons comes completely from the energy required to bind their constituent quarks and not the Higgs field. Clegg makes no claim to have written an all-encompassing guide to everything in the Universe so of course each topic covered leaves you wanting more; also he expects you to do some of the work. Unusually he has not provided a list of further reading, but with the information he has given you it is possible to go to the internet, library, or bookshop and research more of the topic for yourself.

So on balance this is a good introductory book on a wide range of science, which will give the interested student a sound basis for finding out more, as well as providing some exercise in thinking. That there is a coherent explanation for the way the Universe works is a valuable thing to say — it is after all the bedrock of science. It isn't just one damn thing after another — there is a chain of 'because' tying all of these subjects together — but that isn't quite the book Clegg has written. Clegg has described the underlying order in specific topics which, through the chapters and without explicitly linking them, build in complexity from the beginning of the Universe described in dimensions of space and time and space–time, the behaviour of particles and their interaction *via* force carriers, the building of atomic structure, to molecules operating collectively *en masse* to produce the weather and creatures — whose variety is governed by evolution and DNA — and the potential underlying descriptions of it all involving mathematics and symmetries.

So it is a book well worth reading and especially worth reading a second time. — Barry Kent.

About Time: A History of Civilisation in Twelve Clocks, by David Rooney (Penguin), 2021. Pp. 324, 22·5 × 14 cm. Price £16·99 (hardbound; ISBN 978 0 241 37049 0).

This book forced me to think about the relationship between astronomers and time keeping. First, we can be accused of starting it. We were originally in charge, defining words like day, week, month, and year. It was our job to measure the instance of solar noon, and delineate the lunar phase and the sidereal day, and fix the calendar. Second, we must ask how astronomers use it. Do we really need the sweeping second hands on our watches? Do we need the atomic clocks in the Global Positioning System to tell us where we are to the nearest centimetre? Most of us only need to know the time to the nearest minute or so, and when travelling, rely on a map and a bit of O-level geography.

David Rooney is immersed in the technology of time. He was a curator at the Old Royal Observatory at Greenwich and also in the Science Museum, London. He thinks that time is very important, but his book did not convince me. Too little effort was spent on justifying his choice of clocks. Fair enough: I was happy to start with a Roman sundial, and to move on to the great 14th Century cathedral clocks. It was also made clear that a stock exchange needs temporal precision. But where was the discussion of the way clock accuracy improved as the years advanced; and the way in which the price of a decent clock fell with time? John Harrison's chronometer got a mention, and it was made clear that finding longitude at sea helped the founding of the British Empire, but I was surprised that the relationship between clocks and religion was underplayed. Praying at the right time was very important. And the two 1676, year-going Thomas Tompion clocks at Greenwich were omitted. These were so accurate that they enabled John Flamsteed to discover the Equation of Time. The section on time balls was fascinating but I was not convinced that the country that had the most time balls had the best empire. It was interesting that astronomy reared its head again when early 20th Century anarchists and revolutionists chose observatory clocks as targets for their bombs, but did the choice of the lady who was the telephonic speaking clock really underline latent sexism?

Rooney's basic tenet was that a history of clocks is a history of civilization. Unfortunately, I was not over-convinced by his argument. I was left thinking that telling the time was reasonably useful when it came to mankind's advancement but in the main not absolutely essential. This book is an enjoyable, thought-provoking read but has not sent me rushing off to upgrade my seldom-used wrist watch — David W. Hughes.

Exploring the History of Southeast Asian Astronomy, edited by Wayne Orchiston & Mayank N. Vahia (Springer), 2021. Pp. 802, 24 × 16 cm. Price £109·99/$149·99 (hardbound; ISBN 978 3 030 62776 8).

In 2013 December a group of professional astronomers in the Southeast Asian Astronomy Network decided to collaborate by forming a History and Heritage Working Group. Mini conferences were held; astronomers from Thailand, Vietnam, Malaysia, the Philippines, and Indonesia came together, and papers were presented. Those papers have been collected and are published in the book being reviewed.

We are treated to a melange of colourfully and profusely illustrated, well-referenced research papers. On the one hand we are presented with ethnoastronomical discussions of the influences of Buddhist, Islamic, and Christian religious ideas on the region's traditional astronomical practices. Others investigate the archaeo-astronomical remains of solar temples, and tower observatories. Some study the introduction of modern telescopic astronomy into the far-east. Papers review the development of Vietnamese calendars, the historic recording of solar and lunar eclipses and comet sightings, time reckoning and time keeping, the profusion of time balls and noon-time guns, planetary transits, Vedic astrology, Austronesian star groups and the use of their rising and setting times to influence and aid navigation, agriculture, and fishing. Indigenous star maps are reviewed, and the host of lunar mansions is stressed.

European influence is discussed. For example, Father Antoine Thomas (1644–1709) introduced the foundation of modern astronomy to Thailand, and Jean A. C. Oudemans (1827–1906) did a similar job in Indonesia. Much is made of the eclipse visits by European astronomers and the instrumentation they brought with them. French, British, and German astronomers travelled to the region to record eclipses in 1868 August, 1875 April, and 1929 May.

There is much of interest in this book and it will go a long way to encourage more people to study the history of their region's astronomical endeavours and the many ways in which different astronomical systems across the world have interacted. — David W. Hughes.

Advancing Cultural Astronomy: Studies in Honour of Clive Ruggles, edited by Efrosyni Boutsikas, Stephen C. McCluskey & John Steele (Springer), 2021. Pp. 319, 24 × 16 cm. Price £109·99/$149·99 (hardbound; ISBN 978 3 030 64605 9).

Once upon a time, archaeoastronomy meant the measurement of alignments of ancient structures with features on the horizon and their relation to astronomical phenomena, such as the rising point of the Sun at a solstice. These associations were sometimes controversial and Clive Ruggles was instrumental in bringing rigour to the associations through statistical methods. This was followed by the movement of archaeoastronomy into mainstream archaeology. In the absence of written records, we do not know which astronomical phenomena were significant to the builders of the monuments, and the scope has widened to include ethnoastronomy, consideration of the astronomical beliefs of different cultures past and present. The breadth of what has become Cultural Astronomy is reflected in the wide-ranging collection of contributions assembled for this *festschrift*.

Many discuss alignments between monumental structures and features on the horizon and their association with astronomically significant events, with examples from all over the world: Spain, Ireland, South America, and Greek temples around the Mediterranean. It was interesting to read González-García's application of cluster analysis to the orientations of passage tombs and related monuments suggesting a regional variation of tradition, and Prendergast's discussion of the directions taken by the Dead to the Otherworld. The final contributions are concerned with World Heritage sites. In his introduction to these, Cotte relates the contribution of Clive Ruggles to the recognition of archaeoastronomical sites as World Heritage. This is followed by Ghezzi's substantial description and discussion of the Chankillo Solar Observatory and Ceremonial Centre*. I found the description of the site hard to follow: there is no key to the letters marking the various structures in Figs. 2 and 3, and the same letters are used for different structures in different figures. The discussion of the possible use of the site leaves one longing for even the smallest written record.

There are some. In his discussion of the Mesopotamian Calendar in the search for the concepts of solstice and equinox, Steele introduces and translates Sumerian and Akkadian texts concerned with the relative lengths of day and night. Rather different are the problems posed by the translation of the ancient Greek geographers. Amongst the terms discussed by Shipley are the cardinal points of the compass, for each of which the Greeks had two terms where English has one: one based on astronomical directions (*e.g.*, bear for North) and one on wind directions. When translating into English, how does one retain the sense of the original?

I was particularly taken with the comparison of the Greek and Australian Aboriginal stories about the Pleiades and Orion: identification of the cluster with a group of young girls and Orion as a hunter or young man attempting to catch or rape them. Ray and Barnaby Norris suggest a common origin, perhaps prior to 100 000 BC, when the ancestors of both cultures migrated out of Africa. They also discuss the number of naked-eye Pleiades stars: most people today, even in a dark sky, see only six stars whereas most cultures tell of seven.

The contributions are all thoroughly referenced and the production of the book is good. I learnt a lot; but the very breadth of scope and great specialization of the contributions make the book more likely to be dipped into than read through or find a place in many astronomers' libraries. — PEREDUR WILLIAMS.

Expanding Worldviews: Astrobiology, Big History and Cosmic Perspectives, edited by Ian Crawford (Springer), 2021. Pp. 377, 24 × 16 cm. Price £149·99/$219·99 (hardbound; ISBN 978 3 030 70481 0).

What is this book, and why, and does it even belong in *The Observatory*? We need to start with a couple of definitions. "Astrobiology," says editor Crawford, "is concerned with the evolution and prevalence of life in a cosmic context, while Big History aims to integrate human history of life into the deeper evolutionary history of the Universe." In other words, we are supposed to start with the Big Bang (or maybe inflation) and work forward through formation of galaxies, stars, heavy elements, planets, in that order, and then, as the authors and editors mostly interpret what they are doing, specialize on what happened on Earth, taking us forward through biological evolution and culture until we can both send and receive messages across astronomical distances. A subset of the chapters recommend teaching science this way as a way of changing the world

*Shortly after publication, this site was inscribed in the World Heritage List at the 2021 session of the UNESCO World Heritage Committee: see https://whc.unesco.org/en/list/1624 for the better. Hmmm. Starting in 1971, I taught a course called 'Cosmology: Man's Place in the Universe' very much along those lines, though with somewhat less specialization in favour of Earth and, at least in the public talk, a curtailment of the last stages to "and from there on, the evolution from slime moulds to politicians is practically inevitable." The text was (Josef) Shklovsky's and (Carl) Sagan's *Intelligent Life in the Universe*. Well, perhaps the world wasn't ready to be changed for the better.

Sarcasm temporarily out of the way, what is there here to appeal to astronomers of reasonably broad interests? First, and perhaps foremost, Lewis Dartnell (of University of Westminster, London) on the Earth's atmospheric circulation patterns, prevailing winds, the ocean currents they drive, and resulting patterns of sea-borne trade in the era of sails and oars: Hadley cells (0 to ± 30° latitude), Ferrel cells (30–60° latitude in both hemispheres), and polar cells (60–90°). The ocean responds with gyres and currents. The combination allowed Portugal to reach Brazil and the East Indies; Spain to keep western South America and the Philippines in contact, and Britain (*etc.*) to circle Europe to West Africa to the West Indies and back to Europe, transporting sugar, cotton, tobacco, manufactured goods ... and slaves. If you are even half as old as I, you will remember that 15th Century Ming-dynasty China started out around South East Asia and reached (probably) India and Madagascar before abandoning the whole project and turning inward. Looking at the maps in Dartnell's chapter, I couldn't help but wonder whether they had found winds and waves more consistently against them than had the Europeans in the same time frame. Another, explicit, 'a ha!' comes in a chapter by an American author with only an agent, not an affiliation. It is that Earth is the only planet (in our Solar System) on which fire is possible!

By the way, most of the chapters have authors from the UK, followed by Australia and the US, with the Netherlands and Germany each getting a single look-in. The focus is Birkbeck College, home of the editor and the location of the conferences that gave rise to the present volume.

What about us announcing ourselves to the rest of the Universe? Some signals (like broadcasts of *I Love Lucy*) are irretrievably on their way. Paul Quest, of the Beyond the Earth Foundation in Edinburgh, lists 41 deliberate interstellar transmissions (1936 to 2018), some originating in familiar places — Dwingeloo, Arecibo, Algonquin, Tromsø, Canberra; others less so — Yevpatoria, Usuda, Svalbard, Jamesburg — and at powers ranging from 18 kW up to 1·5 MW (frequencies not tabulated). Most were aimed at specific constellations or star systems, and the one message I had heard about before, toward a globular cluster, does not seem to be included.

Several chapters address versions of the question, and answers, called 'the Fermi paradox: where are they?' You have probably thought or heard of all the answers mentioned here already. But let's dip into one more chapter from Lineweaver and Chopra of the Australian National University in Canberra. Using data from published literature, they attempt a table that works backwards from genus Homo *via* 'clad-like steps' (meaning only two things can branch at each step) to all life on Earth, at step 47. This is obviously much more detailed, complicated, and demanding than the Linnaean kingdom, phylum, class, order, family, genus, species taught in American schools before evolution went out of fashion. But, as a guide, in their table we reach great apes at step 3, primates at 8, mammalia at 15, chordata & vertebrata with the sea-squirts at 23, metazoa (sponges) at 31, those slime moulds at 37, eukaryotes (true single cells) at 41, and the rest is archaea, bacteria, and viruses or viri.

Perhaps the answer to Fermi is that the process has reached only those earliest stages on exoplanets. Thus Tony Millikan (of Kings College, London) asks what our ethical attitude should be to extraterrestrial microbes. It is possible that he has not read the Lineweaver and Chopra chapter, since he assumes that those other microbes will be very much like our own. Now, no doubt we humans spend a lot of time, soap, sprays, and other substances trying to eliminate terrestrial microbes (especially now as I write, suitably masked against SARS-CoV-2). Yet probes to Mars have been sterilized as best we-all could, lest they infect or harm some existing or potential microbe community there. Why is this so? And should it be so? The author offers (I think) 'reasons for actions' as an alternative to ethics in some contexts.

I had flagged a number of phrases like "meta-semiotic features" for an 'eh?' paragraph. But let's end closer to home, namely on the Moon with the Apollo programme which consumed 4% of the US GDP in its peak year. Author Nick Spall (a London science writer) has collected some of the major positive outcomes, including enormous advances in miniaturized computer power and "A generation of space scientists would emerge as a legacy of the Apollo years, covering not just lunar science but wider astronomy and cosmology areas." I am a member of that generation — an undergraduate when JFK said we could/would/and should do it; a graduate student when proto-*Apollo 1* blew up (killing astronauts Grissom, White, and Chaffee); a postdoc on 1969 July 20 when *Apollo 11* landed (a good part of my education paid for by entities that had responded to the challenge); and my late husband, Joseph Weber, had an experiment, the *Lunar Surface Gravimeter*, emplaced by the *Apollo 17* crew (Eugene A. Cernan, Ronald E. Evans, and geologist Harrison H. Schmitt). — VIRGINIA TRIMBLE.

The Rise of Astrophysics in Modern Spain: From Dictatorship to Democracy, by Francisco Sánchez, trans. T. J. Mahoney (Springer), 2021. Pp. 296, 23·5 × 15·5 cm. Price £22·99/$29·99 (paperback; ISBN 978 3 030 66425 1).

What a wonderful story this is! Almost single-handed, Professor Francisco Sánchez has driven Spain through the rise of modern astronomy, from the rather moribund state it found itself in after the Civil War to the dynamic situation it can now claim. He started from almost nothing but realized the amazing potential of the skies over the Canary Islands and fought tooth and nail to get that bounty appreciated by the cumbersome layers of governmental bureaucracy. We find him battling with the naysayers, politicians, and rivals in Spanish academia — most of whom are named in this fascinating tale (clearly a bonus forthcoming from his retirement!) — but managing to get the Instituto de Astrofísica de Canarias and the *Gran Telescopio Canarias* up and running. And if ESO had played along, he might have got the *E-ELT* built on the islands as well.

From my own experience with the *IUE* project over its long lifetime, Spain was ready for such a renaissance. At the outset, the country hosting the ESA tracking station near Madrid had a full 'local' complement of very able technical and support staff, but there were no Spanish resident astronomers. However, as time went on, home-grown astronomers came along to play a full part in the operation and exploitation of the satellite. And it is that change from what Sánchez rightly termed 'colonial astronomy' to full involvement that has finally been achieved.

Every large project should have its story told in this frank and honest way. The tale is well told and the translation by Terry Mahoney is excellent. — David Stickland.

Islam, Science Fiction and Extraterrestrial Life: The Culture of Astrobiology in the Muslim World, by J. M. Determann (I. B. Tauris, London), 2021. Pp. 269, 24 × 16·5 cm. Price £51 (hardcover; ISBN 978 0 7556 0127 1).

In 2017, I was asked to host the Ismaili Centre Toronto/Vancouver Public Lecture series titled 'Frontiers of Science and Innovation'. One of our speakers was Dr. Natalie Batalha (University of California, Santa Cruz) who spoke about the *Kepler Space Telescope* and its mission to identify extra-solar planets that satisfy the conditions for hosting life as we know it. Given the venue, I normally try to find some connection between the lecture topic and the contributions of Islamic scientists of the past. I was convinced that finding such a link for Prof. Batalha's session would be near impossible. How wrong I was! I discovered that although Muslim philosophers and scientists revered ancient Greek thinkers, like Aristotle, they encouraged critiquing, challenging, and 'correcting' the Aristotelian worldview. One prominent topic where there was a clear divergence of views was on the uniqueness of Earth and the possible existence of extraterrestrial life. More than a thousand years hence, that discourse continues to inform how Muslims around the world perceive extraterrestrial life and how they engage with this idea/concept. In his recent monograph, Determann explores these views along with other related topics. The survey is impressively comprehensive. It encompasses topics as varied as theology, science, science-fiction-inspired visual art, literature, cinema, UFOs, and even pseudoscience. Geographically, Determann catalogues activities of not only Muslims living in Muslim-majority countries of Asia and the Middle East but also those living in diaspora communities in Europe and North America. If there is a failing, it is that he does not really engage with sub-Saharan and West Africa.

The starting point is several intriguing verses in the *Qur'an*. To put these in context, in his treatise, 'On the Heavens', Aristotle asserted that the Earth was the centre of motion of the Universe, that it contains the entirety of matter, and consequently, there could not be another inhabited world elsewhere[1]. While this argument was generally accepted and even incorporated into Christian thought during medieval times, it conflicts with several verses in the *Qur'an* that not only imply the non-uniqueness of the Earth but also allow for the existence of life elsewhere in the Cosmos. One such verse, "*Al hamdu lillaahi rabbil 'alameen*" (Sura al-Fatiha, Verse 2), which means "All praise is due to Allah, the Sustainer of the worlds" (note that the latter word is plural), is recited by Muslims daily in their prayers. Another, perhaps more intriguing, verse is "And among His Signs is the creation of the heavens and the earth, and the living creatures that He has scattered in them: and He has power to gather them together when He wills" (Sura Ash-Shuraa, Verse 29). Determann refers to both verses and a few others. Over the centuries, these verses have engendered a vibrant discourse on the possibility of extraterrestrial life by early scholars, with one prominent personality, the revered 7th Century scholar, religious authority, and descendant of the Prophet, Muhammad al-Baqir, writing "Perhaps you think that Allah has only created this single world, and you think Allah has not created anyone other than yourselves. Nay by Allah, verily Allah has created a million worlds and a million Adams."[2] Against this backdrop, it is not too surprising that the concepts of cosmic plurality and of alien/non-human life have found fertile ground within the collective imagination across the Muslim world.

Turning to the specific content of Determann's monograph, let me first clarify that this book is not really about the contributions of Muslims to the on-going global scientific effort to identify potentially habitable extra-solar planets or the scientific study of astrobiology. Determann does profile a few scientists working in the area who are Muslims, and while this is useful, the list has significant gaps. Many, like the late A. Bhanji (NASA/JPL, *Deep Space Network*), who had an asteroid named after him in recognition of his contributions, and rising stars like Drs. F. Meru (University of Warwick) and F. Alibay (NASA Mars Exploration Program), to name a few, have been omitted. I also got the impression that Determann was subtly implying that Muslims were more inclined to pursue/support astrobiology research because of faith-based reasons, but the supporting evidence is rather thin. Determann does explicitly state that "when it comes to works about extraterrestrial life, research in the physical and biological sciences was perhaps as important as religion. Some Muslim-majority countries and their diasporas were heavily involved in the advancement of such studies." This may well be, but again, the supporting evidence presented is not convincing. For example, Determann refers to the hosting of the Soviet Cosmodrome by Kazakhstan and the fact that astronomer, Gavriil Tikhov, who was a pioneer in astrobiology and astrobotany, was based in Almaty. The Cosmodrome was, however, not an indigenous, local effort, and Tikhov was neither a Kazakhstani nor a Muslim. Similarly, efforts to establish manned space programmes that Determann references, in and of themselves, do not imply a commitment to astrobiology research.

The monograph's most important contribution is in exploring and documenting just how widely the idea of sentient extraterrestrial life had permeated into the wider culture. Narratives involving extraterrestrials have been, and continue to be, used not only to fuel fringe ideas (like everywhere else) but much more interestingly to frame and discuss pressing societal challenges, offer social and political critique, and give voice to hopes and aspirations. Labelling such interplay "scientific imagination", Determann surveys how extraterrestrials have been, and continue to be, creatively imagined in cinema, theatre, novels, magazines, short stories, and visual art to query contemporary flashpoints due to political and theological ideologies, civil strife, social-justice issues, trauma of colonialism, geo-political insecurities, *etc.* In the process, Determann also convincingly challenges the stereotype that citizens of the Muslim world lack creativity and imagination because of a trifecta of "paternalism of the traditional family structure, the authoritarianism of the state, and the dogmatism of the religion".[3] He demonstrates that authors and artists living under politically repressive conditions can and do produce exceptionally rich media. If anything, repression appears to have invigorated scientific imagination as authors seek to disguise their critiques. Such usage is unlikely to come as a surprise to anyone who is familiar with the rich corpus of Urdu, Arabic, and Persian poetry and ghazals, not to mention classical compilation of tales known as *The Thousand and One Nights* (also known as the *Arabian Nights*).[4] In this regard, the monograph ought to be of value to historians, social anthropologists, political scientists, scholars of film studies, and of course science-fiction aficionados. The Determann monograph is perhaps less useful for scholars interested in a fuller understanding of the discourses about the uniqueness of Earth and of sentient life here and elsewhere by Muslim philosophers and theologians over the ages. The coverage is rather cursory. I also do not think that in its present form, Determann's monograph will be an engaging read for an interested lay reader. The text desperately needs an editor's once-over. It is chock full of irrelevant biographical details and unnecessary diversions that are both tedious and distracting. — ARIF BABUL.

References

(1) Aristotle (~350 BCE) *On the Heavens*, Book 1, Part 8, http://classics.mit.edu/Aristotle/heavens.html

(2) M. M. Rayshahri, *Creation*. In: *Scale of Wisdom: A Compendium of Shi'a Hadith* (ICSA Press), 2008. Also in: (a) M. Golshani, *Creation in the Islamic Outlook and in Modern Cosmology*, in M. Iqbal and S. N. Haq (eds.), *God, Life, and the Cosmos: Christian and Islamic Perspectives* (Ashgate Publishing), 2002; and (b) D. A. Weintraub, *Islam*, in: *Religions and Extraterrestrial Life* (Springer Praxis), 2014.

(3) B. Whitaker, *What's really wrong with the Middle East* (Saqi), 2009.

(4) M. J. Al-Musawi & M. Al-Musawi, *The Islamic Context of the Thousand and One Nights* (Columbia University Press), 2009.

The Beauty of Space Art: An Illustrated Journey through the Cosmos, edited by Jon Ramer & Ron Miller (Springer), 2021. Pp. 301, 28·5 × 21 cm. Price £32·99/$49·99 (hardbound; ISBN 978 3 030 49358 5).

What is and what isn't Art is a discussion that could fill many volumes; and as for beauty — well it's in the eye of the beer holder as we sometimes say under the dark Norfolk skies. I have to confess that when the Editor called for a reviewer for this book I responded almost immediately; in part just to take a look at this 'so called' Space Art. You know the stuff — pictures of white-suited space men on the surface of an invariably orange planet, doing something vaguely geological, against a black sky full of stars, often with a thin hint of a Saturn-like planetary ring sweeping across the vastness. But then the book arrived; and there are indeed a few — actually quite a few — of those classic 'other worlds' images but also an extensive range of visual art through a wide range of time and culture, from ancient Sumerian, through Italian renaissance, French impressionism, American abstract expressionism, and two categories new to me: cosmic impressionism and cosmic expressionism. Whether by accident or design, the copy that I received also allowed for some surreal performance art as I carefully pulled apart two pages which had become glued together — and as befits that former *enfant terrible* of the Young British Artists movement, one of those pages was Damien Hirst's dot painting used as the colour calibration target for the *Beagle 2* Mars lander.

A stand-out sentence for me, that changed my snooty view of space art, appears in a chapter by Steve Hobbs on 'Patrons of the (Space) Arts', in a discussion of art being placed on spacecraft; and incidentally isn't that something worth celebrating? The sentence was specifically about works placed on deep-space probes sent beyond the Solar System eventually to become interstellar objects; these art works "will outlast the Pyramids, cathedrals, and all other earthly monuments", and perhaps even the Sun itself; "they may perhaps be the only evidence that human art ever existed". And if, as is a reasonable possibility, humans are the only expression of consciousness in the entire Universe, that is both a profound and deeply affecting thought. From our cave-dwelling ancestral beginnings to a time long beyond our extinction, humanity making art has left its signature on the Universe.

This A4-sized book is printed on glossy magazine-like paper, enabling clear colour printing on most of the 300 or so pages, at a reasonable price. And though exceptionally well-illustrated, this is more than just a fancy coffee-table picture book. It is arranged in two parts with Part 1 being eight chapters on 'The History of Space Art', and Part 2 another eight chapters exploring 'Styles and Techniques of Space Art'. Each chapter is written by practitioners of the genre, many of them members of The International Association of Astronomical Artists (IAAA), an organization formed in the early 1980s. Part 1 is a very comprehensive account of the history and the practice of making and using artistic techniques to produce illustrations for many purposes but ultimately with the aim of furthering the cause of exploring the cosmos. These chapters lead you through the development of space art from earliest beginnings through stages in which models of planetary surfaces were carefully constructed to be used as the reference for painting, to today's photographic-quality digital artworks. One aspect that unites all of these periods is an absolute adherence to the astronomical data of the time. For example, we have all seen those earliest paintings from the late 1800s of lunar surfaces showing craggy mountain peaks, explained in part, due to the long shadows cast by mountains onto the lunar surface at low illumination angles. It wasn't until Lucien Rudaux's 1937 book *Sur les Autres Mondes* (*On Other Worlds*) that lunar mountains were depicted as eroded, with a smoothed rounded nature. As he explained, he had simply observed bright lunar peaks silhouetted on the limb. His artistry was of course eventually confirmed by lunar probes and the Apollo astronauts. Two sculptures fall outside this purpose of furthering scientific exploration. One, named *Cosmic Dancer*, by Arthur Woods, is a structure of linked elongated cuboid elements that tumbled and twirled in the free fall of the MIR space station, with the sole purpose of being enjoyed by the resident astronauts; and the other a small aluminium figure titled *Fallen Astronaut* by Paul Van Hoeydonck, placed on the surface of the Moon by Dave Scott during an *Apollo 15* moonwalk, as a memorial to some of the US and Soviet astronauts who had died in service. Space art thus recognizes that furthering the cause of exploring the cosmos can also be achieved by inspiration and connection with human emotions.

The first chapter in Part 2, by Michael Carroll, addresses the issue of what is and what isn't 'space art', pointing out that like every genre of artistic expression space art also has different facets and sub genres. Those other-world classical/naturalistic images that I snootily referred to earlier are knowingly described as 'Rocks and Balls'. A subsequent chapter on techniques gives a considered account of the various types of space art: relating space art to 'normal' terrestrial art, leading to the use of experimental and abstract techniques in space art — jokingly referred to as 'Swirly Art'. Were it not for the historical thrust of the Part 1 section of the book this might have made a very nice introduction to the topic as a whole.

Space art is hugely successful when dealing with matters of illustration. For most people our vision of the Universe is shaped not by data but by illustrations — images that have been created or manipulated by talented, artistic image makers. The first real 'image' of the black hole at the centre of M 87 created by the *Event Horizon Telescope*, a network of eight radio telescopes and giant computing capability, is severely lacking in impact and detail when compared to *Black Hole*, an image by Mark Garlick in Chapter 14 of this book. As so often reality is found wanting when compared to art. However, and it is all a matter of personal taste, I found that when space artists attempt less-realistic subjects and look at feelings rather than physics or technology there is a cold sterility about their images, and occasionally when aiming for depth or emotion a sort of greetings-card kitsch results — perhaps with the exception of Alan Bean's depiction of an astronaut on the Moon called *That's How it Felt*, or another astronaut painting by Joseph Minsky called *Oh God How Tired I Am*, which both put the human into the context of space exploration.

As several of the authors comment, not only does space art depict views that humans have not yet seen — but also cosmic phenomena that humans will never be able to see. Human eyes are unlikely to observe directly the scene in close proximity to a black hole, or even the surface of one of the several thousand exoplanets now known. Human eyes would be disappointed by the wide sweep of a galaxy where in the glorious *Hubble* images the low surface brightness has been compensated by data integrated over hours or days. Such scenes are creations of the imagination at work — but imagination guided by science. As such they make space art distinct from most artistic endeavours. Art is traditionally seen as an occupation of the outsider — one who does their own thing; other than the vanity of patrons of portraiture painting, art is generally not a sphere that is overly guided by adherence to facts or the opinion of others.

In 1965 Kurt Vonnegut wrote "I have been a sore headed occupant of a file drawer labelled "science fiction" ... and I would like out, particularly since so many serious critics regularly mistake the drawer for a urinal." These days science fiction is sometime re-branded as 'Speculative fiction' and is now taken more seriously in literary circles. The editors write that space art is flourishing but it is possible that one aim for this book is to reclaim space art in the same way, and to focus the reader's attention from the science-fiction worlds of space monsters and damsels in distress onto the arena of serious art.

This is a comprehensive, fascinating account of space art by experts in the field. The illustrations are wonderful and, yes, some are beautiful. I could have done with an index to the hundreds of art works shown, and although there is an appendix of further reading and resources, a section of numbered references to enable follow-up enquiry would have been useful. But other than those minor quibbles this is an excellent book and I learned a lot — not least to try to be less snobby about what is and what isn't art. — BARRY KENT.

European–Russian Space Cooperation: From de Gaulle to ExoMars, by Brian Harvey (Springer), 2021. Pp. 406, 24 × 17 cm. Price £24·99/$34·99 (paperback; ISBN 978 3 030 67684 1).

There is a general perception that the two superpowers, the United States and Soviet Union, dominated the first decades of space exploration, with a few minor contributions from Europe, China, and Japan. In a race to grab the ideological high ground, these rivals pursued their own scientific, technological, and political programmes, punctuated by an occasional effort to break the barrier of secrecy, most notably the Apollo–Soyuz Test Project of 1975 July. In this space race, Europe and other would-be participants were obliged to take a back seat, feeding off scraps offered by their more powerful neighbours.

In this volume, well-known space writer Brian Harvey takes an in-depth look at the efforts of western-European countries to collaborate with Russia in various fields of endeavour: scientific cooperation, human spaceflight, industrial collaboration, and the *ExoMars* programme. Many of these efforts have previously been ignored by the English-speaking media, so this is a useful addition to the literature. For many years these efforts at East–West collaboration were led by France, where President de Gaulle sought to pursue an independent foreign policy by remaining outside the orbit of NATO and the United States. Following his ground-breaking visit to the Soviet Union in 1966, France was able to fly its own scientific experiments on board Russian spacecraft. By the 1980s, Germany and the European Space Agency were also able to take advantage of Russian expertise, resulting in joint crewed flights to the *Salyut* and *Mir* space stations, as well as more advanced scientific endeavours.

The book also examines industrial cooperation, particularly in the use of Russian launchers — such as the Soyuz launch site created at Kourou in French Guiana. Another chapter is devoted entirely to the ambitious, two-part ESA–Russian *ExoMars* project, which has yet to be completed. One of the most interesting themes covered by the author is the discussion of the Soviet obsession with secrecy and the communication difficulties that arose as a result. Particularly fascinating is the section that deals with the arguments and counter-arguments over the French participation in the *VEGA* mission to Venus and Halley's Comet.

Harvey concludes: "Cooperation with Russia enabled European countries to fly experiments, instruments, satellites and people to places where they could not otherwise have gone, or which would otherwise have been considerably more costly. Cooperation with Europe enabled Russia to attract vital financial resources and specific areas of expertise which it itself had not developed." Reading this book, one cannot but reflect, however, that the Soviet superpower, which dominated space activities from the late 1950s to the 1980s, has now been largely relegated to a second-rate space power, reliant on international projects and finance to continue many of its non-military space activities. — Peter Bond.

Test Gods: Tragedy and Triumph in the New Space Race, by Nicholas Schmidle (Hutchinson), 2021. Pp. 353, 24 × 16 cm. Price £20 (hardbound; ISBN 978 1 786 33185 4).

This is an engaging, readable narrative about a few years in the life of a test pilot as told to the journalist Nicholas Schmidle. Schmidle was for a time 'embedded' in the flight test team during the development of Richard Branson's Virgin Galactic space tourism enterprise. Mark Stucky, the lead test pilot of Virgin's *SpaceShipTwo* gives his reflections and account of events during this process, and given the book's title and the character of the main protagonists, readers should not be expecting shrinking violets or false modesty.

I suppose I should apologise for including in another review for *The Observatory*, yet another reference to an ancient pop record, but this curiously old-fashioned book demands it. I claim it has relevance to this *Magazine* as the third track on the album is titled 'Child of the Universe'. If you know the music of the 70s West Coast country rock band, The Byrds, you will already be familiar with the territory covered by this book. It has the same aura of western mythic masculinity played out against the rugged landscape and spiky flora of the deserts of the American South West. The sleeve cover art of the *Dr Byrds and Mr Hyde* album shows the various band members struggling out of space suits and fighter pilot anti-g suits to emerge as cowboys. In *Test Gods* an almost mirror image shows the team of Virgin Galactic space pilots sauntering across the runway in the baking California sun, wearing those short, zip-fronted wind cheaters or flying jackets so beloved of the macho US male. The jacket will be familiar to UK readers as similar to the one worn by President George W. Bush when he welcomed Tony Blair to Camp David in 2001. In news images of the time the UK prime minister, dressed in a casual blue sweater, tries hard to emulate the Presidential swagger by shoving his hands deep into his jeans pockets. He looks uneasy. Richard Branson the "showboating British mogul" behind the Virgin Galactic project pulls off the look with aplomb. In *Test Gods* he is photographed standing, arms outstretched, in his bomber jacket, messiah-like, emerging from the top of the white Range Rover that is being used to tow Virgin's space plane, *SpaceShipTwo*, out to meet the press.

We know how these test-pilot/astronaut stories work — we have all read *The Right Stuff* or at least watched the movie. Hard living, desperate but driven men battle their way through insuperable odds and overcome personal demons to tame the malevolent forces of the transonic zone. They struggle against blackouts and oxygen starvation to escape death by sheer flying skill, to pull their irascible machines out of inverted hypersonic spins and land safely among the sagebrush and cacti and then have a beer with their mates. This book has all of that. The mates are named people — some of them die in horrific rocket explosions or crashes as rocket ships disintegrate at high altitude.

I have often wondered about astronaut and test-pilot bravery. How is this seeming disregard for personal safety achieved — especially given their detailed knowledge of all the possible failure modes of the craft they fly? Stucky, who seems to have a genetic disposition to a low heart rate, has several attempts at explaining this: "The job is dangerous enough without letting panic get in the way", and he refuses to "live in fear of death [as] life is full of random accidents". Or as the legendary NASA engineer Hugh Dryden commented, the essence of flight tests was "to separate the real from the imagined problems". To do this the test pilots fly the creed — Fly, test, note, adjust; fly, test, note, adjust, and repeat this until a safe, flight-worthy product emerges. Stucky's descriptions of this progression form the core of the book — and so we experience the day-to-day process from his point of view. We learn a little about the technology and engineering behind the hybrid rocket engine and the *SpaceShipTwo* laminated composite structure, and a bit more about the conflict between commercial aims and engineering management requirements. But much more than both of these, we learn about the brotherhood of test pilots and its celebration ceremonies and exchanges of gifts and tokens as bonding symbols. My impression is that it does seem to be exclusively a brotherhood — in this book the sisters are noticeable by their absence. A few professional women are fleetingly mentioned and not one of those is a test pilot or engineer. One woman, Beth Moses, an ex-NASA expert on 'reduced gravity flights', the wife of Virgin's vice-president and director of operations, Mike Moses, takes the passenger role on an early flight, to gather information on 'the customer experience'. Other than a doctor and a museum director and excluding Branson-connected 'celebs', the remaining women are wives, widows, mothers, or in office support roles. This strangely old-fashioned environment makes my 70s rock-music comparison even more appropriate.

No matter how brash and divisive is Branson the showman, the collaboration between Virgin Galactic and Burt Rutan's Scaled Composites aerospace prototyping company have engineered quite a remarkable achievement. To develop the entire infrastructure, launch system, rocket propulsion, pilots, *etc.*, able to put a crewed capsule into near space is not trivial. To demonstrate the intention of doing this and make it safe enough for fare-paying passengers to enjoy is astonishing. Such a feat would have seemed impossible without government funding a few years ago. And yet on 2021 July 11 just such a system was demonstrated, as *SpaceShipTwo*, piloted by David Mackay with Richard Branson on board accompanied by three other passengers, soared up to 53 miles in a rocket ship powered by 'rubber' granules and nitrous oxide to experience a few minutes of weightlessness and view the intense, more-than-velvet blackness of space.

All of the engineering and computer analysis of manned spacecraft counts for nothing without the test pilots. They flew the prototypes that enabled real flight conditions to be experienced beyond the computer hard drive. Schmidle's book is well indexed and the source material detailed, including an account of the author's methodology. But this book should not be seen as primarily about the engineering; rather than a technical story Schmidle provides an insight into the lives and careers of the individuals who flew these particular test flights. Perhaps it also provides an appreciation of all the highly motivated and talented, but sometimes flawed, human beings who have tested the prototype machines that gave humanity the wings to fly and the ability to rocket into space. — Barry Kent.

Annales Astronomiae Novae. Vol. 2, edited by Bogdan Wszołek & Agnieska Kuźmica (Wydawnictwo Astronomia Nova), 2021. Pp. 360, 24 × 16 cm. Price* zł 87 (about £16) (hardbound; ISSN 2719-3616).

At least two fascinating articles in English appear in this volume. The first, by Bohdan Novosyadlyi of the University of Lviv in Ukraine, concerns part of the life of Prof. Eugeniusz Rybka (1898–1988). He was appointed director of the observatory and head of the department of astronomy at the University of Lwów in Poland in 1932 when it was the Jan Kazimierz University. Considerable progress in equipment, staffing, research, and teaching was made over the next few years. Then, after 1939 September 1, the city became part of Ukrainian SSSR, the University renamed for Ivan Franko. More staff were added and plans made for a new observatory out of town. Then the Germans came and closed both the University and the Observatory. Observations for meteorology and navigation soon resumed, under a German-led collaboration with observatories in Warsaw and Kraków, most of the observing being done by Rybka and his son Pszemysław. When Soviet troops approached in 1944, the Germans intended to take all of the equipment from the Observatory back to Germany. Rybka arranged for things to be packed but hidden away, and German troops left Lwów in 1944 July without at least that portion of swag. Of course the Soviet NKVD promptly (1945 January 4) arrested Rybka for collaboration with the enemy. He was soon released, put in a proposal for an Astronomical Institute at the University of Lviv, which was actually in large measure funded. But, on 1945 September 28, Rybka, his family, and at least some of their belongings, personal and scientific, boarded a repatriation train to Poland, where he became observatory director at Kraków, and his son, in due course, a member of the Astronomical Institute of the Wrocław (formerly Breslau) University. He attended at least the IAU General Assemblies in Moscow (1958), Berkeley (1961), Hamburg (1964), Prague (1967), Brighton (1970), and Warsaw (1973),

*The book can be obtained for €25 plus postage, and interested buyers should contact editor Wszołek at bogdan.wszolek@gmail.com The electronic version is a pdf downloadable for free.

serving on the organizing committee of Commission 25 (photometry) and becoming an early member of Commission 41 (history of astronomy). Four other chapters address Rybka's life and work before, during, and after his time in Lviv/Lwów. They are in Polish.

We turn from this harrowing tale from the past to a potentially harrowing tale extending into the future. Kataryna Smolark and Grzegorz Michalek of the Jagiellonian University of Kraków have examined in great detail the behaviour of our Sun during the last two cycles (23 and 24), but with some data going back to cycle 1 at the end of the Maunder minimum (so called because it was discovered by Spörer; Maunder, of course, discovered the Dalton Minimum of the early 1800s). Besides sunspot numbers, they looked at the lengths of the cycles (24 was really short), numbers of spot groups, flares, and coronal mass ejections, geomagnetic disturbances, and aurorae. For some of these, I had not previously even heard of the "customary units", the Dst index (in nanotesla) for geomagnetic storms and the Kp (from *planetarische Kennziffer*) for aurorae (units not given, but values range from about 50 to 200, and again the most recent cycle has been very weak). All the indicators show systematic declines through the last three cycles, 22, 23, and 24. The authors attempt no explanations or predictions, except to express concern about this anomalous state of our star. My thought is that, if we become too accustomed to a perpetually quiet Sun, the next Carrington event will do more damage than would have been necessary.

I began by saying "at least two", because there are also interesting chapters about variable stars, eclipsing binaries, monitoring re-entries of artificial satellites, and "physiology and dysfunction of the excretory system in the micro gravity environment." This is not quite as icky as you might guess from the title, since it deals primarily with bone density, dietary calcium, and kidney stones in astronauts. 'Observatory directors I have known' by your reviewer ends the volume. — VIRGINIA TRIMBLE.

The Chandra X-ray Observatory: Exploring the High Energy Universe, edited by Belinda Wilkes & Wallace Tucker (IoP Publishing), 2021. Pp. 450, 26 × 18·5 cm. Price £120 (hardbound; ISBN 978 0 7503 2161 7).

The year 1999 was a great one for X-ray astronomy with the launch of *Chandra* and ESA's *XMM-Newton* mission within a few months of each other after many decades of effort. You may wonder why (and how) two large X-ray missions were developed in parallel. If so, read this book. *Chandra* provides extraordinary imaging capability combined with spectroscopy, complementing the larger effective area in imaging provided by *XMM-Newton*, alongside its spectroscopic and on-board optical capability. This book takes on the challenge of summarizing the scientific impact of *Chandra* in a modest number of pages.

After a brief introduction, Chapter 2 describes the tortuous path to *Chandra*'s launch. It could well be described as torture given the highs and lows over decades of development. Building any space mission is always difficult but this, as they say, was ridiculous. The final, non-trivial, step was launch in 1999 July *via* the Space Shuttle. Just to add to the excitement, the first launch attempt was aborted with ten seconds to go (proving that whatever they pay astronauts, it's not enough). A second launch attempt was stopped by bad weather, until finally a successful take-off. Following a few weeks to get *Chandra* into its required high elliptical orbit came first light. And what light! The stunning image of the Cassiopeia A SNR still takes my breath away. This success was followed by concern as the effects of radiation damage on the detectors became apparent over subsequent months. Fortunately, operational changes have helped mitigate those effects. Further changes have continued as the mission team take good care of their venerable spacecraft. *Chandra* is another reminder of how much astronomers owe to those who care for and run missions.

The rest of the book is a journey through high-energy astrophysics. Chapter 3 provides a useful overview of how to make X-rays, followed by seven science chapters. As a general-purpose observatory, *Chandra* has made a major impact in many areas of astrophysics. Some of these were fairly predictable, such as resolving SNR and clusters of stars and galaxies, and probing the physics of compact objects ranging from X-ray binaries to distant AGN, and so on. Other topics were perhaps less predictable when the original mission proposal was being developed. For me reading about the emission from Solar System objects, such as Jupiter's aurorae, was fascinating. The images of AGN jets are also truly amazing. Its spatial resolving power permits *Chandra* to detect sources with only a few photons, allowing it to complement *HST* in probing the very distant Universe. The *Chandra* spectroscopic capabilities are also well described in these science chapters, where in particular it can access emission-line diagnostics to test theories, sometimes to destruction.

A final chapter on future missions, although including one just launched, is instructive although a little depressing looking at the time-scales. The ESA-led *Athena* mission is now not due until the mid-2030s, and the possible *Lynx* mission — which would have similar spatial resolution but much more effective area than *Chandra* — is even further away, even if selected. We can only hope that NASA and ESA continue to support the current workhorses which have amply proven their value.

Overall, this is a very nice summary of the effect of *Chandra* on astrophysics. However, at a hefty £120 for a hardback, it's a lot even for a library. — Paul O'Brien.

High Energy Cosmic Rays, 3rd Edition, by Todor Stanev (Springer), 2021. Pp. 342, 24 × 16 cm. Price £119·99/$169.99 (hardbound; ISBN 978 3 030 71566 3).

Author Todor Stanev has been part of the cosmic-ray community for a bit more than 50 years, making his debut at the 11th International Cosmic Ray Conference in Budapest in 1969, as part of a trio of scientists from Bulgaria, reporting the flux of cosmic-ray muons captured by a small cluster of Geiger-Muller counters on top of Mount Musala, at 2925 metres the highest peak in the Balkans. He moved to the Bartol Research Institute at the University of Delaware in about 1980, and, judging from society memberships, thinks of himself as a bearded physicist, rather than a bearded astronomer.

Stanev published the first edition of *High Energy Cosmic Rays* in 2004, the second in 2010, and the effective cut-off date for this third edition is about 2020 September. My first thought when the volume arrived and proved to have a chapter (10) on high-energy neutrino and gamma-ray emission was that the author had had rather bad luck, because the 2021 July 23 issue of *Science* (**373**, 425) includes an article on 'Peta-electron volt gamma-ray emission from the Crab Nebula', which is clearly a high-energy photon no matter where it comes from. But in fact Stanev displays very little interest in the Crab Nebula, which was not indexed and locatable only as part of two pages on supernova remnants, dominated by SN 1987A (shamefully called 1987a, which was a comet Levy). *LHAASO* (*Large High-Altitude Air-Shower Observatory*) does, however, appear at the end of Chapter 9, which locates it at 29° N and 100° E in Sichuan province, though the name sounds as if it should be in Tibet. The altitude is 4400 metres, considerably above Mt. Musala.

There are some gems here! The preface to the first edition makes the point that most of the processes involved in the acceleration and propagation of cosmic rays are also used in their detection. Useful approximations appear for, for instance, the fall-off of CR fluxes *versus* energy (about a factor 50 for each decade up in energy). The author is clearly more interested in cosmic-ray propagation than acceleration, and the case that Galactic ones owe their energies to supernovae and their remnants is really made almost entirely on energetic grounds (though there is a good discussion of the Fermi process and shock acceleration). For the higher energy, extragalactic (on the grounds of gyro-radius) CRs, the acceleration is really only described as "the same, only bigger". On the other hand, the end point of the CR spectrum and its probable association with scattering by CMB photons gets a whole chapter (9), though you may have to resort to the references to learn why this is called the GZK effect. Each chapter, incidentally, has separate references, numbered, up to 80 or more, and the author is sufficiently modest that you must comb these to learn which items in the text come from his own work. One exception is section 10.3.1 on 'Cygnus X-3 Tales'. Stanev is still of the opinion that Cygnus X-3 was emitting some very-high-energy particles, photons, and all, at the same time its radio emission was bright and variable, and that the excitement had all just died away by the time more sensitive arrays had been built. The alternative is a mere statistical fluke.

Now, in addition to these good features, there are some major problems, most of which probably arise from this being a second revision, carried out under the usual instructions from publishers to make as few changes as possible (though there is no excuse for the totally inadequate index!). An *IceCube** White Paper is said (p. 330) to have appeared "this summer".

Some problems arise from imperfect proof reading and the author's not being a native speaker of English. Page 326, for instance, tells us "The deployment of *IceCube* ended in December 2010 and it became taking data in the beginning of 1011." There of course one knows what was meant. I am not so sure about the following from p. 328: "As a result of the two dimensional (energy and penetrating angle) fit of the muon flux was the neutrino cross section at energies reaching 106 GeV." The largest disconnect also concerns cosmic neutrinos. The predictions and Davis experiment begin on page 51; we are left hanging "with the latest publications by the end of 2001" and an inserted paragraph reporting the 2020 November Borexino observation of solar neutrinos from the CNO cycle ("claimed" says Stanev, without explaining his doubts). Finally around page 172 we meet Bruno Pontecorvo (neutrino oscillations) and MSW (Mikheev, Smirnov, and Wolfenstein, enhanced neutrino oscillations in the presence of matter), though even there one has to carry with one the detail that the Davis experiment was sensitive only to electron neutrinos.

* *IceCube* is a high-energy-neutrino detector that makes use of the clarity and scattering properties of Antarctic ice. Stanev is a member of the collaboration, which is headed by Francis Halzen at the University of Michigan.

Lots of references in each chapter, but one would really have liked more; for instance, p. 258 says that the highest energy photon seen from a gamma-ray burst has been 20 GeV. Seen by which detector and when, one is left wondering.

On balance, therefore, a volume that would be useful as part of a group reference library, for instance, when you need to make up homework problems about (very) high-energy astrophysics; but not easy to read without a good deal of background. — VIRGINIA TRIMBLE.

Galaxy Evolution and Feedback across Different Environments, edited by Thaisa Storchi Bergmann, William Forman, Roderick Overzier & Rogério Riffel (Cambridge University Press), 2020. Pp. 494, 25 × 18 cm. Price £98/$130 (hardbound; ISBN 978 1 108 49068 9).

This hefty volume, weighing in at virtually 500 pages, is the Proceedings of IAU Symposium 359, which was held in Brazil in 2020 March with the aim of bringing together "the AGN and galaxy evolution science communities". As usual, it is a mixture of invited reviews of six to ten pages and a large number of short contributions of two or three pages; according to the Preface there are 118 in total. Many are by Brazilian or other South American post-docs and post-graduate students whose work may otherwise go under the radar. Topics included are as would be expected under the umbrella of 'Feedback' and cover a lot of ground. Many of the contributions, though, discuss work already published elsewhere. Depending on what you are looking for, this is either good as it provides a convenient pointer to recent papers, or disappointing as there is less which is completely new. Nevertheless, the final discussion session of the meeting is an intriguing one, as it posed 25 questions relevant to the theme of the symposium and invited participants to attempt to answer them. If you work in the galaxy-evolution field this is certainly worth looking at in your library, but you probably won't want to buy your own copy. — STEVE PHILLIPPS.

Fundamentals of Astrophysics, by Stan Owocki (Cambridge University Press), 2021. Pp. 290, 24·5 × 17 cm. Price £34·99/$44·99 (paperback; ISBN 978 1 108 94812 8).

Highly polished astronomy books designed for the large, and presumably lucrative, US 'astronomy for poets' market abound; this neat little volume is one of relatively few to address the more technically demanding 'astrophysics for science students' readership.

The book's coverage is strikingly extensive, especially given its size; major sections cover 'Stellar Properties' (somewhat broader in scope than might be supposed), 'Stellar Structure and Evolution', 'Interstellar Medium and Formation of Stars and Planets', 'Our Milky Way and Other Galaxies', and 'Cosmology'. The 33 bite-size chapters (and four slightly more technical appendices) appear to cover pretty much all the basics; for example, just opening a few pages at random I find discussions of degeneracy, gravitational lensing, cosmological eras, and the 'ice line'. This selection should underscore that this is a book on *astrophysics*, not astronomy, but it's no less readable for that.

Developed from a course taught not only to physicists, but also to engineers, biologists, and computer scientists, only a modest degree of comfort with basic maths is required to get the most out of it. Indeed, one of the book's attractions is how really quite simple equations — I guess they may average perhaps one a page — are used to illuminate the key physics, without getting bogged down in obfuscating detail or derivations. I can easily imagine 1st- or 2nd-year science undergrads getting (and benefitting from) this volume, and going on to keep hold of it through postgraduate work as a handy go-to for a quick refresher on topics outside their research focus. And all the hallmarks of CUP's best production standards are here, so the book is a pleasure to hold and to look at, with well-chosen colour illustrations and figures used extensively throughout.

While the level and content of the book don't really map directly onto typical single courses in UK universities, the structure readily lends itself to a 'pick and mix' approach. Lecturers will particularly appreciate the exceptionally good sets of questions/exercises that accompany each chapter (and may well find the book worth getting for these alone), skilfully crafted to test understanding at a range of levels. Amateurs looking for a slightly deeper understanding than is afforded by the average astronomy text will also find it accessible, interesting, and informative. Warmly recommended. — Ian D. Howarth.

Introduction to Stellar Dynamics, by Luca Ciotti (Cambridge University Press), 2021. Pp. 347, 25 × 17·5 cm. Price £49·99/$64·99 (hardbound; ISBN 978 1 107 00153 4).

This text is notable for its clarity and rigour. It would be perfect for a course directed at mathematically-minded students, from the second year of undergraduate study on, and individuals could use it for self-study. The exposition is very clear, with chapters and sections starting with nice overviews of what's about to be accomplished, but it's also challenging — the reader is regularly challenged to fill in essential working, often by reference to a problem at the chapter's end. Concepts are laid out with a level of clarity and rigour that one associates more with mathematics than physics, yet the discussion never seems fussy or pedantic. Good students will really appreciate this.

The material is divided into 14 chapters split over three sections. These cover much of the material in Chapters 1–4 of the much longer graduate text by Binney & Tremaine. Two short chapters introduce the essentials of two-body relaxation and dynamical friction. Advanced topics such as action integrals, normal modes, and stability, and thus the dynamics of stellar discs are avoided. The author has excluded these exciting topics in order to cover classical topics in a satisfying, even deep way. He succeeds to the extent that even aficionados of stellar dynamics will enjoy spending time with this book and come away better informed.

This is also a scholarly book. The literature is extensively, yet selectively, cited from recent times right back to the 18th Century as appropriate. Hence the book will make it easy for a newcomer to the field to progress to the research frontier. In this respect the book is timely because by transforming the quantity and quality of the data we have on the motions of stars, the *Gaia* mission is currently placing demands on the science of stellar dynamics that will be met only when that science has been materially extended. — James Binney.

From Crust to Core: A Chronicle of Deep Carbon Science, by Simon Mitton (Cambridge University Press), 2021. Pp. 363, 23·5 × 15·5 cm. Price £34·99 (hardbound; ISBN 978 1 108 42669 5).

This is a nice, readable book printed on good-quality paper. It is a fun read and to be recommended. Running to 15 chapters, it is a fairly substantial work. Most of the book is an overview of the history of Earth science, the subject's roots and how it emerged to become a science, with emphasis on the individuals who contributed. This history may be traced as far back as Eratosthenes and his work on measuring Earth's circumference around 240 BC. The narrative goes on, through Chapter 11, to trace the careers and contributions of a steady stream of frontiersmen who developed the subject into the body of data and understanding that today comprises Earth science. The book reviews the early exploitation of geological resources, the work of founders of the subject such as Smith, Hutton, Darwin, and their contemporaries, and on up to Wegener, Holmes, and the geophysicists, many of whom are still alive, who developed plate-tectonic theory. At Chapter 12 the focus begins to shift to carbon. The distribution of carbon within Earth is briefly described, along with how carbon moves around, the critical compound carbon dioxide, and the isotopes of carbon. A subsequent chapter deals with diamonds, and this is a particularly good read. The book ends by telling the story of the discovery of endolithic life, the search for life deep in Earth's crust, and life at hydrothermal vents. My main criticism of the book is that the title seems inappropriate, as the book mostly focusses on the history and development of Earth science from its early beginnings, and its emergence as a subject in its own right. It could equally well have been titled 'From Darkness to Light: A chronicle of the emergence of Earth Science'. With this caveat, I recommend this book as delivering an enriching contextual narrative of the development of the subject that is well suited to basic background reading for all aspiring Earth scientists.— Gillian R. Foulger.

Other Books Received

Contemporary Kinetic Theory of Matter, by J. R. Dorfman, Henk van Beijeren & T. R. Kirkpatrick (Cambridge University Press), 2021. Pp. 631, 25 × 17·5 cm. Price £145/$190 (hardbound; ISBN 978 0 521 89547 7).

This substantial volume provides a detailed mathematical framework for the qualitative treatment of non-equilibrium processes in classical and quantum fluids, including those found in astrophysical situations.

Here and There

THE LONG MILLENNIUM

The works of Ptolemy in the applied mathematical sciences were the foundation of astronomy, astrology, optics, harmonics, and cartography in the Mediterranean, Near East, and Europe for 15,000 years, until the early 17th century. — *Journal for the History of Astronomy*, **52**, 104, 2021.