MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2014 December 12 at 16^h 00^m
in the Geological Society Lecture Theatre, Burlington House

M. A. BARSTOW, *President*
in the Chair

The President. To begin, I am afraid I have some sad news: to announce the recent deaths of Russ Evans and Don Anderson. Professor Russ Evans was born in 1949, was elected a Fellow in April 1978, and died at the beginning of this month. He was *GJI* Editor 1996–1998 and *GJI* Editor-in-Chief 1999–2006. Don Anderson was an American geophysicist who received the 1998 RAS 'G' Gold Medal. He was born in 1933 and he sadly died also at the beginning of this month. Can I ask you to stand for a minute in silence? Thank you.

On to the formal programme. We have three talks this afternoon, including two from Winton Capital award-winners. I would like to take this opportunity to thank Winton Capital for their support of this award. It's nice to have sponsorship for recognizing the younger members of our disciplines. The first talk will be given by Chris Davies from the Scripps Institution of Oceanography: 'Powering the heat engine in Earth's core'. Let us congratulate him on his award. [Applause.]

Dr. C. Davies. Thank you, Martin, for the introduction. I would also like to thank the RAS and Winton Capital for this award and for inviting me to share my work with you today. The topic of this talk is the energetics of Earth's liquid core, one of the most remote regions of our planet. In particular, I will focus on the thermal and chemical evolution of the core, starting at the present day and going back to the time when the core–mantle system first formed billions of years ago. I will explain why I believe this is an important problem, and present a model of core evolution that would have been considered standard until about 2012. I will then present some significant revisions to that model that have arisen in the past two years.

The liquid core is located some 2900 km below Earth's surface and is sandwiched between the lowermost mantle and the solid inner core. The liquid core is composed primarily of iron and nickel together with some lighter elements that will be specified later. The main product of the core is

our planetary magnetic field, which is generated by a so-called dynamo process that converts kinetic energy of the moving iron into magnetic energy. The fluid motion is vigorous and turbulent. Conceptually we imagine fluid twisting, stretching, and folding magnetic-field lines: these inductive processes defeat electrical resistance and sustain the field we observe at Earth's surface. Energy sources are clearly needed to maintain the motion. The standard picture states that the energy sources derive from cooling of the core by the overlying mantle. The mantle extracts heat from the core, which sets up thermal and chemical buoyancy forces that drive the motion that maintains the field. These buoyancy sources are the focus of this talk.

I will give three reasons for studying the evolution of Earth's core. The first is to understand the generation of the geomagnetic field. On decadal time-scales there are sufficient data to construct global maps of the magnetic-field morphology and its time variations. For example, the radial component of the magnetic field from a recent satellite model (CHAOS4), when continued downward from Earth's surface to the core–mantle boundary (CMB), shows a complex pattern of intense flux patches superimposed on the dominant dipole configuration. On millennial time-scales there are not sufficient data to construct global field models, but time variations of the dipole field can be constrained. The PADM2M 2-Myr model of the dipole moment shows factor 2–3 amplitude variations during that period and also highlights times when the field reversed polarity. On even longer time-scales the data show that the field has existed for at least the past 3·45 Gyr. The key issue is then to establish the conditions in Earth's core that have maintained a strong and reversing magnetic field for the last 3·45 billion years.

The second reason to study core evolution is because it ties to the evolution of the whole planet. The total heat flow across Earth's surface today is estimated at 46 ± 3 TW, of which an estimated 5–15 TW is flowing across the CMB. One third of Earth's total heat flow is a significant amount, but CMB heat flow is hard to constrain, hence the large error bars. An independent estimate of CMB heat flow can be derived from our knowledge that the geomagnetic field has existed for 3·5 Gyr: the CMB heat flow must be high enough to power the dynamo for that period. Studying core evolution allows us to constrain CMB heat flow not just today, but over the last 3·5 billion years.

The final reason for studying core evolution is related to the solid inner core. The inner core boundary (ICB) is located where the ambient core temperature profile T_a intersects the melting temperature of the liquid-iron mixture, T_m. In early times T_a exceeded T_m everywhere; there was no inner core. Because T_m increases with pressure and is steeper than T_a, the inner core grows from Earth's centre outward as the planet cools. In the top $\sim$ 100 km of the inner core, the western hemisphere is seismically slower than the eastern hemisphere; the innermost few-hundred km of the inner core may also be seismically distinct. Unravelling this striking heterogeneity depends crucially on the time-scale for inner-core growth, and hence the evolution of the core as a whole.

The reason to study core evolution now is due to recent calculations of the thermal conductivity, k, of liquid-iron mixtures. Until 2012 most estimates of k were obtained by extrapolating from experimental measurements conducted at much lower pressure–temperature conditions than those pertaining in Earth's core (pressure varies between 135 and 330 GPa and the temperature is several thousand Kelvin). Those studies found k in the range 20–50 W/m/K with little depth variation. Recently, k has been calculated at core pressure–temperature conditions for the first time using computational mineral-physics

methods based on Density Functional Theory. These calculations show that k at the CMB is 2–3 times higher than previous estimates and increases by a factor of 1·5 with increasing depth. These results have been verified by at least three different groups using different models and so a key question is: how does a higher value of k affect models of core evolution?

Core evolution is modelled by gross thermodynamics, not through numerical simulation of detailed flow and field patterns. We assume that convection is sufficiently vigorous to maintain the core in a well-mixed and chemically uniform state and seek the time evolution of this state. The idea is to model the core as a heat engine. There is some input energy, derived from the CMB heat flow Q, and the core energy budget determines the useful work done by the heat engine, which is related to the magnetic field generated by the dynamo. The core is not a perfect heat engine and so there will be some dissipative effects, *e.g.*, due to thermal conduction. The key question is: what conditions are needed to maintain the geomagnetic field for the past 3·5 billion years?

To calculate the core energy budget we apply the first law of thermodynamics, which in this context states that the heat sources inside the core balance the heat extracted across the CMB, Q. Note that Q is determined by mantle processes, not core processes. There are four dominant heat sources: (*i*) Q_R, the heat produced by any radiogenic elements; (*ii*) Q_S, the heat energy available because the core is cooling from a hot primordial state; (*iii*) Q_L, latent heat released by freezing the solid inner core; and (*iv*) Q_G, gravitational energy arising because light elements partition preferentially into the liquid phase upon freezing. The energy balance is then

$$Q = Q_S + Q_L + Q_G + Q_R = A dT_{cmb}/dt + Q_R.$$

The first three terms are proportional to the core cooling rate, dT_{cmb}/dt: faster cooling corresponds to higher CMB heat flows as expected. This equation does not contain the magnetic field, because magnetic energy is dissipated inside the core. To account for dissipative processes we must use the second law of thermodynamics to obtain an entropy balance:

$$E_A(k) + E_J = E_S + E_L + E_G + E_R = B dT_{cmb}/dt + E_R.$$

In this equation, each energy source has an associated entropy, which essentially describes its thermodynamic efficiency. The new terms on the left-hand side are positive. $E_A(k)$ is the entropy due to thermal conduction: it depends on the thermal conductivity k. I will refer to E_J as the dynamo entropy: it represents the dissipation that must be accomplished to sustain a given magnetic field. Note that the new high k values increase E_A, and hence decrease E_J, all other aspects being equal: higher k leads to a less-efficient dynamo. Note also that these equations allow us to relate the input to the core heat engine, Q, to the useful work, E_J, through the core cooling rate dT_{cmb}/dt. The terms A and B are integrals that depend on the material properties of the core.

The main uncertainty in estimating A and B arises from the density jump $\Delta\rho$ at the ICB. The inner core is denser than the outer core, partly due to the phase change and partly because the outer core is relatively enriched in lighter elements. $\Delta\rho$ is therefore the primary constraint on core chemical composition; unfortunately the best estimate is $\Delta\rho = 0.8 \pm 0.2$ g cm^{-3}. I will use the Fe–Si–O core-chemistry model, which has been well studied. Changing $\Delta\rho$ from 0·6 g cm^{-3} to 1·0 g cm^{-3} increases the core O content from 0·08 to 0·17 and decreases the core Si content from 0·1 to 0·02 in order to preserve the mass of the core, which is well-known. Increasing $\Delta\rho$ also slightly changes the

conductivity and reduces the core temperature everywhere because adding light elements depresses the melting temperature. I will use this variation in $\Delta\rho$ to demonstrate the uncertainty in model results.

Results for the present-day core energy budget are expressed by relating Q and E_J. Estimates of Q are in the range 5–15 TW. E_J is hard to estimate; a reasonable value obtained by combining numerical and theoretical calculations is 4 MW/K. I first consider models with $k = 28$ W/m/K, an established value in the literature prior to 2012. There are two basic findings: (i) E_J is positive for all values of Q, (ii) generating a magnetic field with 4 MW/K of associated entropy requires Q in the range 5·5–7 TW depending on $\Delta\rho$. With the new (higher) values of k we find that: (i) E_J is positive if $Q > 5\cdot5$–7·5 TW, (ii) generating a magnetic field with 4 MW/K of associated entropy requires $Q > 9$–13 TW. The dynamo is much less efficient with higher conductivity. The fact that Earth possesses a magnetic field places a strong minimum bound on Q of 5·5–7·5 TW because E_J must be positive.

Results for core-evolution models are summarized in terms of the inner-core age, the core temperature at 3·5 Gyr, $T_{3\cdot5\mathrm{Gyr}}$, and the CMB heat flow at 3·5 Gyr, $Q_{3\cdot5\mathrm{Gyr}}$. Present estimates for the lower-mantle solidus span the range 4150 ± 150 K; a $T_{3\cdot5\mathrm{Gyr}}$ above that value suggests partial melting of the lowermost mantle in the past. Both Q and E_J are both poorly known in the past. We start by considering models with $E_J = 0$ for all time, which give the slowest core cooling rate, oldest inner-core age, lowest CMB heat flows, and coolest early core. These models are end-member scenarios; in reality the core will cool faster, the inner core is younger, *etc*. With $k = 28$ W/m/K we find that (i) the inner core is over 3·5 billion years old, older than the magnetic field itself, (ii) $T_{3\cdot5\mathrm{Gyr}}$ is below the estimated lower-mantle solidus, implying that the lowermost mantle never melted, (iii) Q is only 5 TW, which can easily be supplied by mantle convection. With the new (high) values of k we find that (i) the inner-core age is between 700 and 1200 Myr, (ii) $T_{3\cdot5\mathrm{Gyr}}$ is between 4600 and 5300 K, (iii) and $Q_{3\cdot5\mathrm{Gyr}}$ is between 17 and 21 TW. Taking a more reasonable (positive) value for E_J gives $\tau_{\mathrm{ic}} < 500$ Myrs, $T_{3\cdot5\mathrm{Gyr}} > 4900$ K, and $Q_{3\cdot5\mathrm{Gyr}} > 18$ TW regardless of $\Delta\rho$.

In summary, revised estimates of the thermal conductivity of liquid-iron mixtures, calculated at core temperatures and pressures for the first time, have significantly altered the standard picture of core evolution. At present, a minimum of 5·5–7·5 TW of heat must be leaving the core in order to generate a magnetic field; the real value is likely to be more like 12 TW, which is a significant fraction (one quarter) of the total heat leaving the Earth. The inner core is a very young feature of the planet, having grown to its present size in 500 Myr rather than the conventional estimate of 1 Gyr. In early times the core was so hot that the lowermost mantle must have been partially molten unless the lower-mantle solidus has been strongly underestimated. Finally, CMB heat flows that perhaps exceeded one third of the present-day value were needed to maintain the early core dynamo. Those values are so high that one might wonder whether cooling alone was sufficient to power the early dynamo. That fundamental question is currently the subject of intensive research.

I would like to end by thanking my collaborators Dario Alfe, David Gubbins, Monica Pozzo, and Francis Nimmo.

The President. We have time for a few questions. I'd just like to start very quickly. If you had a different model for the magnetic field would you get the same size of field as we currently have? To clarify, I mean if the field is being generated in the mantle, not the core.

Dr. Davies. Yes, you would. That was one of the problems with the model.

You have to match a reasonable field strength. You have to appeal to fairly drastic electrical conductivity.

Mr. H. Regnart. At what rate is it now reckoned that the inner solid core is growing radially?

Dr. Davies. The standard number is 0·3 mm per year, but now that must be at least twice that.

Dr. A. Chapman. Just a small point of observation: it was Edmond Halley in the late 17th Century who suggested that the Earth's inner rotation was due to a number of rotating metallic spheres. He suggested that they produced both the magnetic field and westward drift. That was a brilliant idea for *circa* 1695 and not too far from the truth!

Mr. J. C. Taylor. I don't think you mentioned the still-contentious super-rotation of the inner core. What would your view on that be, and could that be an influence on outer-core convection?

Dr. Davies. One of the latest studies on inner-core rotation is that it's not a super-rotator any more, it's a shuffle. Apparently it's been rocking back and forth. In some sense, we always expected it would do that because it should be strongly gravitationally locked to the mantle. It shouldn't be just zooming round and round. From my understanding, since the original 1996 paper on super-rotation, the super-rotation rate has been getting slower and slower until it gets close to zero. And recently it's been suggested it goes both westward and eastward over time. There was work recently suggesting that you could produce the westward drift through electromagnetic torques that are a response to the inner core shuffling around.

The President. I don't see any more burning questions, so let's thank our speaker again. [Applause.] The astronomy talk from the pair of the Winton Capital award-winners will be given by Benjamin Joachimi from University College London, who received his certificate at NAM. He will be speaking on 'Cosmology with galaxy shapes'.

Dr. B. Joachimi. Large galaxy surveys produce millions or, in future, billions of faint-galaxy detections whose morphologies can be analyzed to yield powerful probes of structure formation as well as galaxy evolution, by exploiting weak gravitational-lensing effects. In my presentation I will highlight two areas of research in this field, one that investigates the major astrophysical systematic of weak lensing and one that establishes the fundamentals of quantifying the statistical errors of large-scale-structure measurements.

Gravitational lensing is an effect predicted by General Relativity, and indeed provided the first observational verification of Einstein's theory. Light travels along geodesics, which deviate from straight lines in a curved space–time. As a consequence, in the vicinity of a large mass like a galaxy cluster, light rays are bent such that their paths resemble those through a magnifying glass in optics — the cluster acts as a gravitational lens. Close to the lens, the images of background objects are magnified and distorted into spectacular, tangentially aligned arcs. Further out and away from this régime of 'strong' lensing, background galaxies are still weakly sheared, *i.e.*, a circular image is mapped into an ellipse, but this effect remains at the percent level of the intrinsic ellipticity of galaxies and is thus unobservable for an individual galaxy. However, by averaging over a large number of galaxies, it is possible to retrieve a measurement of gravitational shear. The use of statistics to uncover lensing effects defines the realm of weak lensing.

Gravitational light deflection also acts on the images of distant field galaxies whose light is continuously deflected by the large-scale matter distribution

between those sources and Earth. The resulting gravitational shear is a sensitive probe of the properties of the intervening large-scale matter distribution (and this includes all gravitating matter) and its evolution, as well as the geometry of the Universe *via* the distances between the sources, the various lenses, and the Earth. This so-called cosmic shear can be employed to constrain properties of dark energy and test the predictions of Einstein's gravity on cosmological scales. The same data also yield maps of the dark matter and measure its distribution around samples of individual galaxies. Recent examples of those measurements can be found in the publications of the *CFHTLenS* collaboration. Forthcoming projects like the ESA *Euclid* satellite, the *Large Synoptic Survey Telescope*, and the *Square Kilometre Array* in the radio régime will feature weak lensing as a key probe and will produce measurements of unprecedented quality and statistical power.

Such high-precision data necessitate a thorough understanding of potential systematic effects, and methods to control and eliminate them. This is particularly true for intrinsic alignments of galaxy shapes which constitute the limiting astrophysical systematic of cosmic shear. Cosmic-shear statistics are usually based on the correlation of the measured ellipticities of pairs of galaxies. The measured ellipticity is composed of the intrinsic galaxy ellipticity plus a small modification by gravitational shear. The latter is recovered in the correlation if one assumes that the intrinsic ellipticity of one galaxy is uncorrelated with those of other galaxies. However, galaxies are generally not randomly orientated on the sky, but do show a tendency to align themselves. These alignments mimic the cosmic-shear signal and can lead to catastrophic biasses on cosmological parameters if ignored.

Our understanding of galaxy alignments is still limited. The simple models available are generally based on the tidal-torquing and tidal-stretching paradigms, *i.e.*, it is assumed that the angular momenta of galaxy discs, or the forms of stellar orbits in spheroidal components, are coupled to the matter distribution in the galaxy's environment by tidal forces, thus leading to correlations between galaxy shapes over megaparsec distances. Such alignments have been seen with high significance in *N*-body simulations. Less clear is the link between the angular momenta and shapes of the dark-matter and the luminous-galaxy components, which we have only recently begun to quantify in large hydrodynamic simulations. We extended well-established semi-analytic models of galaxy formation by simple models of galaxy ellipticity and its alignment with the underlying halo as an efficient means to incorporate results from hydrodynamic simulations and effective prescriptions of 'sub-grid' physics.

Using the rich galaxy samples supplied by the Sloan Digital Sky Survey, particularly for relatively bright, early-type galaxies, intrinsic alignments have been detected with high significance. We demonstrated that simple, in part phenomenological, models describe a wide range of galaxy samples well, *e.g.*, finding that the strength of galaxy alignments increases linearly with galaxy luminosity. There is unfortunately no clear picture for the typically fainter, higher-redshift, and disc-dominated-galaxy samples characteristic of cosmic-shear surveys. For those galaxies we lack suitable data-sets, and those available have not yielded clear detections to date. In light of this it is paramount to develop mitigation strategies that have a minimal dependence on model assumptions. We showed that cosmic-shear data are able to self-calibrate intrinsic alignment signals by additionally exploiting galaxy clustering and the cross-correlations between galaxy positions and gravitational shears, signals that can be obtained without any extra observations. With reasonable priors

from physically motivated intrinsic-alignment models and external constraints on their free parameters, parameters of dark matter and dark energy may eventually be assigned smaller statistical errors in such a joint analysis than for a pure weak-lensing signal.

While the first topic of my talk has strong links to extragalactic astrophysics, the second one is a purely statistical issue, yet it is equally relevant to a successful exploitation of large-scale surveys. For the long list of statistics that can be extracted from these surveys we usually do not have good models of their errors and cross-correlations, encoded in their covariance matrix. Hence, one resorts to creating many realizations of mock data-sets from N-body simulations and estimates the covariance matrix from them. Alternatively, one can employ resampling techniques like the bootstrap or jack-knife to create quasi-independent realizations from the actual data. In either case one has a finite number of samples to compute the covariance, so the estimate will be noisy. Usually, this estimate needs to be inverted for likelihood or regression analysis, a non-linear process. In much of the physical sciences, the standard maximum-likelihood sample-covariance estimator is used for these purposes without questioning its properties or performance.

This generally leads to biassed, and also inefficient, inference, as the inverse of the sample covariance is a biassed estimator of the inverse covariance. This fact has been known in the statistical community since at least the 1960s, and for Gaussian-distributed data this bias is known analytically (by analyzing the moments of an inverse Wishart distribution). If many realizations are available, the noise in the covariance, and thus the bias in its inverse, is small. As the number of realizations approaches the size of the data vector, the bias diverges, *i.e.*, the covariance becomes singular and cannot be inverted any more. Even if this bias can be corrected for by its analytic expression, the variance on the inverse covariance estimate still diverges. In a recent publication we have quantified these issues and propagated them into cosmological-parameter constraints, demonstrating that noise in the data covariance leads to biasses and additional variance in the statistical errors on cosmological parameters.

On the basis of those results we derived requirements on the minimum number of N-body simulations (or resamples) needed for covariance estimation to avoid adverse effects on cosmological parameters. For the large data-sets of future surveys, these requirements would be challenging to meet. However, in this situation the standard sample covariance estimator is a very poor, *i.e.*, inefficient, choice of estimator and should be avoided altogether. A lot of work on covariance estimators has been done in statistics in the past decades. As an example, I outlined the performance of a linear-shrinkage estimator which is composed of a linear combination of the sample covariance and a 'target', *i.e.*, a model that contains (possibly approximate) prior knowledge on the form of the covariance. An analytic estimator of the optimal linear combination of the two components exists, which will lean towards the sample covariance if the noise is low or the target a bad approximation of the data, but will otherwise 'shrink' the covariance estimate towards the target and thus beat down noise. Depending on the quality of the target, this shrinkage estimator can dramatically reduce the bias and variance of the inverse covariance and enable a covariance estimation even if the number of realizations (each of which could correspond to a costly N-body simulation) is smaller than the number of data points one would like to include in the likelihood analysis.

These topics are but two examples of the challenges we face on the route to precise and accurate cosmology with galaxy shapes and large-scale-structure

surveys. As I hope to have illustrated, these challenges may not be limited to a tedious hunt for systematics but can constitute interesting and fruitful research themes themselves, with exciting links to galaxy formation and evolution, as well as statistics.

The President. Question time.

A Fellow. You didn't mention the possibility of correlations they found from telescope image distortions; does that mean they are under control?

Dr. Joachimi. No. It's just because I don't have time! We want to measure the shapes of galaxies that maybe cover ten pixels. If your telescope optics and camera generate slight distortions, that messes this up badly. Modelling the point-spread function of the telescope including the ellipticity induced by this system is of paramount importance. Measuring it from the ground is even more challenging as you have the atmospherics which tend to blur images and make them more circular. If you have telescope jitter as well, it becomes even more complicated. It's why we expect the best measurements to be from space. That is the primary case for having the *Euclid* satellite.

Dr. I. Mandel. You're wondering about chance alignments, or alignments because of local over- or under-densities. Presumably, locally, it looks like a lensing signature? Globally, there's a difference: the lensing signature should have a cross shape and this alignment due to over- and under-density should have a divergence shape. So can't you use that global information to tell the difference?

Dr. Joachimi. Not as such. The cross correlation between lensing and intrinsic alignment actually turns out to be an anti-correlation. This reduces the total signal, but does not help us to differentiate between the signals. What does help us is the different redshift dependence. This is the only model-independent way to tell lensing and intrinsic alignments apart. You are referring to an E/B-mode decomposition analogous to polarization data, which we do indeed do on weak-lensing data, but both the lensing and relevant intrinsic-alignment signals do not generate B-modes to first order, so this cannot be used to distinguish them.

Professor J. Barrow. Does a bootstrap resampling of your data-set help you with your starter problem? You don't need to make assumptions about Gaussianity and so forth.

Dr. Joachimi. Absolutely. The problem is that we have very-long-range correlation across the sky. We need the largest modes of the power of the distribution all across the sky. Therefore we never have truly independent patches of sky that you can use for bootstrapping. The jack-knife seems to be a bit more stable, but again you get problems due to large-scale correlations.

The President. Thank you. [Applause.]

Our final talk is the James Dungey Lecture. I shall read the citation. Professor Sandra Chapman has made outstanding contributions to our understanding of the solar wind and the magnetosphere. Among her many achievements, she has led landmark research on turbulence in the solar wind and nonlinear dynamics in the magnetotail.

Her research career is strongly interdisciplinary, spanning space- and laboratory-plasma physics, climate, and neuroscience. She contributed to the data analysis and modelling of turbulence both in space and magnetically confined fusion plasmas, as well as focussing on wave–particle interactions, plasma acceleration, and heating.

She has demonstrated a strong commitment to engaging with the general public, most recently through a project exploring how scientific ideas can be communicated through art. She is an outstanding speaker who can draw on

the application of nonlinear and complex-systems concepts to a wide variety of fields, even outside physics. For these reasons, Professor Chapman is awarded the Royal Astronomical Society's James Dungey Lectureship. [Applause.] Her talk today is entitled, 'Reconnection and turbulence: thinking in pictures'.

Professor Sandra Chapman. [It is expected that a summary of this Lecture will appear in a future issue of *Astronomy & Geophysics*.]

The President. Time for questions.

A Fellow. Regarding your partial variance of increments (*PVI*) method for determining whether you have reconnection, how do you distinguish reconnection from a rotational discontinuity — an angular jump in the direction of the magnetic field?

Professor S. Chapman. Well, *PVI* alone doesn't distinguish those things. They're distinguished by people looking at the reconnection events.

The Fellow. You claim to get a very good level of agreement between *PVI* and reconnection.

Professor S. Chapman. You take the *PVI* then look and identify the reconnection events in the usual way. Then you ask, do these things turn up when you see large *PVI*? It's more of a statistical correlation. What you're asking for, you can't do, but it's a nice start.

Dr. G. Q. G. Stanley. Many years ago, you gave a speech to the Society where you were using sugar as a model and it was cascading. Do you still use the cascade in your models?

Professor S. Chapman. It's a bit tricky when you put magnetic fields in. The fluid idea is that you drive it on a large scale until you produce large eddies and they break down into smaller-scale eddies. When you put the magnetic field and the dynamics in, it becomes rather more interesting. A possible picture, in terms of kinetic plasmas, is that you want to stir up the phase space of the particles. A nice way to think of it is that you have streaming particles and they interact *via* the wave field. They create smaller and smaller scales in the phase space. There are no collisions so how do you increase entropy? However, if you keep winding it up, the scales become so small eventually they do thermalize. That is how you get from structure and magnetic fields to heating. It's a tricky problem: how do you heat a plasma when there are no collisions? You have to create these fine scales.

The President. Can we thank Sandra again for a great lecture? [Applause.] I'd like to wish everyone a happy Christmas and a peaceful New Year. I can invite you to seasonal drinks in the RAS library immediately following this meeting. Finally, the next A&G RAS meeting will be on Friday, 2015 January 9.

SPECTROSCOPIC BINARY ORBITS
FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 242: HD 471, HD 3791, HD 4703, AND HD 8739

By R. F. Griffin
Cambridge Observatories

As in many of the recent papers in this series, orbits are offered for four spectroscopic binaries. The ones in this paper are all in a small area of sky between 0 and 1½ hours RA and between 18° and 30° declination. The spectroscopic-binary nature of all except HD 471 came to light in observations of a presently unpublished extension to Area 11 of the 'Clube Selected Areas' programme.

HD 471 is an 8^m main-sequence star, about type G0, in Pegasus; it has an orbit with a modest eccentricity of 0·3 and a period of 463 days. About 30″ away from it there is an $11½^m$ c.p.m. companion, whose radial-velocity (recently, at least) accords reasonably well with the γ-velocity of the primary star. HD 3791 is probably of type K0 III or thereabouts; its orbit has a period of 793 days and an eccentricity similar to that of HD 471. HD 4703 is known from its parallax to be a giant, and its colour index suggests a type of about K2. The period is 951 days and the orbital eccentricity 0·56. HD 8739 was found by *Hipparcos* to be a close 'visual' binary with a separation of 0″·3; there is, however, a serious discrepancy between the *Δm* values of 2^m·94 found by *Hipparcos* itself and the 1^m·40 given by *Tycho*. Any dip that may be given in radial-velocity traces by the 'visual' secondary (which is likely to be of late-A or F type) must be permanently blended with the dip given by the K-giant brighter component, which varies over only a small range ($K < 2$ km s^{-1}). The visual system must have an orbital period of many centuries, and is not to be equated with the spectroscopic orbital motion, which has a period of about 8½ years and an eccentricity of about 0·54. No feature that could represent a signature of the spectroscopic secondary has been noticed for any of the four stars whose orbits are given here.

Introduction

The stars treated in this paper are all within a small area of sky, largely because three of them feature (as noted in the summary above) in the same observing programme that is itself confined to a set of small areas. It involves the late-type *Henry Draper Catalogue* stars in 16 areas distributed systematically (in terms of Galactic coördinates) around the sky. Some of the areas are at declinations accessible only from southern-hemisphere observing stations; only ten are observable (and one of *them* only marginally) from Cambridge, whence a lot of radial velocities of programme stars was published[1] nearly 30 years ago. The

remaining areas were observed much later, on a series of special expeditions to use the Geneva Observatory's *Coravel* spectrometer on the 61-inch Danish telescope at ESO, and *their* results were published[2] in 2006. The imbalance between the hemispheres was then reversed, not because the telescope at ESO was bigger or the site or the radial-velocity spectrometer better than those at Cambridge (although all of those differences did exist), but because the density of stars in the *Henry Draper Catalogue* in the southern hemisphere is so much higher than in the northern one. More than two-thirds of all *HD* stars are in the southern hemisphere.

That had happened quite casually. Mutually similar systems (8-inch telescopes arranged for direct photography of the sky through objective prisms) were deployed at the two observing sites — Cambridge, Massachusetts, in the northern hemisphere, and Arequipa, Peru, in the south. Each was provided with two alternative objective prisms whose respective apex angles of 5° and 13° gave dispersions differing by a factor of about three. I quote (with minor changes, in square brackets, that are warranted by the lack of appropriate context for appreciating the original wording here) from the *Introduction* to the first volume of the *Henry Draper Catalogue*[3]⋆ explaining how the extraordinary imbalance between the hemispheres came about. "It appeared that the definition was better with the prism giving the larger dispersion [at Cambridge] and with the prism giving the smaller dispersion [at Arequipa]. For this reason, the spectra of much fainter stars could be classified from the photographs taken in Arequipa, than from those taken in Cambridge." Apparently no binding instructions were given as to which dispersion was to be employed: the actual observers, who are not even identified in the introductions to the nine volumes of the *Henry Draper Catalogue*, were free to use their own discretion, which led them to use the prism that gave the better definition at the respective sites. Accordingly, fainter (and correspondingly more numerous) stars gave classifiable (if lower-dispersion) spectra on the Arequipa plates than on the Cambridge ones.

The significance of that matter in the present context is that, when all the relevant *HD* stars within the (equal) areas initially defined by the writer for the purposes of the 'Clube Selected Areas' programme had been observed, there were far more of them in the southern hemisphere, just because the *Henry Draper Catalogue* is far richer there owing to the lower dispersion of the spectra that formed its observational basis. In an effort to redress the imbalance, the northern Areas were arbitrarily re-defined, considerably enlarged, and the newly included stars were measured when observing time permitted. The originally observed[1] stars in the northern areas were also re-observed. Naturally, a number of previously unknown spectroscopic binaries was recognized, both among the original stars (which had typically been observed only two or three times in the initial investigation) and among the newly included ones. The present paper

⋆The *Introduction* is accompanied by a *Frontispiece* that reproduces a number of photographs of stellar spectra and illustrates examples of each of the major spectral classes. In the absence of an informative caption or any reference in the text beyond a mention that it is reproduced from an earlier volume[4] of the *Harvard Annals* (where we can learn that it shows slit spectra taken at a very much higher dispersion and requiring exposures of the order of an hour on first-magnitude stars), it is entirely misleading as an illustration of the sort of spectra that were classified in the *Catalogue*. The ensuing volumes of the *Henry Draper Catalogue* bear other frontispieces, consisting successively of portraits of Henry Draper; his wife; the (then recently deceased) Harvard Director Pickering; and the variation of the photographic density of the continuum in spectra of different types. It is only in the sixth volume of the *Catalogue*[5] (after the demise of Pickering and the appointment of S. I. Bailey as Acting Director at Harvard) that the *Frontispiece* finally reproduces a genuine objective-prism plate (of the higher of the two dispersions) of the sort that was used for the classifications in the *Catalogue*.

discusses three stars that fall into the latter category, in the extended Area 11, as well as HD 471, which is not far outside that extended Area.

The discussion above is not to be misconstrued as a denigration of the *Henry Draper Catalogue*, which (even as it now approaches its centenary) is without doubt a wonderful piece of work. The present writer's appreciation is demonstrated by his preferential use of it (albeit after constellation designations and the *Bright Star Catalogue*) in designating the objects discussed in the 200-odd papers in the present series, as well as in many others elsewhere. The magnitude of effort that went into the *Catalogue* is perhaps underlined by the fact that a modern effort at re-classification of the same stars [reference deliberately omitted] ground to a halt part-way through.

HD 471

If the number of stars in the *Henry Draper Catalogue* (225300) is divided by the number of stars whose orbits have been presented in the series of papers of which this one is a member (488 so far, with slight uncertainty arising more from doubt as to *what*, rather than inability, to count), one finds that the series has treated about one star for every 462 in the *HD*[*]. The subject of this present section of the present paper has the lowest *HD* number to appear in any of the titles of the series, and is seen to be remarkably close to the number by which statistically there *ought* to have been one star. What that seemingly neat arithmetic conceals, however, is that Paper 144[6] was devoted to HR 5, whose *HD* number is only 123, handsomely beating 471 for smallness! But we could try to redeem the situation by claiming that HR 5 naturally represented the first 462-star *tranche* of the *Henry Draper Catalogue*, and HD 471 is quite well placed to represent the second one. Sufficiently-troublesome people with long memories might then object that Paper 126[7] was on HD 483, and/or that Paper 170[8] treated HD 553! But the orbit that takes the ultimate prize for the smallness of the *HD* number, that of HD 1, though presented in this *Magazine*, was in a paper[9] that was not included in the present series; and the orbit of HD 7 is known to the writer but its publication is delayed, perhaps indefinitely in view of his already-advanced age, because it still has a gap of several years in phase coverage.

Descending from such semantic banter to more prosaic information, we may remark that HD 471, at about 25° north declination, is on the eastern border of Pegasus, where that constellation adjoins Andromeda. The object is about a quarter of the way down the left-hand side of the Square of Pegasus (as seen by observers in north-temperate latitudes); it is about 3°·6 almost due south of the second-magnitude B star α Andromedae, which marks the top-left corner of the Square and whose 97-day orbit was first divined by R. H. Baker[10] well over 100 years ago. Nearer to HD 471 (little more than 2° north-preceding) is the visual/spectroscopic binary system 85 Pegasi, which was shown in Paper 177[11] to be actually a triple system, though with the third component attested only by the otherwise inexcusably large mass function[†]. Despite its proximity in the

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[*]The division sum neglects the fact that a (very) few of the 488 orbits belong to stars which have no entries in the *HD*, or are only visual companions to true *HD* stars.

[†]My appeal to people who may have access to the *Hubble* telescope or to a large telescope with adaptive optics to *see* the third component directly or to measure its radial velocity seems not (yet) to have proved fruitful.

sky, 85 Peg has an *HD* number that differs from that of HD 471 by almost the maximum possible, because at the (1900) epoch of that *Catalogue* it was actually on the opposite (preceding) side of the equinoctial colure from HD 471 (it isn't *now*). The latter star was carried by precession past the colure in 1820; even at the time that it featured in the *BD*[12], in epoch-1855 coordinates, its R.A. was still less than two minutes of time. Even nearer than 85 Peg to HD 471, indeed only about 12′ north-preceding, is the 6^m K giant HR 19 (HD 417) — the first star that is not known to be at least binary to receive a mention in this paper.

HD 471 seems never to have had its spectrum classified on the MK system, so the *HD* classification[13] of G0 still 'rests on the table'. The colour index, however, in combination with the substantial proper motion (more than 0″·2 per annum) that marks the star out as a dwarf, suggests an appreciably later type, which will be shown below to be somewhat discordant with the absolute magnitude. The proper motion was determined just 100 years ago by the industrious astrometrists Porter, Yowell & Smith[14] at Cincinnati; they were able, already at that time, to call upon astrometry that had been published in no fewer than eight previous catalogues, spanning 117 years and starting with the epoch-1793 position (more than a minute of time in R.A. *before* the equinoctial colure) by Lalande[15], in whose work the star is numbered 47352 and appears on the penultimate page (p. 1184) of a great catalogue that finishes at no. 47390. It is only fair to recall that Lalande's observations[16] were reduced anew and the resulting positional precision much improved through the efforts master-minded by Baily[15] on behalf of the British Association for the Advancement of Science. A proper motion that was actually less precise than Baily's value was published in 1963 from the Lowell Observatory[17], where, however, a much fainter (11½^m) star about 30″ south-preceding was recognized as a common-proper-motion companion. The stars were given *Giclas* identifications as G130-48 and G130-47.

The proper motion of the system being large enough to encourage the expectation of a measureable parallax, the latter quantity was determined[18] for the brighter star about 50 years ago from photographs taken with the 30-inch *Thaw* refractor at the Allegheny Observatory; the value found was 0″·029 with a 'probable error' of 0″·005. The (revised[19]) *Hipparcos* value is 0″·0194 ± 0″·0014.

The *UBV* magnitudes and colours of both stars of the visual system have been measured by Eggen[20] and by Sandage & Kowal[21]. Both parties made their observations from Mt. Wilson, but whereas Eggen used the 100-inch reflector Sandage & Kowal made do with the 60-inch. Their results are set out in the informal table here:

Star	V m	$(B-V)$ m	$(U-B)$ m
Eggen[20] { A	7·77	0·68	0·15
B	11·46	1·38	1·25
Sandage[21] { A	7·79	0·65	0·16
B	11·52	1·30	1·11

Lepine & Bongiorno, in a paper[22] whose title refers to "New distant companions to known nearby stars" (a category in which the companion to HD 471, recognized[17] more than 40 years previously, could not qualify), gave the *V* magnitudes of the pair as 7·78 and 10·94; a suspicion might arise that the apparent brightening of the secondary star, by fully half a magnitude in

comparison with the earlier measures[20,21] set out just above, could have been occasioned by light from the bright star spilling into the measuring diaphragm.

The parallax of star A translates to a distance modulus of 3·56 ± 0·16 magnitudes, so its absolute magnitude must be close to +4^m·2; always provided that B really *is* at the same distance, that of B must be about +7^m·9. According to a tabulation[23] of the properties of main-sequence stars, the spectral types corresponding to those absolute magnitudes should be about F9 and K7, with uncertainties (arising largely from that of the parallax) of only about one subtype in each case. It is satisfactory to notice that the difference in the colour indices of the two stars is nearly in accord (but see the paragraph immediately below) with an expectation based on the difference in their *V* magnitudes and the assumption that they lie on the same main sequence as one another, with the same distance modulus.

It might be mentioned that HD 471 has been regarded as metal-weak, and features in papers whose titles include the words 'subdwarfs'[21,24] and 'metal-poor'[25], but actual assessments[25,26] (only photometric, however), of the star's metal abundance attribute to it a logarithmic deficiency of only about 0·15, which is not enough to vitiate significantly the relationships between its physical, photometric, and spectroscopic properties. Metal-weakness, if at all substantial, should make a late-type star appear bluer than would normally correspond to its spectral type, so it is at first sight troublesome to notice that the colour indices[20,21] of HD 471 correspond to a main-sequence type of G3 or G4 whereas the absolute magnitude would place it in the range F8–G0. The obvious way of resolving that discrepancy is to accept that HD 471 has evolved appreciably off the zero-age main sequence. The initial evolution of a solar-type star is upwards in the H–R Diagram, *viz.*, towards higher luminosity at almost constant colour index. In the Copenhagen survey[26] of 14000 F- and G-type dwarf stars in the solar neighbourhood, HD 471 is credited with an age of 14·4 × 10^9 years — a time that is at least as long as the currently supposed age of the Universe. It is plenty long enough for a star that started on the ZAMS at type G3 or G4 to have evolved to the extent of increasing its luminosity by something like half a magnitude, which is all that is needed to reconcile the best information that we have for HD 471 in respect of its luminosity, on the one hand, and its colour indices, on the other.

Astrometry, radial velocities, and orbit of HD 471

The *Hipparcos* astrometry of HD 471 (HIP 754) was noted[27] as coming from what its authors called a "stochastic solution", meaning one in which the residuals of the individual observations were significantly greater than the uncertainties of the measurements themselves. A potent source of such difficulties is of course orbital motion. A relatively small number of astrometric orbits (235) was determined in the original *Hipparcos* publication, but in many other cases the orbital motion, while recognizable as a raggedness in the parallax/proper-motion solution, was too small and/or too chaotic to lead at all readily to an orbit. However, after the large and (in the sight of many eyes) more important work on the whole *œuvre* had been completed, and enthusiasts were at leisure to see what more they could squeeze from the underlying data, Goldin & Makarov managed to retrieve some additional orbits in two papers[28,29] published in 2006 and 2007 respectively; they gave orbits first for 65 *Hipparcos* stars and then for 81 (with a large overlap of 44 with the earlier 65). It is the second paper[29] that particularly concerns us here, since the first entry in its table of orbits is
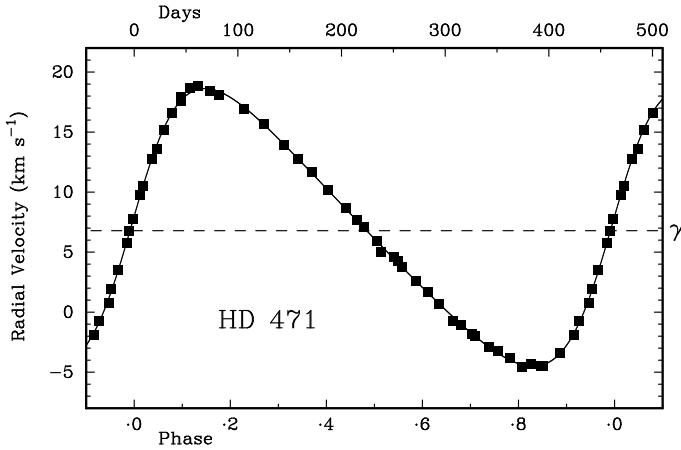
FIG. 1

The observed radial velocities of HD 471 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All the observations were made with the Cambridge *Coravel*.

that of the star of present interest — indeed, it is noted in the initial summary ('Abstract') of the paper as one of three "astrophysically interesting objects".*

The Goldin & Makarov papers have represented a fruitful source of 'new' spectroscopic binaries to engage the present writer's interest; a few of the orbits have been published, but more remain still under observation. Their orbital periods are quite moderate — since the duration of the underlying *Hipparcos* observations was only about three years, no orbits with periods much longer than that could be divined from them. The astrometric period found by Goldin & Makarov for HD 471 was 483^{+12}_{-13} days. The star features in a table of binary orbits subsequently published by Malkov *et al.*[32], where the period is given in years as 1·322382 ± 0·035592. The precision is astounding — a millionth of a year is only about half a minute. One notices, however, that despite the precision of the *numbers*, the standard error is given to five 'significant' figures, which obviously cannot be warranted. Multiplying the numbers by 365·25 to obtain the corresponding quantities in days, we find that they are 483·0000255 and 12·999978, respectively! — they are evidently derived directly from Goldin & Makarov[29] but in the course of quotation and the change of time unit from days to years their precision has allegedly been amplified by a factor of about 40 000! The eccentricity, too, was almost equally unhelpfully 'improved' from the original[29] $0·22^{+0·41}_{-0·20}$ to 0·2200.

HD 471 was placed on the writer's observing programme in the autumn of 2009, and its radial velocity has been measured 49 times with the *Coravel* spectrometer at the coudé focus of the Cambridge 36-inch reflector. The observations are set out in Table I and readily lead to the orbit whose elements will be found, along with those of the other binary stars discussed below, in Table V towards the end of this paper. The orbit is illustrated in Fig. 1. The period of about 463 days (determined to about five hours — we cannot hope to get it

*The paper also remarks that just two of the stars that feature in the table of orbits already had 'accurate spectroscopic orbits'; one of them was 6 Boo (HIP 67480), for which the present writer's 1985 orbit[30] was cited (it has since been confirmed and improved[31]).

TABLE I

Radial-velocity observations of HD 471

All the observations were made with the Cambridge Coravel.

Date (UT)		MJD	Velocity km s^{-1}	Phase	(O − C) km s^{-1}
2009 Oct.	24·99	55128·99	−3·4	0·886	+0·1
Dec.	22·81	187·81	+9·8	1·013	0·0
2010 Jan.	30·77	55226·77	+17·6	1·097	0·0
Aug.	24·13	432·13	+4·6	·540	+0·1
	28·12	436·12	+4·3	·549	+0·2
Sept.	1·10	440·10	+3·8	·557	0·0
	15·05	454·05	+2·6	·587	0·0
Oct.	7·02	476·02	+0·7	·635	0·0
	27·96	496·96	−1·1	·680	−0·1
Nov.	10·91	510·91	−2·0	·710	0·0
	23·89	523·89	−2·9	·738	0·0
2011 Jan.	14·81	55575·81	−4·5	1·850	−0·1
Sept.	13·08	817·08	+11·7	2·371	+0·2
	28·09	832·09	+10·2	·403	0·0
Oct.	16·03	850·03	+8·7	·442	+0·2
Nov.	2·01	867·01	+7·1	·478	+0·1
	17·94	882·94	+5·0	·513	−0·6
2012 Jan.	2·76	55928·76	+1·7	2·612	+0·1
	26·79	952·79	−0·7	·664	−0·3
July	23·11	56131·11	+13·6	3·048	−0·4
Aug.	15·11	154·11	+17·9	·098	+0·2
	31·14	170·14	+18·8	·133	+0·2
Sept.	12·12	182·12	+18·4	·158	−0·2
Nov.	3·00	234·00	+15·7	·270	+0·1
	21·89	252·89	+13·9	·311	−0·1
Dec.	5·82	266·82	+12·8	·341	0·0
2013 Jan.	31·77	56323·77	+7·7	3·464	+0·1
Feb.	19·77	342·77	+5·9	·505	0·0
July	10·08	483·08	−4·6	·808	−0·2
Sept.	3·07	538·07	−0·7	·926	+0·2
	15·04	550·04	+1·9	·952	+0·2
Oct.	6·01	571·01	+7·8	·998	+0·1
	15·98	580·98	+10·5	4·019	−0·1
	23·99	588·99	+12·8	·036	+0·1
Nov.	4·95	600·95	+15·2	·062	−0·2
	12·93	608·93	+16·6	·079	−0·1
	29·89	625·89	+18·7	·116	+0·4
Dec.	27·79	653·79	+18·1	·176	−0·3
2014 Jan.	20·76	56677·76	+16·9	4·228	−0·2
Aug.	29·11	898·11	−1·8	·703	0·0
Sept.	23·09	923·09	−3·2	·757	+0·2
Oct.	4·99	934·99	−3·8	·783	+0·2
	25·01	955·01	−4·3	·826	+0·2
Nov.	3·97	964·97	−4·5	·848	−0·1
Dec.	5·85	996·85	−1·9	·916	−0·2
	19·84	57010·84	+0·8	·947	−0·3
	28·80	019·80	+3·5	·966	+0·1
2015 Jan.	6·75	57028·75	+5·8	4·985	−0·2
	8·79	030·79	+6·8	·990	+0·2

to half a minute!) satisfactorily corroborates the Goldin & Makarov result from the *Hipparcos* astrometry. The astrometric amplitude, a_0, at $9 \cdot 8^{+3.9}_{-1.5}$ milliseconds of arc, is just half the parallax (though with considerable uncertainty) and could therefore be expected to correspond to half an astronomical unit — which is just what it does, since the spectroscopic value of $a_1 \sin i$ is about 70 Gm (0·47 AU) and the inclination found astrometrically is so high (74^{+9}_{-11} degrees) that $\sin i$ is little short of unity.

The orbital eccentricity is close to 0·3 and is unusually accurately determined. The mass function of 0·065 $M_\odot$ implies, if the primary star is supposed to have a mass near 1 $M_\odot$, a minimum mass of about 0·55 $M_\odot$ for the secondary, about the mass of a very-late-K star with $M_V \sim 8^m$ — a star very similar to the visual companion, in fact. With a ΔV of about four magnitudes it could not be expected to be visible in the radial-velocity traces — nor is it; and there is no sign of any inflection in the radial-velocity curve where it crosses the γ-velocity. As far as the mass function can tell us, the secondary could be brighter, to any degree, if the orbit had an inclination far removed from 90°, but the absence of any indication of its presence in the radial-velocity traces or orbit is just what is to be expected on the basis of the astrometrically determined inclination, noted above, of about 74°.

The faint visual companion to HD 471

Half a minute of arc south-preceding HD 471 (p.a. 238°) there exists the $11\frac{1}{2}^m$ c.p.m. companion that is mentioned above and which was measured photometrically by Eggen[20] and Sandage & Kowal[21]. The Lowell paper[17] of 1963 appears to be the earliest one to identify the faint star as being physically associated with HD 471. Unfortunately the present writer was unaware of the significance of the companion star until he surveyed the literature in the course of preparing to write this paper. Three quick efforts to measure the almost invisibly faint companion in the January dusk gave the following results: 2015 Jan. 10·76 +4·9, Jan. 15·78 +6·3, Jan. 16·76 +4·5 km s^{-1}, with internally assessed (and likely therefore to be optimistic) standard errors of about 0·7, 0·7, and 0·5 km s^{-1}, respectively. The last one, which was integrated to a somewhat higher count level than the first two, is illustrated in Fig. 2. The mean of +5·2 ± 0·9 km s^{-1} could be considered to be in reasonably close accord with the γ-velocity (+6·8 km s^{-1}) of the primary star, and thereby to support the strong impression given by the common proper motion that the faint star really *is* a physical companion to HD 471. Of course, there must be a *caveat* that such a brief observing campaign offers no guarantee against the possibility that the faint star might itself be a spectroscopic binary with a γ-velocity considerably different from the velocities recently measured for it, but the similarity of the mean of the recent measures to the γ-velocity of HD 471 itself certainly looks significant *prima facie*.

Since the difference of velocities is within two standard deviations of zero, there is no real need for further discussion, but it is possibly of interest to consider how much the radial velocities of the two visual components could differ. Their projected separation of about 30″ at a distance of about 50 pc represents a minimum linear separation of about 1500 AU, and with a total mass of about 1·5 $M_\odot$ the relative velocity in a circular orbit would be about $30\sqrt{1 \cdot 5/1500}$, or almost 1 km s^{-1} (30 km s^{-1} being the velocity of the Earth in its orbit round the Sun, thereby representing a system with a separation of 1 AU
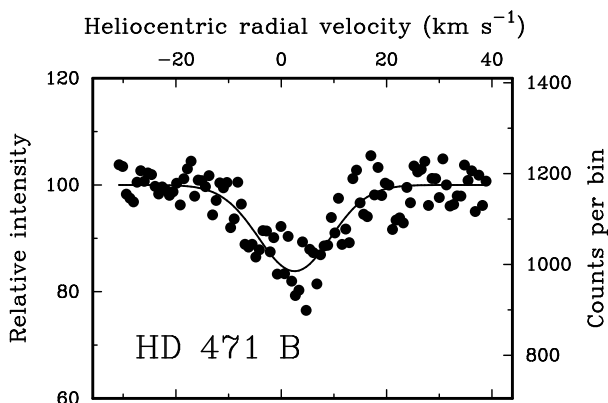
FIG. 2

Radial-velocity trace of the common-proper-motion companion 30″ distant from HD 471, obtained with the Cambridge *Coravel* on 2015 January 16.

and a total mass of $1\ M_\odot$). The difference in radial velocity could be reduced by projection effects to any degree (and could equally well be of the wrong sign!), but also it could in principle be up to $\sqrt{2}$ times the circular velocity in the improbable case in which the stars were now at periastron in a suitably orientated orbit of high eccentricity.

The dark count of the photomultiplier in the *Coravel* instrument is not normally of much significance, but in the case of HD 471 B it contributed something like half the total 'photon' count (the faint star is almost 13^m in the *B*-wavelength region used by the *Coravel*), thereby halving the depth of the cross-correlation 'dip' in comparison with what would be observed with a noise-free system. Doubling the depth of the actually observed 'dips', one of which is illustrated in Fig. 2, would bring them to the good depth that would be expected for a main-sequence star of the companion object's putative very-late-K type. Thus there is nothing in the observations reported here to cast doubt on the reality of the association, already strongly suggested by the common proper motion, of the faint star with HD 471.

HD 3791

This star is to be found close to the $4^m{\cdot}4$ object ε Andromedae, which is only about $0°{\cdot}6$ south-following it. It has certainly not been popular with astronomers, as it seems to have neither ground-based *UBV* photometry nor any spectral classification beyond the K0 of the *Henry Draper Catalogue*[33]. *Tycho 2*[34], however, has come partly to the rescue, with photometry of $V = 8^m{\cdot}63$, $(B-V) = 1^m{\cdot}08$; from the colour index, the most probable spectral type is K0 III, although a mid-K dwarf type is also possible. The *only* paper retrieved by *Simbad* for HD 3791 is one[35] giving red and infrared colour indices; it does also give an observed *V* magnitude of $8^m{\cdot}65$, in reasonable agreement with the *Tycho 2* value noted above.

The radial velocity of HD 3791 was first measured by the writer at Haute-Provence in 1998. That and the ensuing observations made at Cambridge in late 2002, 2003, and 2004, and early 2005, agreed well with one another apart from

<center>Table II</center>

<center>*Radial-velocity observations of HD 3791*</center>

<center>*Except as noted, the observations were made with the Cambridge Coravel.*</center>

Date (UT)		MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
1998 July	23·12*	51017·12	+0·9	$\overline{2}$·768	−0·2
2002 Oct.	4·04	52551·04	0·5	0·702	−0·2
2003 Oct.	27·01	52939·01	8·9	1·191	+0·1
2004 Dec.	31·77	53370·77	1·0	1·735	+0·2
2005 Jan.	14·75	53384·75	0·9	1·752	0·0
Aug.	16·08	598·08	11·2	2·021	0·0
Sept.	7·09	620·09	12·0	·049	+0·2
Oct.	5·05	648·05	12·4	·084	+0·8
Nov.	5·04	679·04	10·5	·123	−0·3
Dec.	8·91	712·91	9·4	·166	−0·1
2006 Jan.	28·76	53763·76	7·5	2·230	−0·1
Feb.	25·78	791·78	6·3	·265	−0·3
Mar.	6·78	800·78	6·4	·277	+0·1
July	24·10	940·10	3·1	·452	+0·4
Aug.	30·09	977·09	2·5	·499	+0·5
Sept.	23·04	54001·04	1·9	·529	+0·2
Oct.	26·98	034·98	1·5	·572	+0·3
Nov.	24·00	063·00	0·8	·607	−0·1
Dec.	16·88	085·88	0·5	·636	−0·3
2007 Jan.	10·84	54110·84	0·9	2·667	+0·2
July	27·12	308·12	5·2	·916	−0·5
Aug.	7·12	319·12	7·0	·930	+0·5
	30·11	342·11	8·4	·959	+0·2
Sept.	8·11	351·11	8·8	·970	−0·1
	26·11	369·11	10·1	·993	0·0
	30·04	373·04	10·2	·998	−0·2
Oct.	31·96	404·96	11·5	3·038	−0·1
Nov.	23·99	427·99	11·7	·067	−0·1
Dec.	10·91	444·91	11·3	·089	−0·3
2008 Jan.	7·86	54472·86	10·8	3·124	0·0
July	24·11	671·11	4·0	·374	0·0
Aug.	15·13	693·13	3·2	·401	−0·3
2009 July	5·09	55017·09	1·5	3·810	−0·2
	30·13	042·13	2·3	·841	−0·2
Aug.	16·12	059·12	3·4	·863	+0·2
Sept.	4·08	078·08	4·5	·887	+0·3
2010 Aug.	6·12	55414·12	5·3	4·310	−0·1
	28·12	436·12	4·6	·338	−0·2
2011 Sept.	13·08	55817·08	1·7	4·818	−0·2
Nov.	27·91	892·91	5·4	·913	−0·1
2012 Jan.	26·79	55952·79	10·1	4·989	+0·2
Feb.	7·75	964·75	10·1	5·004	−0·5
2013 Feb.	19·77	56342·77	1·9	5·480	−0·4
Oct.	16·01	581·01	1·0	·781	−0·2
Dec.	9·87	635·87	2·9	·850	+0·2
2014 Sept.	23·10	56923·10	+8·3	6·212	+0·2

<center>*Observed with Haute-Provence *Coravel*.</center>

one nasty discordance, but in the summer of 2005 the velocity had become completely different. Thereafter, observations made monthly (when the star was accessible) soon led to the discovery that the orbital period is only a little over two years; after the first cycle, suitable timing of the observations has allowed the seasonal gaps to be filled in, so the 46 measurements that are listed here in Table II provide reasonably uniform phase coverage of the orbit. The elements are included in Table V, and the orbit is plotted in Fig. 3. The most salient quantities are the period of 793 days, determined to one day, and the moderate eccentricity of 0·30. The mass function is very small and does not encourage any expectation that the secondary star should be visible in the radial-velocity traces.

HD 4703

HD 4703 is a 9^m star that is about 2° south-preceding the $4^m·4$ double-lined binary η Andromedae — one of the few double-lined giants known, because it does not take much inequality of the masses to cause the components of a binary system to undergo their giant-branch evolution at different epochs. Again we are obliged to *Tycho 2* for such photometry as is available; in this case it gave $V = 8^m·93$, $(B − V) = 1^m·14$. And again the only spectral classification is that in the *Henry Draper Catalogue*, and is necessarily K0 because that type was one of the characteristics that *defined* the choice of stars from the *HD* for the 'Clube Selected Areas' programme★.

The star was on the *Hipparcos* programme, and has a (revised[19]) parallax of 4·63 ± 1·03 arc-milliseconds, corresponding to a distance modulus of 6·7 ± 0·5 magnitudes — so the absolute magnitude appears to be about $+1^m·2$, with a similar uncertainty, and the star appears to be a giant, albeit somewhat on the faint side for luminosity class III. In the absence of significant interstellar reddening, the colour index would indicate a type of about K2.

How McDonald, Zijlstra & Boyer[37] manage, just by taking the reciprocal of a parallax that is good to one part in 4½, to obtain a distance that they consider to be worth giving to better than one part in 200 000 (they list the distance as 215·980 pc), is beyond normal comprehension. Another extraordinary figure is the one given by de Bruijne & Eilers[38], saying that in order for the precision of the hoped-for *Gaia* proper motion not to be appreciably damaged by perspective acceleration arising from the radial velocity of the star, the radial velocity must be determined to within 4091·46 km s^{-1}. There has been ample occasion for the writer to rail previously[39] at the enormities illustrated in this paragraph, whereby computer-accessible attachments running to 117 955 lines could easily have been weeded by the authors concerned to (probably) just a few hundred lines, and then the references would not unnecessarily clutter up the *Simbad* bibliographies of an extra 117 000 stars. Despairing of the likelihood that any such improvement will be forthcoming, however, the writer wishes to explain that, while he is afraid that he will remain aware of the references[37,38]

★The other criterion was a 'photometric' magnitude, given in the *Henry Draper Catalogue* as being within half a magnitude of $9^m·0$. Those magnitudes were intended to approximate to visual ones; they were not measured on purpose for the *Catalogue* but were taken, where available, from earlier Harvard works as described in the introductory material that is common to all nine of the volumes of the *Catalogue*. Where — as for the majority of stars, including the three with which this paper is concerned — there was no Harvard photometry, the magnitudes listed were simply the *B.D.*[36] ones, *i.e.*, Argelander's eye-estimates, with tabular corrections that were intended to put Argelander's numbers as nearly as possible onto the received scale of visual magnitudes.
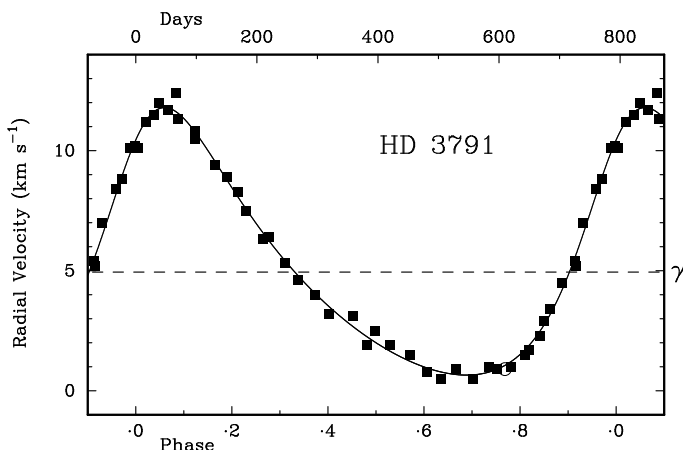
Fig. 3

The observed radial velocities of HD 3791 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All the observations were made with the Cambridge *Coravel* apart from the first one, which was made at Haute-Provence and is plotted as an open circle at about phase ·75. (The usual convention in this series of papers of plotting Haute-Provence measures as filled circles leads to indistinguishability in this instance.)

concerned, he resolves not to include them in any more of these papers unless indeed he happens to treat an object for which they may have actual relevance.

The first radial-velocity observation of HD 4703 was made at a time in 1978 adjacent to that for HD 3791, and the same thing happened on two of the three ensuing occasions (in the remaining case the two stars were observed on consecutive nights). It took some time to be sure that one was dealing with a binary system, because after there was a discordance between the first two observations, the third one agreed with the first — but then the fourth agreed with the second, and it was at *that* point (2005 January) that the star was transferred to the observing programme for binaries and was subsequently observed monthly, with the results given in Table III. There is one radial velocity to be found for HD 4703 in the literature, given as $-11\cdot22 \pm 0\cdot46$ km s^{-1}, by Famaey *et al.*[40], who managed to deduce on that slender basis that the velocity is constant. Since no date is available, their observation cannot be included in Table III. The 67 observations that *are* in the table yield the orbit whose elements are listed in Table V below and which is portrayed in Fig. 4. The period is 950·7 days, with an uncertainty this time of only 0·9 day, and the eccentricity is quite high, 0·56. The mass function is considerably smaller even than that of HD 3791, and holds out little hope for the visibility of the secondary.

HD 8739

HD 8739 is to be seen in Pisces, about 1° south of the pair of 5½-magnitude stars 93 (ρ) and 94 Piscium. (Both those stars are noted in the *Bright Star Catalogue* as having variable radial velocity, but there does not seem to be any good evidence that that is so in either case, though the six old Lick[41] observations of 93 Psc, which is a fast-rotating early-F star, have a bad scatter,

<div align="center">

Table III

Radial-velocity observations of HD 4703

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

</div>

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
1998 July 23·12*	51017·12	−10·4	$\bar{3}$·943	−0·1
2002 Oct. 5·05	52552·05	−16·3	$\bar{1}$·557	0·0
2003 Oct. 27·03	52939·03	−9·6	$\bar{1}$·964	−0·1
2004 Dec. 31·77	53370·77	−17·0	0·418	−0·2
2005 Jan. 8·77	53378·77	−17·0	0·427	−0·2
Feb. 8·75	409·75	−17·3	·459	−0·6
Aug. 7·13	589·13	−15·8	·648	−0·1
Sept. 7·10	620·10	−15·5	·681	0·0
Oct. 26·01	669·01	−14·6	·732	+0·4
Nov. 18·93	692·93	−14·8	·757	−0·1
Dec. 17·86	721·86	−13·5	·788	+0·8
2006 Jan. 28·76	53763·76	−12·8	0·832	+0·8
Feb. 8·76	774·76	−13·3	·843	+0·1
July 24·12	940·12	−10·5	1·017	+0·5
Aug. 11·15	958·15	−12·8	·036	−0·3
30·11	977·11	−13·6	·056	+0·3
Sept. 9·08	987·08	−14·5	·067	0·0
20·10	998·10	−15·3	·078	−0·3
30·10	54008·10	−15·5	·089	−0·1
Oct. 25·03	033·03	−16·2	·115	−0·1
31·99	039·99	−15·4	·122	+0·8
Nov. 24·00	063·00	−16·5	·146	0·0
Dec. 2·85	071·85	−16·5	·156	+0·1
2007 Jan. 10·85	54110·85	−17·0	1·197	−0·1
Feb. 3·79	134·79	−17·2	·222	−0·2
Aug. 6·14	318·14	−16·7	·415	+0·1
Sept. 8·12	351·12	−16·6	·449	+0·1
Oct. 5·02	378·02	−16·5	·478	+0·1
Nov. 8·97	412·97	−16·2	·515	+0·3
2008 Jan. 7·88	54472·88	−16·2	1·578	0·0
Feb. 8·76	504·76	−16·0	·611	0·0
July 25·12	672·12	−14·7	·787	−0·4
Sept. 19·03	728·03	−13·4	·846	−0·1
Oct. 18·98	757·98	−12·8	·877	−0·3
31·98	770·98	−12·2	·891	−0·1
Nov. 21·94	791·94	−11·6	·913	−0·2
Dec. 2·89	802·89	−10·8	·925	+0·2
26·87	826·87	−9·6	·950	+0·4
2009 Jan. 20·84	54851·84	−9·0	1·976	+0·3
29·82	860·82	−9·9	·986	−0·6
Feb. 3·78	865·78	−9·1	·991	+0·3
21·79	883·79	−10·8	2·010	−0·4
Sept. 4·08	55078·08	−17·0	·214	0·0
Oct. 12·00	116·00	−17·2	·254	−0·1
Nov. 17·89	152·89	−17·1	·293	0·0
Dec. 20·88	185·88	−16·8	·328	+0·2
2010 Jan. 29·80	55225·80	−16·9	2·369	+0·1
Mar. 2·77	257·77	−16·9	·403	0·0

TABLE III (*concluded*)

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
2011 Sept. 13·09	55817·09	−9·4	2·991	0·0
Oct. 14·99	848·99	−11·4	3·025	+0·2
19·08	853·08	−11·8	·029	+0·2
24·00	858·00	−12·6	·034	−0·2
Nov. 2·02	867·02	−13·5	·044	−0·4
17·95	882·95	−13·9	·061	+0·3
Dec. 3·88	898·88	−15·4	·077	−0·4
28·85	923·85	−15·5	·104	+0·3
2012 Mar. 1·78	55987·78	−16·5	3·171	+0·3
Aug. 15·13	56154·13	−16·8	·346	+0·2
2013 July 26·13	56499·13	−15·6	3·709	−0·4
Oct. 6·01	571·01	−14·4	·784	0·0
24·00	589·00	−14·1	·803	0·0
Nov. 4·95	600·95	−14·2	·816	−0·3
12·93	608·93	−13·6	·824	+0·1
2014 Jan. 20·76	56677·76	−12·4	3·897	−0·4
Feb. 20·79	708·79	−10·8	·929	0·0
Aug. 13·15	882·15	−16·3	4·112	−0·3
2015 Jan. 10·78	57032·78	−17·3	4·270	−0·2

⋆Observed with Haute-Provence *Coravel*.

with a range of more than 20 km s^{-1}.) Further (about 3° south-following) from HD 8739 is 99 (η) Piscium, which at magnitude 3·62 is the brightest star in the constellation⋆.

HD 8739 is an *Hipparcos* star, and has a (revised[19]) parallax of 2·74 ± 1·06 milliseconds of arc. Its distance is accordingly uncertain by about 40%, and any luminosity estimate that depends on knowing its distance is uncertain by a factor of about two. Nevertheless, in the same way as they did in the case of HD 4703 noted above, McDonald, Zijlstra & Boyer[37] quote the distance as 364·960 pc and the luminosity of the star as 73·71 solar luminosities, while De Bruinje & Eilers[38] tell us that, in order not to spoil the precision of the hoped-for *Gaia* parallax determination, we have got to know the radial velocity of the star to an accuracy of 16232·52 (or, by another calculation 16374·19) km s^{-1}. Such figures offend against scientific principle and reinforce the present writer's determination, noted above, not to refer to those papers in future. Even just giving a reference to such papers, in this citation-sensitive age, is liable to be regarded as helping implicitly to increase the countenancing or even approval of them; there is no place, in retrieval procedures, for a black mark to be assigned to retrieved papers, or for a reference to perceived shortcomings to result in the attribution of a negative count, of (say) minus 5 in serious cases like this one, in the census of references! To include approval ratings in retrieval systems would

⋆Pisces is a remarkable constellation for its richness in Flamsteed-numbered stars, whose numbers reach 113, even though to the naked eye the constellation is barely visible! It is one of only five constellations in which the Flamsteed numbers run up to more than 100; the others are Aquarius (108), Hercules (113), Taurus (139), and Virgo (110) — all much more visible as constellations than Pisces. After η, the only stars in Pisces that are (slightly) brighter than fourth magnitude are γ (Flamsteed 6) and α (Flamsteed 113); the last is actually a visual double star whose components individually are fainter than 4^m.
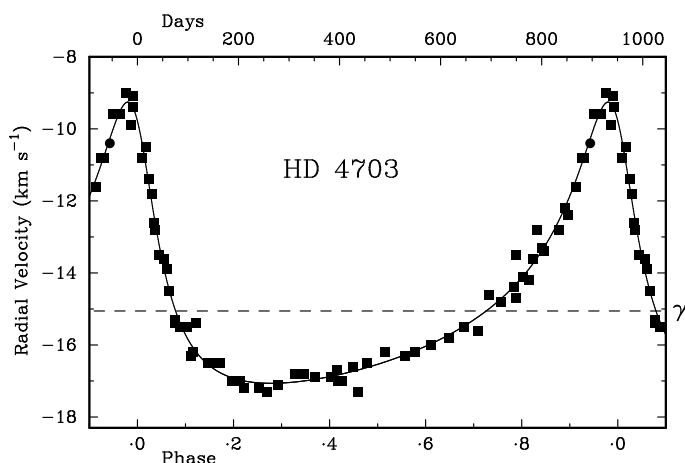
As Fig. 3, but for HD 4703. Again there is one Haute-Provence measure, near phase ·9, but in this case the diagram reverts to the usual convention of plotting it as a filled circle.

admittedly compromise the 'bean-counting' mathematical precision of a mere numerical survey, but think how much it might enhance the value to the user! — and it might even bestir authors who found their papers black-balled.

Yoss, Karman & Hartkopf[42] undertook a major photometric programme concerning stars in the +15° *Selected Areas*[43] whose radial velocities (more than 500 of them) had been published in 1971 by the present writer in a report[44] on the first large programme undertaken by the then-novel cross-correlation procedure[45] of previously un-measured stars. They found the V magnitude and $(B - V)$ colour index of HD 8739 to be 8$^{\mathrm{m}}$·57 and 1$^{\mathrm{m}}$·23, respectively. Their *DDO* photometry identified the star as a giant, and provided an estimate of its distance as 528 pc, which is within the uncertainty of the value implied by the *Hipparcos* parallax. Eggen[46], too, has given the V magnitude as 8$^{\mathrm{m}}$·57. *Hipparcos* gave the magnitude in its private 'Hp' system[47] as 8$^{\mathrm{m}}$·717[48] as the mean of 127 measurements, which, according to a tabulated transformation[47] with argument $(V - I)$ (also listed[48] in the *Hipparcos* catalogue), equates to about $V = 8^{\mathrm{m}}$·55. The colour index is that of a giant whose type is K2 or K3.

A clever thing that *Hipparcos* did was to resolve HD 8739 and see it as a close 'visual' double star, with[48] a separation of 0″·320 ± 0″·048 at a position angle of 280°; the *Δm* is given[48] as 2$^{\mathrm{m}}$·94 ± 0$^{\mathrm{m}}$·30, implying that the companion adds only about 0$^{\mathrm{m}}$·07 to the total brightness of the system. The individual magnitudes of the components are given in the Hp[47] system in Vol. 10 of the catalogue as 8$^{\mathrm{m}}$·787 ± 0$^{\mathrm{m}}$·019 and 11$^{\mathrm{m}}$·723 ± 0$^{\mathrm{m}}$·283.

Fabricius & Makarov[49] have quoted those same Hp magnitudes for the two stars, but they have in addition listed individual magnitudes for them from the *Tycho* photometry that was also carried out by the *Hipparcos* satellite. It is, however, difficult to understand how the *Tycho* magnitudes can refer to the same stars. Since both Hp and the *Tycho* V_T are supposedly quite close to V, and

the ΔHp is given[48] as $2^{m}\cdot94$, one would expect the ΔV_T to be comparable — but no, it is only $1^{m}\cdot40$, the individual V_T magnitudes being given as $9^{m}\cdot01$ and $10^{m}\cdot41$ (they add up to $8^{m}\cdot75$). And ΔB_T is given as only $0^{m}\cdot98$ (the individual magnitudes being $10^{m}\cdot51$ and $11^{m}\cdot49$), showing the fainter star to be much bluer than the brighter, as would indeed be the case if the former were a main-sequence star and the latter a giant. *That* is quite reasonable, since the rather uncertain parallax equates to a distance modulus of about $7^{m}\cdot8$, albeit with an uncertainty of the order of a magnitude; it would indicate an M_V for the system of about $+0^{m}\cdot8$, with similar uncertainty — so the system could well consist of a K giant plus a late-A- or F-type main-sequence star, depending on whether we believe the ΔHp or the ΔV_T as the true difference in magnitude. But it remains disagreeable that, for the fainter component, B_T, which can be considered a stand-in for B, is actually brighter than Hp, which is analogous to V, giving an apparently negative '$(B − V)$' colour index for that component, while the direct $(B_T − V_T)$ comparison gives the colour index as $+1^{m}\cdot08$.

The seeming discordance in the input data makes it inappropriate to try to produce for the system a model any more definite than the one that has just been indicated. Moreover, the HD 8739 system must be of higher multiplicity, since we shall show below that it is a spectroscopic as well as a 'visual' binary, and the secondary objects cannot be one and the same since their orbital periods are very different. At the distance of nearly 400 pc implied by the parallax, the angular separation of the 'visual' components, of about $0''\cdot3$, represents a linear separation of more than 100 AU, which even in a system whose total mass may well be a few solar masses must imply an orbital period of the order of a thousand years, whereas the period of what must evidently be recognized as a spectroscopic sub-system involving the visual primary is less than ten years.

Radial velocities and orbit of HD 8739

Just like the last two stars treated above, HD 8739 was observed because it fell within Area 11 of the Clube Selected Areas, and again like those objects it was included in that Area only after the northern Areas were arbitrarily increased in size in order to provide a number of stars that otherwise satisfied the selection criteria ($m_v = 9^{m} \pm 0^{m}\cdot5$ and *HD* type K0) that was more comparable with the numbers in the southern Areas[2]. By chance Area 11 overlaps one of the genuine original (Kapteyn[43]) Selected Areas in the $+15°$ declination zone, and HD 8739 happened to have been observed, as noted above, in the first major programme[44] undertaken after the writer developed an instrument[45] that measured radial velocities photoelectrically by cross-correlation. In that work, HD 8739 was measured three times — once in 1966 when the instrument was new, and twice in 1969; the initial measurement did not agree well with the other two (there was a discrepancy of more than 3 km s^{-1}) but the procedures for getting good velocities had not been fully worked out in 1966, and the discrepancy was not regarded as being necessarily significant.

The first new radial-velocity measurement was made with the Cambridge *Coravel* in 2002 and agreed very well with the 1969 measures, but when the next observation was made, two years later, there was a definite discordance of $3\cdot5$ km s^{-1}, which prompted the transfer of the object to the spectroscopic-binary programme. Disappointingly little then happened to the radial velocity, and only two observations per season were made in the next three years, but then it was rather grudgingly admitted that, taken together, they did show a slow drift of the velocity, and a régime of monthly measurements was instituted. There are now 47 *Coravel* observations; they are listed in Table IV, after the

TABLE IV

Radial-velocity observations of HD 8739

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

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
1966 Sept. 13·10*R	39381·10	+19·1	$\overline{4}$·581	−3·4
1969 Sept. 28·08*	40492·08	22·7	$\overline{4}$·941	−0·1
30·01*	494·01	23·4	·941	+0·6
2002 Sept. 29·07	52546·07	23·1	0·846	−0·2
2004 Oct. 27·07	53305·07	19·6	1·092	−0·2
2005 Jan. 14·77	53384·77	20·4	1·118	+0·4
Dec. 17·86	721·86	20·9	·227	0·0
2006 Oct. 3·09	54011·09	21·4	1·321	0·0
Dec. 2·93	071·93	21·7	·340	+0·2
2007 Jan. 31·76	54131·76	21·6	1·360	0·0
Mar. 3·79	162·79	21·4	·370	−0·2
Aug. 10·14	322·14	22·2	·422	+0·4
Sept. 16·10	359·10	22·2	·433	+0·3
Oct. 20·00	393·00	22·0	·444	+0·1
Nov. 14·93	418·93	21·7	·453	−0·3
2008 Jan. 5·89	54470·89	22·4	1·470	+0·4
Feb. 11·81	507·81	22·0	·482	−0·1
Aug. 15·15	693·15	22·0	·542	−0·3
Sept. 20·08	729·08	22·4	·553	0·0
Oct. 18·99	757·99	22·2	·563	−0·2
Nov. 18·97	788·97	22·4	·573	0·0
Dec. 30·80	830·80	22·9	·586	+0·4
2009 Jan. 24·80	54855·80	22·8	1·594	+0·3
Feb. 21·79	883·79	22·3	·603	−0·2
Aug. 20·14	55063·14	22·8	·662	+0·1
Oct. 25·05	129·05	22·7	·683	−0·1
Dec. 28·78	193·78	22·7	·704	−0·2
2010 Mar. 2·78	55257·78	22·6	1·725	−0·4
Aug. 6·14	414·14	23·5	·775	+0·4
Oct. 20·09	489·09	23·4	·800	+0·2
2011 Sept. 13·12	55817·12	23·1	1·906	−0·1
Nov. 27·91	892·91	23·0	·930	0·0
2012 Jan. 12·80	55938·80	22·8	1·945	0·0
Feb. 7·76	964·76	22·6	·954	0·0
Mar. 1·79R	987·79	21·3	·961	−1·1
Aug. 5·13	56144·13	20·3	2·012	0·0
Sept. 4·12	174·12	20·0	·022	0·0
Nov. 3·07	234·07	19·5	·041	−0·2
Dec. 1·95	262·95	19·8	·050	+0·2
2013 Jan. 31·77	56323·77	19·7	2·070	0·0
Feb. 27·79	350·79	19·7	·079	0·0
Sept. 3·14	538·14	20·1	·139	−0·1
5·12	540·12	+20·3	·140	+0·1

TABLE IV (*concluded*)

Date (UT)	MJD	Velocity km s^{-1}	Phase	(O−C) km s^{-1}
2013 Oct. 24·03	56589·03	+20·2	2·156	−0·1
Nov. 19·92	615·92	20·6	·165	+0·2
2014 Feb. 1·77	56689·77	20·6	2·189	0·0
Aug. 29·14	898·14	20·8	·256	−0·2
Oct. 10·09	940·09	20·8	·270	−0·3
Nov. 2·96	963·96	20·9	·277	−0·3
Dec. 5·86	996·86	+21·3	·288	+0·1

*Observed with original spectrometer at Cambridge; wt. ¹⁄₁₀.
RRejected.
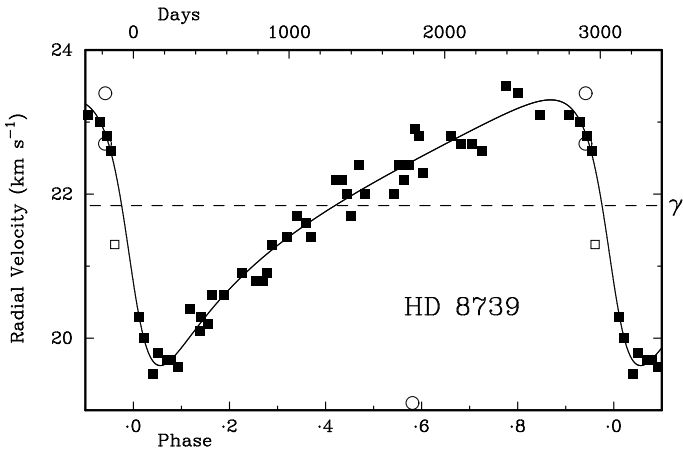
FIG. 5

The observed radial velocities of HD 8739 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. This orbit looks more ragged than the previous ones, largely owing to what is, for this series of papers, the rather small amplitude (1·84 km s^{-1}) of the star's velocity variations*. All but three of the observations have been made with the Cambridge *Coravel* and are plotted as usual with filled squares. The open square is a similar observation that has been rejected on account of its excessive residual. The three large open circles represent observations made nearly fifty years ago with the original radial-velocity spectrometer[45] at Cambridge. The two near the peak of the curve have been given a realistic weighting of ¹⁄₁₀; by greatly extending the time base they appear to make a considerable improvement in the standard error of the orbital period. The third early measurement (the earliest of all, dating from 1966 before the velocities obtained with the then-new instrument were as reliable as they soon became) is seen right at the bottom edge of the diagram and has been rejected.

*There was no orbit with K as small as 2 km s^{-1} in this series until Paper 104, which gave the orbit of 47 Cyg whose amplitude is just 2·00 km s^{-1}. Smaller amplitudes have since been found for the following stars, with the number of the paper and the amplitude in km s^{-1} following in brackets: HD 148224 (141, 1·53); HD 114761 (167, 1·45); 56 Peg (186, 1·47); HD 212859 (217, 1·03); HD 11571 (226, 1·93); and HD 110583 (234, 1·43). The writer was a co-author of a paper[50] that presented what looked very much like an orbit, with a K as small as 0·69 km s^{-1}, thirty years ago, but misgivings have subsequently been felt as to whether the radial-velocity variations that it indubitably showed had an orbital origin.

three obtained with the original instrument in the 1960s, and document an orbit of small amplitude and considerable eccentricity. One measurement, made in bad conditions in a possibly misguided effort to document a part of the rather sudden fall in velocity around periastron, that by misfortune largely occurred *between* observing seasons, has a residual more than five times the r.m.s. value of the others and has been rejected. The period obtained from the rest of the *Coravel* measurements is 3154 ± 52 days. Since the orbital period turns out to be near a half-integral number of years (about 8½ years), the unfortunate gap in the phase coverage of the data during the relatively rapid fall in velocity around the time of the periastron passage could be made good in the next cycle of the variation, in 2020/21, but it might be tempting Providence for the writer (now in his 80th year) to expect still to be active then.

   When plotted on the *Coravel* orbit, the two 1969 observations stand rather perversely near the maximum of the velocity curve in terms of velocity but near the minimum in terms of phase; their phasing can be mended without unduly damaging the fit of the solution to the *Coravel* observations by introducing them into the solution with a weight arbitrarily set at 0·1, whereby they are pulled into tolerable agreement with the orbit, whose period is refined to 3087 ± 16 days — a tolerably acceptable change of a little more than one standard deviation from the *Coravel*-only solution. Nothing can be done to accommodate the first observation of all, from 1966; it still gives a residual of more than 3 km s^{-1} (almost as much as the whole range of the star's actual variation!) and has had to be rejected. The final orbit is illustrated in Fig. 5 and its elements have been included in Table V. The only comment to be made on the orbit is that the mass function is very small, so the mass of the spectroscopic secondary and/or the orbital inclination must be small.

Table V

Orbital elements for HD 471, 3791, 4703, and 8739

Element		HD 471	HD 3791	HD 4703	HD 8739
P	(days)	463·44 ± 0·18	793·4 ± 1·0	950·7 ± 0·9	3087 ± 16
T	(MJD)	56108·7 ± 0·9	54374·7 ± 3·9	54874·5 ± 2·3	56108 ± 21
γ	(km s^{-1})	+6·78 ± 0·03	+4·94 ± 0·05	−15·06 ± 0·04	+21·84 ± 0·03
K_1	(km s^{-1})	11·57 ± 0·05	5·57 ± 0·06	3·90 ± 0·07	1·84 ± 0·06
e		0·293 ± 0·003	0·303 ± 0·010	0·562 ± 0·010	0·544 ± 0·021
ω	(degrees)	274·7 ± 0·8	319·3 ± 2·2	30·1 ± 1·7	112 ± 4
$a_1 \sin i$ (Gm)		70·48 ± 0·29	57·9 ± 0·7	42·2 ± 0·8	65·7 ± 2·3
$f\,(m)$ $(M_\odot)$		0·0651 ± 0·0008	0·0123 ± 0·0004	0·00333 ± 0·00019	0·00119 ± 0·00012
R.m.s. residual (wt. 1) (km s^{-1})		0·19	0·27	0·29	0·20

References

(1) R. F. Griffin, *MNRAS*, **219**, 95, 1986.
(2) R. F. Griffin & A. P. Cornell, *MNRAS*, **371**, 1140, 2006.
(3) A. J. Cannon & E. C. Pickering, *HA*, **91**, 2, 1918.
(4) A. J. Cannon & E. C. Pickering, *HA*, **64**, no. IV, p. 90, 1909. (Described on pp. 115, 122.)
(5) S. I. Bailey, in A. J. Cannon & E. C. Pickering, *HA*, **96**, iii, 1921.
(6) R. F. Griffin, *The Observatory*, **110**, 51, 1999 (Paper 144).
(7) R. F. Griffin & C. D. Scarfe, *The Observatory*, **116**, 19, 1996 (Paper 126).
(8) R. F. Griffin, *The Observatory*, **123**, 129, 2003 (Paper 170).
(9) R. F. Griffin & R. D. McClure, *The Observatory*, **129**, 28, 2009.

(10) R. H. Baker, *Publ. Allegheny Obs.*, **1**, 17, 1908.
(11) R. F. Griffin, *The Observatory*, **124**, 258, 2004 (Paper 177).
(12) F. W. A. Argelander, *Astronomische Beobachtungen auf der Sternwarte zu Bonn* (Adolph Marcus, Bonn), **4**, 70, 1861.
(13) A. J. Cannon & E. C. Pickering, *HA*, **91**, 20, 1918.
(14) J. G. Porter, E. I. Yowell & E. Smith, *Publ. Cincinnati Obs.*, no. 18, Part I, p. 7, 1915.
(15) F. Baily, *A Catalogue of Those Stars in the Histoire Céleste Française of Jérôme Delalande . . .* (R. & J. E. Taylor, London), 1847.
(16) J. J. le F. Lalande, *Histoire Céleste Française* (Imprimerie de la Republique), 1801.
(17) H. L. Giclas, R. Burnham, Jr. & N. G. Thomas, *Lowell Obs. Bull.*, **6**, p. 1 (no. 120), 1963.
(18) N. E. Wagman, *AJ*, **72**, 957, 1967.
(19) F. van Leeuwen, *Hipparcos, the new reduction of the raw data* (Springer, Dordrecht), 2007.
(20) O. J. Eggen, *AJ*, **68**, 483, 1963.
(21) A. Sandage & C. Kowal, *AJ*, **91**, 1140, 1986.
(22) S. Lepine & B. Bongiorno, *AJ*, **133**, 889, 2007.
(23) C. W. Allen, *Astrophysical Quantities* (Athlone, London), 1973, p. 206.
(24) G. Fouts & A. Sandage, *AJ*, **91**, 1189, 1986.
(25) C. Allen, A. Poveda & M. A. Herrera, *A&A*, **356**, 529, 2000.
(26) [Announced by] B. Nordström *et al.*, *A&A*, **418**, 989, 2004.
(27) *The Hipparcos and Tycho Catalogues* (ESA SP-1200) (ESA, Noordwijk), 1997.
(28) A. Goldin & V. V. Makarov, *ApJS*, **166**, 341, 2006.
(29) A. Goldin & V. V. Makarov, *ApJS*, **173**, 137, 2007.
(30) R. F. Griffin, *JA&A*, **6**, 77, 1985.
(31) R. F. Griffin, *JA&A*, **30**, 87, 2009.
(32) O. Y. Malkov *et al.*, *A&A*, **546A**, 69, 2012.
(33) A. J. Cannon & E. C. Pickering, *HA*, **91**, 53, 1918.
(34) [Announced by] E. Høg *et al.*, *A&A*, **355**, L27, 2000.
(35) [Announced by] W. W. G. Scharlach & E. R. Craine, *PASP*, **92**, 845, 1980.
(36) F. W. A. Argelander, *Astronomische Beobachtungen auf der Sternwarte zu Bonn* (Adolph Marcus, Bonn), **3–5**, 1851–55.
(37) [Announced by] I. McDonald, A. A. Zijlstra & M. L. Boyer, *MNRAS*, **427**, 343, 2012.
(38) [Announced by] J. H. J. de Bruijne & A.-C. Eilers, *A&A*, **546A**, 61, 2012.
(39) R. F. Griffin, *The Observatory*, **135**, 15, 2015 (Paper 240).
(40) [Announced by] B. Famaey *et al.*, *A&A*, **430**, 165, 2005.
(41) W. W. Campbell & J. H. Moore, *Publ. Lick Obs.*, **16**, 17, 1928.
(42) K. M. Yoss, R. A. Karman & W. I. Hartkopf, *AJ*, **86**, 36, 1981.
(43) J. C. Kapteyn, *Plan of Selected Areas* (Hoitsema, Groningen), 1906.
(44) R. F. Griffin, *MNRAS*, **155**, 1, 1971.
(45) R. F. Griffin, *ApJ*, **148**, 465, 1967.
(46) O. J. Eggen, *PASP*, **102**, 242, 1980.
(47) Ref. 27, **1**, Tables 1.3.1 & 1.3.5.
(48) *ibid.*, **6**, 137; **10**, DC26.
(49) [Announced by] C. Fabricius & V. V. Makarov, *A&A*, **356**, 141, 2000.
(50) R. D. McClure *et al.*, *PASP*, **97**, 740, 1985.

REVIEWS

Archaeoastronomy and the Maya, edited by G. Aldana y Villalobos & E. L.
    Barnhart (Oxbow Books, Oxford), 2014. Pp. 165, 27·5 × 21·5 cm. Price £45
    (paperback; ISBN 978 1 78297 643 1).

This well-presented, colourful work contains seven chapters from papers
presented at a symposium held in association with a meeting of the Society
of American Archaeologists in Austin, Texas, in 2007. Introductory and
concluding remarks by Gerardo Aldana y Villalobos, one of the editors, helps
to place papers within the historical development of archaeoastronomy and of
Mesoamerican studies. The topic is the archaeoastronomy of Mesoamerica,
with a focus on the Maya. The volume is not a comprehensive summary of all
the work that had been done prior to the conference, despite a fair introduction
and the helpful but brief summaries at the beginnings of most of the chapters.
It is rather an update to the field at the moment the conference was held.
Therefore, a previous knowledge of Mesoamerican astronomy is needed to be
able to comprehend the papers, especially those dealing with calendrics. The
glossary, although helpful, is insufficient. As a consequence, most readers will
need to consult a comprehensive sourcebook before tackling this volume. This
reviewer may be prejudiced, but thinks that the first two sections of Chapter 12
of *Exploring Ancient Skies* by Kelley & Milone[1] is probably the most accessible
source and supplies also a general background for basic astronomical as well as
archaeological ideas; two others are Aveni's *Skywatchers of Ancient Mexico*[2] and
The Ancient Maya, by Sharer[3].

The first and second chapters, papers by Harold H. Green and Ivan Šprajc,
respectively, involve classical archaeoastronomy, linking in the rise and set
azimuths of the Sun over monuments, buildings, and natural fore-sites, at
the equinoxes, solstices, and on the dates when the Sun passes through the
zenith and nadir at specific sites with local terrain and architecture. Thus these
papers build on the rich legacy of investigators such as Horst Hartung and
Tony Aveni, among others, whose contributions are briefly summarized in this
volume. Green makes the case that the separation of the solar events in time
as observed at the old Mayan site at Chocolá may have provided the basis for
important elements of the Mayan generic Mesoamerican calendar, particularly
the long 260-day interval between zenith passages on either side of the winter
solstice. Šprajc argues that the alignments observed at Teotihuacan, an ancient
site in central Mexico, were repeated throughout the central Mayan lowlands.
It is not uncommon to find such applications of structure to places where
they do not quite fit; medicine-wheel sites in North America, and sundials in
use in the ancient world, provide other examples. This demonstrates that the
re-applications, at least, were not intended to be observational platforms or
devices.

In the third paper, Mendez *et al.* discuss hierophanies, *i.e.*, plays of light
and shadow at key events in the civil calendar at the important Mayan site of
Palenque. The ceremonies at these events (the solstices, equinoxes, and the
days when the Sun passed through the local zenith and nadir) seem to be
embodied in the iconography in the buildings, the interpretations of which are
discussed in detail. In another paper (Ch. 5), Mendez and Karasik interpret
the hierophanies at Palenque further, attempting to tie them to the depictions
on monuments, and to the cosmic temporal frame and divine kingship. This
is discussed further below. It may be useful to point out that in discussing
alignments, the physical altitudes of fore-sights and back-sights (including

the observing platform), whether natural or constructed, should be specified.

In the fourth paper, Aldana y Villalobos introduces the interesting idea that the Venus Table in the *Dresden Codex*, a Mayan book which had been assumed to tabulate either a record of observations or a warning table of the various appearances of Venus in the sky, may be instead oracular in nature, listing the omens that would presage rain, drought, and destruction. The idea has currency, given the intertwining of the Venus and seasonal cycles. An eight-solar-year interval encompasses five cycles of Venus apparitions; it will be recalled that a single synodic period of Venus includes the following phenomena: morning star, when at western elongation Venus rises in the morning sky before (and so west of) the Sun; invisibility (due to passage at superior conjunction); evening star, when Venus at eastern elongation appears east of the Sun, in the west after Sunset; and a second period of invisibility when Venus at inferior conjunction passes between us and the Sun. This single synodic interval is striking as Venus' *arcus visionis* first in the morning and then in the evening sky, waxing and waning in brightness with changing distance from the Sun and illumination. Due to the relative placements of the Earth and Venus with respect to the nodes of the orbit, five such synodic cycles are needed to repeat a complete set of the motions of Venus on the sky. So, if for a particular prognosticated event, the sky were overcast, or if the date were incorrectly predicted or interpreted, a different reading of the circumstances could be made from that if the phenomenon was indeed observed as predicted. Of course, this 'cheat factor' need not necessarily impact the contents of the table, but investing it with layers of meaning could have increased the significance or sacredness of the book to the Maya. This interpretation thus provides a safety net for an astronomer who happened to be a chief priest and/or to whom the ruling elite was closely associated. Astronomers in other cultures were not so fortunate. In ancient China, the failure to prognosticate accurately would not have been without consequences for the astronomers involved.

In Chapter 5, Alonso Mendez and Carol Kerasik discuss the current alignments at Palenque supporting the importance of solar passages through the zenith and the nadir of the sky, conceived of as the central axis of the world, and represented in text and depictions at that site. One cannot prove that the alignments seen in doorways and through windows were intentional, but they are certainly plausible. So far so good. However, I found this paper somewhat problematic and not only because it seems to draw inspiration from Santillana & von Dechend, whose suppositions about early recognition of precessional effects remain, as far as I know, unsubstantiated. Although some of the issues raised below about this paper have counterparts in other chapters, the exposition here requires, I think, detailed focus on those issues. The authors claim that on the 'Creation Date', 13.0.0.0.0 4 Ahau 8 Cumku, in the Mayan calendar, held to be August 13, 3114 B.C. (Gregorian), the Sun passed through the zenith at local noon, the Moon was full, and Mintaka (the westernmost or in older parlance, leading, star) in Orion's belt "reached the nadir of the night sky." The expressed era base, as well as the much-vaunted 2012 termination date in connection with the birth date of Palenque's great ruler Pacal, ties his reign to the very origin of the world system of time and place, as well as its end. It is a grand vision. Here are some sticking points: (*i*) citing a specific Gregorian or Julian date for a Mesoamerican date implies a specific correlation constant, the determination of which has not yet been universally accepted. At the least, a few comments would be in order to mention the value and the basis for its selection. (*ii*) There is no discussion of the sky software and its capability. A claim about the sky in a remote epoch requires a lot of confidence in the adopted sky-plotting software.

One needs to know if obliquity variation as well as precession is being applied. The former affects the solar declination and thus the date of solar zenith passage, the latter the declination of Mintaka, and thus its location in the sky with respect to the horizon. Absence of a correction for obliquity variation is not a problem for results and alignments at the time Pacal and his successor ruled (mid-7th Century AD); it is, however, a significant problem for that remote 'Creation date'. Were I doing this, I would want to compare the results from the software used with those of other packages and discuss its accuracy. Here, the software package is not mentioned, although in Chapter 3, Mendez *et al.* mention STARRY NIGHT DELUXE as the software used to produce their sky charts for that chapter. Whether or not it or another package was used for the work described in Chapter 5, it must be asked: does it or does it not apply the obliquity variation? Not everyone does, and software providers are not always forthcoming about what is or is not applied. For remote epochs, for example, what values were adopted for δT (a correction for the non-uniform rotation of the Earth) which strongly determines whether or not a solar eclipse will be visible at a particular site and at a particular instant. The variation of the ecliptic is known (*cf, e.g.*, ref. 1, p. 103), and in August, 3114 BC, $\varepsilon = 24°·04$, a departure of about a solar diameter from the current value. Applying the precession selection option in the VOYAGER III star-chart software I have at hand, I find the Sun to transit the celestial meridian on the date specified at an altitude of 86°, not 90°, and a Moon that is 92% illuminated, so not full. It does show the Sun to pass through the zenith, but on August 31, not August 13. Incidentally, it may be worth mentioning that the Sun passes through the zenith when it reaches a declination equal to the site latitude and that this occurs twice during the year at any site the latitude of which is less than the obliquity of the ecliptic, the value of which is the Sun's highest declination. Finally, the precessed declination of Mintaka is $-17°$ 26′ as given by VOYAGER III and so will pass through the nadir nightly for many years around that date; therefore this alone is no firm indicator of any unique importance of the August 13 date. The point, though, is not that one sky-simulation program may be more accurate than another; in fact I have no idea which may be more accurate, but only that the software and what is being applied by it should have been explicitly discussed. (*iii*) Regardless of the accuracy of any sky simulation, one may wonder how an unobserved nadir passage of even such an apparently culturally significant star as Mintaka would be a valid expectation without an understanding of spherical astronomy. One could see how the nadir passage of the Sun could be divined given the symmetries in the calendar year, but for the stars (and for the Moon, with its complex behaviour) it is less clear. Even if this could be achieved, however, the very thing that is required for accurate renditions of the real sky at a remote era raises serious questions about the current analysis and interpretations. (*iv*) If indeed the interpretation that stellar events at a date that precedes the Mayan civilization by millennia were correctly divined, it could only be by back-calculation, but such a calculation requires a precise knowledge of precession, in other words, that the declination of an object that today is at $\delta = -00°$ 17′, and in the mid-7th Century at $-02°$ 19′, would have appeared at $-17°$ 27′ at the 'creation'. Vague suggestions of the changing stellar background of the seasonal solar markers would seem to be insufficient to render such an accurate result. If the interpretation is accurate, and the Maya did not know anything about precession, how could Mintaka have been predicted to be at the nadir location on the era base date? Similarly, the prediction of the Sun at zenith on a remote date in the past requires knowledge of the variation of the

obliquity of the ecliptic, as we have seen. I would conclude they had knowledge of neither phenomenon and that an inference or supposition that they did must be based on misinterpretation. (*v*) A final puzzling issue in this paper is the interpretation of the turtle glyph as a representation of the three linear stars in Orion's Belt (consisting, in increasing right ascension, of δ Ori = Mintaka, ε Ori = Anilam, and ζ Ori = Alnitak) as a triangle of 'stars' carried on the back of what does indeed look like a turtle. It is left unexplained why an inscriber would represent a straight line of stars as a triangle. One would have supposed that an observational astronomer (or indeed anyone who looked at the night sky) would raise objection, just as a modern astronomer would if a cartographer misrepresented the sky. Neither art nor symbol need be scientifically precise, but one could be forgiven for wondering if the triangle of objects shown on the back of the turtle refers to a different asterism altogether, such as the northern part of Orion (head and shoulders), the stars of which actually form a triangle. It would have been nice to have had some discussion on this point. (The authors do mention that among the modern Maya in Guatemala, the triadic shape of their hearths is compared to the real triangle of stars formed by Alnitak, Saiph, and Rigel. This only sharpens the issue.) Obviously, this reviewer found the paper very provocative but it raises many interesting ideas that could be pursued further once the issues are addressed.

Susan Milbrath's Chapter 6 is concerned mainly with Venus' iconography, *i.e.*, the representation of Venus in books and monuments at various stages of its cycles, *i.e.*, across the eight years (equal to five synodic periods of Venus's motion on the sky), an interval referred to here as the Venus Almanac. The iconography involves the myth which observations continually verify and thus validate. Venus is portrayed as a warrior in its Morning Star phase, and as a feathered serpent inside the belly of the Earth Monster prior to its birth at heliacal rising, its first appearance before sunrise. Milbrath traces the Venus Almanac in post-classic sources such as the *Codex Borgia* and at least elements of it in the *Codex Nutall*, the *Madrid Codex*, and the *Dresden Codex*, as well as on numerous monuments.

An iconographic study is explored in the final chapter by Michael Grofe in great depth in an examination of individual glyphs as they appear on carved monuments all over Mesoamerica. Following an introductory glyph, an Initial Series contains a calendar date, in its most complete form: (*i*) "long count", the number of days since some initial date in the remote past — the era base (*e.g.*, 13.0.0.0.0 = 13 baktun, 0 katun, 0 tun, 0 uinal, and 0 kin or day unit, a modified vigesimal or base-20 system, with the modification introduced by having 18 uinals = 1 tun); followed by (*ii*) the *Tzolkin* (analogous to our day of the month and month name, such as 2 December); and then (*iii*) the *Haab* (analogous to a number of a day in the week and a week name, such as 8 Monday.) For further details of the complex but very interesting system and how the cycles work together, see one of the references mentioned above. After this "initial series" there follows a "supplemental series". It is on the latter and on the components of Glyph G, in particular, that Grofe focusses. It has been suggested to be a lunar calendar of some kind, an eclipse prediction or "warning" table, a list of the order of the planets in a nine-day week (an idea championed first by Thomas Barthel and then elaborated by David H. Kelley for the glyphs on Pacal's coffin at Palenque and at other sites), and an agricultural calendar involving the cultivation of maize, a critical food crop among the Maya. Grofe argues that the series of Glyph G components represent the lunar nodes — the intersection of the lunar orbit and the ecliptic, and indicate when the Moon and

Sun may both be near it (the eclipse limits). If the interpretation were accurate, the result would be an eclipse prediction or warning table. Clearly this is an active research topic.

Aldana y Villalobos concludes the volume with a consideration of the mind-set of the Mesoamerican astronomer. The categories of Bruno Latour are held up as a means to elucidate the nature of the often complex data presented by the architecture, monuments, and books of Mesoamerica and the relationship between inscriber and the data provider. In this context a distinction is made between *inscription*, namely the astronomical tables and other products, such as stele inscriptions, and the *inscription device*, the 'astronomer'. Latour's categories lead him to raise questions about the social, political, economic contexts of the astronomy that has been recorded and if the astronomer had the ability and knowledge to record the data. This begs the question whether the cyclicities embedded in the calendar were divined through pure empirical astronomy, as for example, the discovery of the five Venus apparitional cycles splayed across the sky for eight solar years, or were perhaps initially inspired by the maize agricultural cycle and subsequently linked to astronomical cycles. Such an interpretation calls into question more than the purely astronomical content of the tables that have been studied; agricultural phenomena are, after all, primarily annual phenomena. The questions that Aldana y Villalobos raises are legitimate but they hardly need a constructionist viewpoint to invoke them. Personally, I doubt the efficacy and thus the utility of applying a modern epistemological framework to cultures that, in the end, we know very little about. Moreover, the application of such constructs to even contemporary science has been challenged, for example, by Olga Amsterdamska, whom Aldana y Villalobos cites. Nevertheless, if this framework inspires investigators to examine closely the social, agricultural, political, religious, and economic interactions with the 'astronomy' behind the monuments and inscriptions, one can hardly condemn it. What is clear from the iconography is that the associations among the astronomy, the sacred myths, and the "mythistory" as Aldana y Villalobos calls it, of the rulers, are very rich indeed.

In addition to what has been discussed already, the volume as a whole suffers from the non-uniformity in the English spellings of *Tzolkin* and *Haab* names. Thus we see, *e.g.*, the name for house, spelled variously *Ahau*, *Ahaw*, and *Ajaw*, and the name for the five unnamed days at the end of the 360-day *Tzolkin* is written *uayab* or *wayab*. Although the deficiencies detract, the authors' scholarship and enthusiasms carry the day, so we can only look forward to reading about further research in this ever vital field.

Concluding acknowledgement: I have to confess that up to a few years ago I would have referred any request to review a book on Maya archaeoastronomy to my esteemed colleague Dave Kelley, who actually carried out seminal work in this field, and whose great knowledge of cultures and language appeared virtually boundless. Regrettably he is no longer with us. I am certain that his comments on this volume would have been vastly more illuminating and generous than my purely astronomical and far less encyclopaedic knowledge permits. — EUGENE MILONE.

References

(1) D. H. Kelley & E. F. Milone, *Exploring Ancient Skies: A Survey of Ancient and Cultural Astronomy* (Springer, New York), 2011.
(2) A. F. Aveni, *Skywatchers of Ancient Mexico* (University of Texas Press, Austin), 2001.
(3) R. J. Sharer, *The Ancient Maya* (Stanford University Press, Stanford), 2006.

The Beginning and the End: The Meaning of Life in a Cosmological Perspective, by C. Vidal (Springer, Heidelberg), 2014. Pp. 379, 24 × 16 cm. Price £44·99/$69·99 (hardbound; ISBN 978 3 319 05061 4).

This is not the usual book offered to *The Observatory* for review. It is philosophy, and speculative philosophy at that. Still, it is philosophy that is grounded in cosmology, and there can lie its appeal to *The Observatory*'s readers. So, for which astronomers is this book? It is for those who have wondered about, say, the fine tuning of the Universe, about responses to creationism and intelligent design, about a 'God of the Gaps', or about the multiverse. It is for those who puzzle about the end of renewable energy sources or the red-giant Sun rendering the Earth uninhabitable (shades of the film *Interstellar*), about the development of civilization, about alternative biology, and about heat death as the destiny of the Universe. It is certainly more of a book for the armchair, or deckchair, than the desk ... and a wet towel handy to wrap around your overheated brain will be a help.

Clément Vidal is completely systematic in the development of his speculations. He begins by outlining what his six dimensions of philosophy are and how they produce a comprehensive and coherent worldview, critical to giving meaning to our lives. He then analyses the origin of the Universe in Part II. This progresses in Part III into his speculations, embedded in relevant science, on the future of the Universe in which he considers vastly expanding biology and energy scales. Vidal's 'Cosmological Artificial Selection', or his 'Starivores', or the role of black holes, could be hard to swallow at their first bite, but he invokes solid futurists to argue that he is making the best attempt to understand the origin, future, and meaning of life.

While Vidal frequently includes religion and the spiritual, and has a final chapter on cosmological ethics and immortality, this is not a theological work, so some will need to supply that dimension themselves to his hypothesis. However, if you enjoy a highly speculative adventure, then I recommend this challenging book. One can admire Vidal's methodology, within its philosophical limits, without having to agree with (all) his conclusions. — CHRISTOPHER CORBALLY.

Religions and Extraterrestrial Life: How Will We Deal with It?, by D. A. Weintraub (Springer, Heidelberg), 2014. Pp. 234, 24 × 17 cm. Price £19·99/$34·99 (paperback; ISBN 978 3 319 05055 3).

This is a valuable and interesting survey of how many of the world's major religions think about extraterrestrial intelligent life (ETIs). And for those with an interest in, but limited knowledge of, these religions the book also provides a handy introduction into their basic ideas.

Some people have commented on the similarity of SETI to a religion with the strength of belief of its practitioners being in contrast to the lack of evidence. This is of course mistaken, since SETI searches to test defined hypotheses with clear-cut results — even if the significance of the searches is disputed. However, there is in fact a link between SETI and religious thinking in that many religions have views on the existence of extraterrestrial intelligent life. Although none of those views seems to be of use in guiding the design of SETI searches or casting light on their significance, there are interesting questions to consider. Which of the world's major religions consider the possibility of intelligent extraterrestrial life, what do they think its nature might be, and how might they react to an actual discovery of ETIs? Up until now most studies of these questions have

concentrated on the Christian religions, reflecting the American and European dominance in SETI studies. This book gives the most extensive survey yet for a much wider range of the world's religions.

After a brief review of the history of western thinking on ETIs, and a summary of recent exoplanet research (the present hot topic in astronomy but one, to my mind, that will only be of major interest for SETI thinking when we develop telescopes capable of detecting signs of life on nearby Earths), Weintraub surveys 24 religions, including Judaism, Christianity in its Protestant, Roman Catholic, Anglican, Unitarian, Quaker, Seventh-Day Adventist, Jehovah's Witnesses and Fundamental forms, Mormonism, Islam, Hinduism, Buddhism, Jainism, Sikhism, and Baha'i. As can be seen from this list Christianity is still the focus, but the coverage of other faiths is extensive. Most religions seem to be open to the possibility of ETIs, and indeed for many Eastern religions they are a natural part of their cosmologies, although some of those cosmologies are at variance with what we already know about the physical Universe. However, some variations of the Christian religion have such an emphasis on the uniqueness of Jesus that they would regard other ETIs as of no religious importance.

As an endnote, the Acknowledgements say that Vanderbilt undergraduate Wolf Clifton spent a year studying the relation between ETIs and Eastern religions and his work "was valuable in guiding [the author] toward many interesting ideas". It would be interesting to learn more about the extent of Clifton's contribution. — ALAN PENNY.

The Meaning of Liberty Beyond Earth, edited by Charles S. Cockell (Springer, Heidelberg), 2015. Pp. 272, 24 × 16 cm. Price £117/$179 (hardbound; ISBN 978 3 319 09566 0).

Down here, on the surface of planet Earth, we humans should all be conversant with the rules, regulations, and ownerships which combine to define the social environment for our individual freedom. But let us move away from Earth's surface. Looking back over the last decade or so, the maximum number of people who have been living in space at any one time is fourteen. This number is, however, bound to grow as time progresses. So we can look forward to a future of ever larger and more populous space colonies. The big question is "are the people out there really free?", when, for example, the oxygen they breathe is not just 'around', as it is on Earth, but its manufacture is critically controlled by others. How is a human's liberty constrained when everyone in the space colony is dependent on complex survival systems? Vacuous space is lethal and humans are frail. Out there, away from Earth, you cannot live independently; you are a member of a society whether you like it or not.

In 2013 June the UK Centre for Astrobiology, University of Edinburgh, and the British Interplanetary Society organized a discussion meeting on the topic of extraterrestrial liberty. The papers presented at that meeting generated essays and these essays are collected together in the book under review. It starts by delving into science fiction and exploring the social and anthropological implications of off-Earth colonies. We then question whether the escapist or utopian attitudes to space colonization are justified. How does culture, entrepreneurship, and economics thrive in space? Is John Locke's *Second Treatise on Government* (1690) relevant? What role does censorship, surveillance, law enforcement, and health-care play? What happens to our liberty if we discover other 'life' out there and what are our responsibilities for the liberty of those

life forms? What would happen if warfare broke out between belligerent space colonies? Is a federal government the only one suitable for space colonies? How are space children to be educated? And looking into the distant future, might not a colony that is completely separate from the Earth develop a form of society completely different from the one down here?

This book transports us to the pioneering phase of a new branch of our subject — astrosociology. And what an engaging, stimulating and thought-provoking book it is. — DAVID W. HUGHES.

Astrobiology, History, and Society, edited by D. A. Vakoch (Springer, Heidelberg), 2014. Pp. 375, 24 × 16 cm. Price £117/$179 (hardbound; ISBN 978 3 642 35982 8).

"Where are they?" asked Enrico Fermi, about a century after William Whewell (who coined the word "science", but must have meant something different from our current understanding) argued that it was other worlds, not Christianity, that should be rejected. The question is still with us, but the argument has gone very much out of fashion, according to most of the chapters in Vakoch's book. He and his team of 19 chapter authors have traced the history of "the extraterrestrial life debate" from ancient times to the present and then gone on to consider the possible "societal impacts of discovering extraterrestrial life". The authors are mostly Anglophones (from the US, UK, Canada, Australia) plus two Francophones, though a few of the odder sentences suggest input from that same Graustarkian with a good reading knowledge of Umbrellastanese who writes the instructions for assembly of toys late on Christmas Eve. Two of my favourite examples: "data initially interpreted as evidence for Martian vegetation was explained … as being due to a form of water (deuterated hydrogen) in the Earth's atmosphere" and "However, whereas Strughold was considered as 'The Father of space Medicine' he was also unfortunately taken over by Nazis".

The earlier chapters include a number of factoids about individual astronomers and other scholars. I was sorry to learn authoritatively that Peter van de Kamp claimed, right to the end of his active astronomical life, that astrometry from Sproul Observatory really had found planetary companions to Barnard's star. The much wilder astrometric companion claims of T. J. J. See are not mentioned. In a happier vein, at least one astronomer, Gavriil Adrianovich Tikhov, was at Pulkova Observatory from 1906 to 1941, thus surviving Stalin's murderous attack on the scientists there who had foreign connections. Tikhov had worked in France and Switzerland around 1897 to 1904 and lived on to die at Alma-Ata Observatory in Kazakhstan in 1960. He belongs to the astrobiology story because he started studying earthshine in 1914, though it was left for later workers to show that the light thus twice filtered through Earth's atmosphere shows evidence for water, land, clouds, ice, and vegetation on its surface. Tikhov also carried out a number of laboratory experiments bearing on spectra of chlorophyll and plants under what we would now call extremophile conditions.

The 'impact' chapters also range very widely, and I was struck with two conclusions. First, Kathryn Denning opines that, what happened between Cook and the Hawaiians, Cortez and the Aztecs, and so forth are unlikely to be useful as analogies of first contact between advanced aliens and us, and that "instead of using past social conditions to make guesses about what would happen if a detection occurred, we might use our knowledge of present social conditions to help ensure that the science can continue to be done".

Second is the thrust of a chapter, 'Would the discovery of ETI provoke a religious crisis?', by Ted Peters. His answer is mostly no, based on a survey to which there were almost 1300 responses from individuals in multiple religious traditions, including non-religious. For no sample did more than 17% of the adherents feel that their personal beliefs would be heavily damaged, and in no case did more than 33% think that their group traditions would be undercut. This may well be so but we are not told (*a*) how many surveys were sent out to get this many responses, (*b*) how the recipients were selected, (*c*) the numbers from each religious tradition (five flavours of Christians, plus Jews and Buddhists, but no Moslems and no Hindus, though the responses are described as "world-wide"), (*d*) the statistical significance of any of the numbers reported. It is perhaps not very likely that these fewer than 1300 people are a good sample of the 7 billion or more who may have an opportunity to witness first contact. Asking a non-representative sample had Landon beating Roosevelt in 1936, Dewey beating Truman in 1948, and, remarkably, what's-his-name beating Obama in 2012.

Vakoch's index lists astrobiology, astrobotany, astrosociology, and astrotheology and I would be sorry if lack of statistical rigour in the last two were to cast aspersions on the best work in the first two.

As for standard astronomical aspects of the debate, almost nothing is said about chemistry of the interstellar medium, meteorites, and so forth; and the 'planets' chapter has dated rapidly, saying little about the major results from the *Kepler* mission. — VIRGINIA TRIMBLE.

Masters of the Universe, by H. Kragh (Oxford University Press), 2015. Pp. 285, 22·5 × 14 cm. Price £25 (hardbound; ISBN 978 0 19 872289 2).

The subtitle of this book is *Conversations with Cosmologists of the Past*, from which you might expect that it's an oral-history project. And in a way it is, but with a twist. In his Foreword, Helge Kragh introduces us to a *fictional* great-uncle of his, who was very interested in the development of cosmology. After the death of the uncle, Helge came into possession of his papers, and was fascinated to find manuscripts of historical value. The great-uncle had a secret passion: he interviewed distinguished scientists who had contributed to progress in cosmology. And what an eclectic collection — interviews with Svante Arrhenius, Albert Einstein, Willem de Sitter, Georges Lemaître, George Gamow, Fred Hoyle, and several others. Logically a *fictional* interviewer can only produce *fictional* interviews. The author has risen to the challenge of authenticity by using contemporary sources such as correspondence and papers in order to re-construct the circumstances of the interview. The end result is a new kind of history that gives the reader a more intimate and fuller version of what the scientist was thinking at the time of the imagined interview.

For each interview we are given the place, date, and language used. This is followed by a frame-setting introduction by the interviewer. The interview transcripts are rich in detail and finely nuanced. They reminded me of the literary school of naturalism, as practised by Émile Zola, for example, or Daphne du Maurier. Kragh is very good at making the reader feel close to the interviewee because the replies are aimed at the reader rather than a note-taking interviewer. From personal knowledge I can judge that the voices of Hoyle, Bondi, Dirac, and Gamow are authentic. I did not spot any anachronisms. Nothing struck me as far-fetched or indeed fanciful. At the end of each interview there are really helpful notes that give more depth to the imagined

interviews. It's there that you'll find the references to the source material. This is an outstanding book, suitable for the numerous leisure (or pleasure) historians in the astronomy community. — SIMON MITTON.

A Journey through the Universe: Gresham Lectures on Astronomy, by I. Morison (Cambridge University Press), 2014. Pp. 356, 25 × 18 cm. Price £25/$39·99 (hardbound; ISBN 978 1 107 07346 3).

As its title indicates, this book is largely a transcript of a series of lectures which, as Gresham Professor of Astronomy, the author gave in London over four years from 2007. Its publication was delayed until 2015 so that findings from the *Kepler* and *Planck* space observatories could be incorporated, and within the constraint of its modest size it presents a comprehensive review of current cosmology.

My own introduction to cosmology was *via* the works of George Gamow (*Birth and Death of the Sun*, 1940; *Biography of the Earth*, 1941; and the entertaining Mr. Tompkins sagas — *Wonderland*, 1939, and *Exploring the Atom*, 1945), and Ian Morison's book provides an admirable summary not only of the increase in our knowledge of the subject over the last seventy years but also of the means by which it has been attained. However, it must be acknowledged that Gamow was not far off the mark in many areas (think Cosmic Microwave Background), and his books set a benchmark in enthusiastic lucidity.

Normally, when given the pleasant task of reviewing a book, I like to read it through rapidly, spend some time assimilating its content and then return for a more detailed assessment of key areas. In this case, the book being essentially a series of lectures, such a method is not appropriate; who in their right mind would attend a series of twenty-three lectures with no more than a three-minute comfort pause between each? To do justice to the author I rationed myself to not more than two chapters *per diem*, and so avoided the danger of being borne down by a surfeit of information whilst prolonging the pleasure to be gained from reading this clear account of what has been going on.

The extent to which our knowledge of the Universe has increased over the last seventy years is of course principally due to the rapid development of observational techniques, and this book gives an excellent account of them. One chapter is specifically devoted to telescopes past and present, and the *Hubble Space Telescope* has much of another to itself. Of equal importance, and of course linked to telescopy, have been the space probes and space observatories which in terms of knowledge gained probably represent a greater achievement by NASA than landing men on the Moon; and Ian Morison is punctilious in providing details of these activities, which have pulled in for us a range of data that would have flabbergasted Galileo, startled Newton, and possibly even surprised Einstein.

While knowledge has expanded exponentially, our actual comprehension of how it all works has not, probably on account of our increasing perception that quantum mechanics and General Relativity are at odds, and this point is well covered in a chapter of the book headed 'Proving Einstein right', which describes recent observations confirming his prediction that mass (now in the form of distant galaxies) 'bends' light and radio transmissions, goes on to give a clear account of the *LIGO* gravitational-wave detector, and concludes by touching upon the possibility that gravitons (if they can be found to exist) might be the key to linking the very small and the very large.

The chapters are sequential, starting with a brief historical review and

then moving to the Sun, the planets, unpleasant meteoroid possibilities, our Galaxy and its black holes, SETI, other galaxies, curvature of space (the author commendably calls for non-curved space to be referred to as Euclidian rather than flat), dark matter and energy, and finally the beginning and possible end of everything. In other words the book lives up to its title, and provides a fascinating and thorough overview of current cosmological awareness. It is easy to follow and does not trouble the reader with abstruse mathematical concepts; the chapter on time is all about increasingly accurate methods of measuring its passage rather than presenting it as a fourth dimension; and it only touches briefly upon string theory and multiverses, the author acknowledging that such matters are not wholly within human comprehension (even if computers appear to cope creatively with them).

As a series of lectures, there is inevitably some degree of repetition in the book — the paragraph on pages 202/3 concerning the black hole at the centre of our Galaxy is, for example, repeated on page 211 — but this does not detract from its merit, and it is written throughout in an informal style which leaves the reader feeling that he is present at those lectures. The book is copiously illustrated with black-and-white figures in the text and eight colour plates, has at the end of each chapter a short list of useful books which enlarge upon the relevant topics, and is attractively presented for easy reading (an increasingly important point in these days of Kindles and the Web).

I recommend it heartily to all Gamow devotees and anyone else who wants to have an up-to-date (well, nearly: the discovery that *Beagle 2*, mentioned on page 51, successfully soft landed is too recent to be included) awareness of what is known, and what remains mysterious, about the Universe. If only Galileo, Newton, and Einstein had still been around to receive copies of it, how interesting their comments would have been! — COLIN COOKE.

The Lost Elements: The Periodic Table's Shadow Side, by Marco Fontani, Mariagrazia Costa & Mary Virginia Orna (Oxford University Press), 2014. Pp. 531, 23 × 15·5 cm. Price £25·99 (hardbound; ISBN 978 0 19 938334 4).

Alfred Nobel, according to my late husband, Joseph Weber, did far more damage with his prize than ever he did with his explosive, because of the blood-thirsty competitions for the former. From a similar point of view, Mendeleev with his periodic table was responsible for much chemical rancour because he made it clear that there could only be a finite (and rather small) number of additional elements to be discovered and named by their discoverers, at least until Glenn Theodore Seaborg broke the trans-Uranic barrier.

Along the way, more than 400 non-elements were reported and given names, from Accretium to Zunzenium. Most of the methods and people involved were chemical and chemists, with physics and physicists joining the fray after World War II. Forty-one names were proposed for element 94 alone (not counting Plutonium, which won), many sounding astronomical, like Sunonium and Big Dipperium (but Big Bearium was supposed to be element 96).

There is, however, a truly astronomical corner of this enormous, cluttered room, in which reside Nebulium, Coronium, Etherium, and Newtonium, supposedly found outside the bounds of Earth and laboratory. The first two are just about known to astronomers today (because they turned out to be forbidden transitions of common elements and iron and its neighbours in highly-ionized states). The other two were cherished by Mendeleev near the end of his life (while he was also opposing He, Ne, Ar, and Kr). The authors credit the late Margherita Hack, the first Italian woman professor of astronomy, for

much of the information on those four non-elements, but I am sure she was not responsible for dating Dimitri Ivanovich's death to "February 2 [January 30 according to the old Julian calendar] 1907"; since dates in the two calendars were separated by more like 14 days than 4, they cannot both be right.

Conceivably there are other errors among *The Lost Elements*, but there are also just an enormous number of fascinating, believe-it-or-not facts, to which I shall return often. Conflict-of-interest statement: my copy of the volume was a complimentary one, provided by the third author at a session on lost elements at the 2014 August meeting of the American Chemical Society, where I spoke on Nebulium and Coronium, but also on helium and technetium in stars. — VIRGINIA TRIMBLE.

Les Constellations des Potins d'Uranie, by Al Nath (Venngeist, Duttlenheim, France), 2014. Pp. 296, 21 × 15 cm. Price €29 prepaid, inc. worldwide shipping (about £21) (paperback; ISBN 978 2 9542677 2 2).

This work, written under the pseudonym of Al Nath by a long-time professional astronomer, gathers together 50 articles that have been written for various journals under the general heading of 'Potins d'Uranie' (which may be loosely translated as 'Gossip by Urania'). The whole series of individual articles, which cover a wide range of astronomical topics, short biographies of astronomers, and similar material, is written in a light-hearted manner. They began in 1977 and continue today. All are available in pdf versions at http://www.potinsduranie.org. (A visit to the website is highly recommended.) This book is a compilation of those articles dealing with the constellations, together with others linked to various celestial objects.

The pieces generally begin with the retelling of some legends about the heavens — from the American Pacific north-west, for example — various folktales or other accounts, followed by a description of a constellation linked (sometimes tenuously) to the preceding text. The folktales and local reminiscences generally relate to the area referred to as 'les Hauts-Plateaux', which is more formally known as the 'Haut Fagnes' region of eastern Belgium, adjacent to the German border. This area, now a German–Belgian nature reserve, is a high plateau with large areas of upland bogs of sphagnum moss, rather than being a sedge or reed fen as might be inferred from the name 'Fagne'.

This region is part of Walloon-speaking Belgium, and some of the words used are in the specific local dialect, so will almost certainly be unfamiliar to many readers of French. Many of the dialect usages are specifically explained, but for other words an excellent Walloon dictionary that may be of assistance in some (but not all) cases may be found at http://www.lexilogos.com/wallon_langue_dictionnaires.htm.

The book is profusely illustrated, with about 400 pictures, most in colour, with images of astronomical objects, portraits, charts of the constellations (taken from Wikipedia), and many illustrations from atlases, such as those by Bayer, Bode, and Hevelius.

As mentioned, the links between tales and the constellations are sometimes somewhat tenuous or rely on the use of puns. I don't doubt that I have missed many of the latter, and I have still to figure out why a fictional Scots sailor, Jim McCullogh, is introduced from time to time, especially when he is said to be disembarking from a TGV Atlantique at Paris-Montparnasse or travelling on an ICE (Inter-City Express) between Leipzig and Hamburg. In the first case it appears to be to introduce a bistro called *Le Chien qui fume*, itself introducing

the canine constellations (CVn, CMa, & CMi), and in the second, to introduce the *Auerbachs Keller* in Leipzig, the Leipzig Observatory, and the constellations of Crater and Libra.

Quite apart from the tales concerning the constellations, many of which will already be familiar to most astronomers, there are other interesting nuggets within the introductory tales. One that I may mention is that the church of the village of the Hauts-Plateaux has a twisted spire like that of Chesterfield Parish Church, although the helicoidal form was apparently introduced deliberately in the belief that it would lessen wind resistance. (Helicoidal vanes are added to certain cylindrical chimneys for just such a reason.)

One might wonder who would benefit from reading this book, given that many of the astronomical tales and biographies are familiar, and that it is not only in French, but includes Walloon words and material. One article (No. 6 'Le catalogue d'Hipparque retrouvé?') makes the point that too many scientists are unaware of material published in other languages, and tend to rely upon web search engines to find papers of relevance. But without entering search terms in other languages, valuable references may go undetected. So perhaps all astronomers should read this book — learning French if necessary — to broaden their horizons. — STORM DUNLOP.

How to Find the Apollo Landing Sites, by J. L. Chen (Springer, Heidelberg), 2014. Pp. 253, 23·5 × 15·5 cm. Price £31·99/$34·99 (paperback; ISBN 978 3 319 06455 0).

This book describes itself as being "for everyone who wants to be able to connect the history of lunar exploration to the Moon visible above". It seeks to meet its aim by offering a practical guide to the location of the Apollo landing sites for users of small-to-medium telescopes. It also covers the sites of the Ranger-probe impacts, as well as those of the unmanned Surveyor craft. Obviously the detail of such sites is not visible in Earth-based telescopes and the book makes use of recent imagery from the *Lunar Reconnaissance Orbiter* (*LRO*) to show close-up views of landing sites and of the hardware left behind. Along the way it provides an outline account of the aims, events, and achievements of each mission covered.

The main problem with this volume is its scattergun approach, which means that it is difficult to identify a purposeful line of argument or even envisage a clearly defined target readership. It tries to be 'all things to all men', dipping — often very briefly — into such disparate topics as the phases and motions of the Moon, lunar geology, how to choose a telescope and mounting, types of eyepieces (including some of historical interest only), anecdotes surrounding the lunar landings, and even speculation about future missions and how they might be funded. The result is a volume that lacks clear direction and coherence, and all the topics raised have been covered better elsewhere. The reader seeking sound guidance on practical lunar observation would be better advised to consult Gerald North's *Observing the Moon: The Modern Astronomer's Guide* (Cambridge University Press, 2014); Don Wilhelm's classic *To a Rocky Moon* (University of Arizona Press, 1993) gives a much more secure account of lunar geology and the science of the US Moon programme; and Philip Stooke's magisterial *International Atlas of Lunar Exploration* (Cambridge University Press, 2007) offers a much more complete and systematic description of man's missions to the Moon.

The present book also shows signs of having been put together hastily, and it could have been more carefully edited. There are typos, stylistic awkwardness and oversights, and a tendency to repetition. Some of the illustrations are inadequately or wrongly captioned (*e.g.*, Fig. 13.4, which features the crater Eratosthenes, not Copernicus as labelled — although Copernicus is just visible on the horizon).

All in all, although the reader approaching the Apollo story for the first time might find features of interest in this volume, those looking for a sustained and coherent account will probably wish to look elsewhere. — BILL LEATHERBARROW.

Stratonauts: Pioneers Venturing into the Stratosphere, by M. von Ehrenfried (Springer, Heidelberg), 2014. Pp. 236, 24 × 16·5 cm. Price £31·99/$34·99 (paperback; ISBN 978 3 319 02900 9).

Everyone is familiar with the term 'astronaut', which (with the exception of the United States) is usually applied to anyone who flies above an altitude of 100 km. This book is dedicated to another group of equally heroic pioneers who have contributed to our knowledge of Earth's upper atmosphere by venturing into the stratosphere. As the title suggests, the volume concentrates on the individuals who risked their lives to reach ever greater altitudes — some in the name of scientific and technological research, some in pursuit of altitude records, and a few hoping for personal fame and publicity.

Although the many vehicles that carried these individuals into the stratosphere are briefly described, this is not a book for technophiles. On the other hand, the author, a former NASA sensor operator on a high-flying aircraft, has striven to include all of the stratospheric flights that have taken place since the early 20th Century. He also includes a brief summary of early balloon flights, and voyages which required special breathing apparatus or pressure suits. Even supersonic transport aircraft and *SpaceShipOne* get a mention.

Other chapters include the physiological and medical problems of flying above the troposphere, types of pressure suits, and some aspects of pilot training. One of the most unexpected appendices is devoted to Area 51, the region in Nevada which has become synonymous with alien-conspiracy stories.

The book is illustrated with more than 150 photographs, some showing the hardware which enabled the stratonauts to reach such dizzying heights, but most of them are portraits of the flyers themselves. — PETER BOND.

Fundamentals of Spacecraft Attitude Determination and Control, by F. L. Markley & J. L. Crassidis (Springer, Heidelberg), 2014. Pp. 486, 24 × 16 cm. Price £67·99/$99 (hardbound; ISBN 978 1 4939 0801 1).

This book may be for specialists in satellite projects, but as such it is of exceptional quality in both the range of subjects covered and the detail of that coverage. With ever-increasing demands from astronomical satellites for pointing accuracy and stability, this book has a lot to offer to those of us involved in the developments and data processing for such projects, describing in detail external forces as well as the effects of non-rigidity. As such it is a modern replacement for the now 37-year-old *Spacecraft Attitude Determination and Control* by James R. Wertz, which has been a major reference in this field for over three decades. Markley & Crassidis cover about everything that is relevant in this field, from the very basics of vectors, quaternions, through attitude kinematics and dynamics and sensors and actuators to methods for attitude

determination and attitude control. This is supplemented by substantial appendices providing further details on, amongst others, quaternions, orbit dynamics, and estimation theory. Real-life examples are used throughout the book, illustrating actual applications. Problems to solve are found at the end of each chapter. Although this is not a standard subject taught in astronomy, this book does provide essential background to issues that become ever more important in the development of astronomical satellites. And it is here that I have my only reservation with respect to this volume: the ESA astrometric missions *Hipparcos* and *Gaia*, with their very high requirements on attitude control and reconstruction, are nowhere referred to. Similarly, a discussion of the effects on the spacecraft attitude of clanks, the discrete adjustments of a spacecraft body to temperature changes, I could not find either. Still, this is a very worthwhile volume, highly recommended for anyone involved in astronomical or other satellite projects. — FLOOR VAN LEEUWEN.

Starmus: 50 Years of Man in Space, edited by G. Israelian & B. May (Starmus, through Carlton Books), 2014. Pp. 224, 28·5 × 23·5 cm. Price £30 (hardbound; ISBN 978 1 62795 26 8).

Held in Tenerife in 2011, the first Starmus festival brought together some of the most celebrated names in both astronautics and astrophysics, delivering a *mélange* of popular-level talks on topics ranging from the historical to cutting-edge. The 'mus' in Starmus was linked to a concert performed by Brian May (who also spoke to 'Our Mission in Space' in the lecture programme) and Tangerine Dream; whether the music was of historical or cutting-edge interest must be a matter of personal interpretation (an extended extract is available on YouTube, so you can judge for yourself).

I have to admit to being slightly bemused by the whole Starmus concept, but as far as I can make out it's intended as a very-high-end outreach activity, and a flagship for Canarian cultural tourism. Starmus's credentials as a prestige event are quickly established by listing just a few names from the register of speakers: Neil Armstrong, Buzz Aldrin, Alexei Leonov, Richard Dawkins, Kip Thorne, George Smoot … two dozen lecturers in total, nearly all of whom could be described as 'celebrities' in at least some contexts. These people don't come cheap — the interested reader can easily google some representative speaker's fees — and I understand that the event, heavily underwritten by the regional government, ran a loss at the sort of level that would keep the Cookie Monster in Duchy Originals for a very long time. Nevertheless, the festival was evidently successful enough to justify a second event, in autumn of 2014, with a similarly distinguished list of speakers.

The book is the written record of the talks from Starmus 2011, each around a half-dozen pages long, extensively illustrated in full colour with diagrams, with images both familiar and not so familiar, and with reportage photography from the event (professionally taken, and in a different league to the happy snaps often seen in conference proceedings). I imagine that most contributions were written specifically for the book, but many have the flavour of edited transcripts of talks, even though they are not merely verbatim records; that is, even in written form, they remain 'talks'. This has the benefit of lending a sense of immediacy to many articles, although the other side of the coin is that some authors allude to (*e.g.*) "the next illustration" without it always being entirely clear to which figure they're referring. (The illustrations are all captioned, but they're not numbered.)

While the talks are grouped with notional thematic links, in practice they're quite diverse, and range in tone from philosophical to prosaic. Topics include personal reminiscences of the pioneer astronauts, the origin and evolution of life, cosmology, black holes — essentially, the roll call of astro-linked 'sexy' subjects likely to be of interest to the "non-specialist but intelligent and inquiring" target audience. Certainly the level of the written contributions is well tuned to a readership at that level.

This is almost, but not quite, a coffee-table book; almost, but not quite, a popular-science book. I suppose my impression is that the whole is, if anything, rather less than the sum of the parts, but since no-one is likely to read this cover-to-cover, that scarcely matters; I certainly enjoyed dipping into it more or less randomly. Thus, while I remain at somewhat of a loss when it comes to identifying for whom this book is intended, its high production values, very modest cost*, wide-ranging scope, prestigious contributors, and authoritative essays, should make it a very attractive package for *someone*. — IAN D. HOWARTH.

Tourists in Space: A Practical Guide, 2nd Edition, by E. Seedhouse (Springer, Heidelberg), 2014. Pp. 281, 24 × 17 cm. Price £24·99/$44·99 (paperback; ISBN 978 3 319 05037 9).

I haven't come across a book on space tourism before as this is such a new subject. The author seems eminently placed to write a book of this type with a list of impressive qualifications in and out of the aerospace industry. The history of space tourists is not long, with numbers still in single figures, and only those with very deep pockets (*circa* $35–50 million per launch) for a ten-day stay on the *Space Station*. The story so far is really the preparation for space tourism, with spaceports ready or in-build for the anticipated influx of clients which the author's research puts at thousands.

The book describes the several companies who are building sub-orbital craft, and vying for your custom if you have $200–250K in your back pocket. Orbital tourism, it seems, is a whole order of magnitude more difficult to achieve. Orbital space habitats are discussed, the most likely being inflatable types, none of which have yet been flown, which leaves the *Space Station* the only destination for the short- to medium-term future.

The main thrust of the book is in the form of sub-orbital and orbital ground-school 'manuals'. These manuals detail what sub-orbital and orbital flight operators may require the prospective tourist to train for and be thoroughly aware of, covering psychology, physiology, emergency egress, and many other factors to make the experience an enjoyable and safe one.

Training for orbital flight and extended time in orbit is altogether more rigorous, with training for survival in different climates should your capsule land off course and not be found for an extended period being just one of the extra modules. I particularly liked the piece of advice: if you can't change your underwear for a week, take it off and give it a good airing! A short section is devoted to speculating about tourism to Mars and beyond, and while it makes a good read, it's science fiction. The book was published before the tragic crash of *Spaceship Two*, and this is going to set back the cause of space tourism yet again, but the author's enthusiasm for the subject comes through. The book is written

*As I write (2014 December), the book is widely available through on-line distributors at little more than half the already reasonable recommended retail price.

with authority and humour and if you have any interest in going to space it's a good read. You'll learn lots. — MALCOLM GOUGH.

Pearls of the Southern Sky: A Journey to Exotic Star Clusters, Nebulae and Galaxies, by D. Willasch & A. Slotegraaf (Firefly Books, Richmond Hill), 2014. Pp. 176, 21·5 × 31 cm. Price £25/$39·95 (hardbound; ISBN 987 1 77085 445 1).

As I am about to embark on trip to New Zealand, the request to review this book could hardly have come at a better time. Weighing just over 1 kg, it's a bit heavy for the suitcase, but that is more than adequately compensated by the high quality of the 71 beautiful full-size colour plates. These are arranged according to the season and R.A., and have been chosen subjectively for their prominence in the southern sky. Even the orientation of each image on the page is done aesthetically, as the authors point out. Facing each picture there is a page of text explaining, amongst other things, how to find the object, what one can expect to see, who discovered it, and what the object actually is. The R.A. and Dec. (presumably at Epoch 2000·0), scale, and catalogue designations are also given; and, importantly, a table at the back gives details of the source, the camera, and the processing used for each image.

A comprehensive set of appendices gives just about everything the reader could want, including a summary of the lives of stars, the properties of the different classes of object, a bibliography, and tables to relate object names (some of them informal) to catalogue designations. The text appeared generally, but not entirely, free of typographical errors.

The format is A4 'landscape', and, as such, it is in no way a handbook. It needs to be opened flat on the table, and attempts to use it outdoors in the dark will inevitably lead to it being dropped or its spine being damaged. (It would be better to copy the relevant sheets before going outside.)

To summarize, this book is a splendid compendium of images of southern, deep-sky objects, and it would be well-suited to a domestic coffee table, an airport lounge, or a travel-agent's office. I found the book inspiring, but as an amateur astronomer going abroad, I will be marking the positions of these "pearls of the southern sky" on my trusty copy of *Norton's* and using that! — JOHN HOWARTH.

Concise Catalog of Deep-Sky Objects, 2nd Edition, by W. H. Finlay (Springer, Heidelberg), 2014. Pp. 441, 23·5 × 15·5 cm. Price £22·99/$39·99 (paperback; ISBN 978 3 319 03169 9).

I have not read the first edition of this book which came out in 2003, so this review is self-standing; however, the publisher notes that the new edition adds amateur images of the Messier objects and details an additional 50 'southern sky' objects. Most of these pictures are quite good, and have been rendered well in the review copy (which has not always been the case in Springer books), but often annoyingly require a page turn so you can't compare the text with the image.

Each object has a small table with common data such as constellation, type, position, apparent size, age, distance, and apparent magnitude. There is also a short textual description, often with further information or discussion. I sampled a large number of the objects in this book and compared to various

reliable internet sources (*Simbad*, *NED*, *SEDS*) and the data seem to be correct compared with current sources. Another thing I found a little annoying is that the Messier objects are repeated in the NGC section of the book. Oddly some of the descriptive text is slightly different for the same object in each section, though not in any material sense — the facts about the object are the same.

This is certainly a useful source of information which might take some time to gather from internet sources for a particular object, though maybe it does not have as wide a coverage as you might like. Of course, books such as this will become out of date over time, but it should be a useful reference for many years. — CALLUM POTTER.

An Amateur's Guide to Observing and Imaging the Heavens, by I. Morison (Cambridge University Press), 2014. Pp. 321, 25 × 19 cm. Price £25/\$39·99 (hardbound; ISBN 978 1 107 61960 9).

The author's stated objective for this book is to be a "one-stop reference providing extensive information and advice about observing and imaging equipment". It generally does this very well and it contains one of the most accessible and informed reviews of currently available telescope systems that I have seen in any recent book.

Early on the author says "I do not believe that you can write about anything without having actual experience of its use". While the generality of that statement can be debated, I think that it is spot on in the specific case of a book which aims to guide observers through the vast range of different types of equipment and techniques that exist in the early 21st Century. There are too many astronomy books on the market where the authors simply repeat what they have read elsewhere with little or no direct experience of the subject. That is not the case here and Ian Morison seems to have owned, borrowed, or used practically every telescope that he writes about. A consequence of this approach is that the first half of the book reads a bit like an edited set of equipment reviews, but I didn't find that to be a problem since the different sections fit together well. The discussion of different telescope types is sufficiently general that the frequent mention of actual brands doesn't distract too much, and in many places they help to set the abstract discussion of refractors, reflectors, and so on in a practical context. Following the excellent description of telescope optics, I was rather disappointed to find that the discussion of mounts was rather superficial. As the author says, the mount is generally more important than the telescope when it comes to minimizing observing hassle. Despite this he only allocates six pages to discuss equatorial mounts and much of that space was taken up with polar alignment.

The second half of the book covers visual observing and imaging. The visual-observing section gives a good general overview based on the author's considerable experience. The imaging section covers all of the modern approaches (planetary 'webcam' imaging, DSLR, and cooled CCD) and again was based directly on the author's experience. These chapters are clearly written and generally error-free but I do think they suffer from being too specific to particular software packages. In a practical book such as this it is tempting to include detailed step-by-step guides, and that is what the author does here, but sections of the book are then in danger of reading like web-based 'HowTo'

guides. Much of this information goes out of date very quickly and could end up being more of a hindrance than a help to observers who use different tools. This is one of the limitations of the conventional book format.

In general the author has done a good job condensing the bewildering array of equipment and techniques available to the modern observer into a coherent discussion. The book is well produced although there was a serious problem with my copy in that the images were printed far too dark, so much of what the caption describes is lost. I spotted only a few errors, most of which were typos, and none of which were serious. Despite the limitations of format this book will appeal to many amateur astronomers who are looking for a detailed review of modern equipment and techniques. — NICK JAMES.

Choosing and Using Astronomical Filters, by M. Griffiths (Springer, Heidelberg), 2014. Pp. 269, 23·5 × 15·5 cm. Price £22·99/$39·99 (paperback; ISBN 978 1 4939 1043 4).

This book is intended for use by amateur astronomers who wish to observe a wide variety of astronomical objects visually or photographically. It is definitely not intended to help those who wish to use filters for scientific purposes, although these are mentioned briefly. The 'about the author' section at the start of the book contains an impressive list of his background achievements as both a professional astronomer and as a science popularizer, and therefore it is with some disquiet that this reviewer has to find so much wrong with the book.

The book contains details and background to the history and progress that has been made through the use of filters and it is one of the pleasanter aspects of the author's style that he has many details or anecdotes about some of those who have made earlier progress with this subject. He progresses rapidly over the subject of visual, photographic, and CCD/DSLR observations and gives details of what can be expected from each technique. Several pages are spent discussing the characteristics of various filters and where they might prove most useful. The author then spends several pages detailing how different filters can help with observing the Moon, and there are several colour prints of the Moon at various phases through various filters. The author then turns to visual or photographic observing of Solar System objects starting with Mercury and Venus. He lists the advantages of various filters and whether to observe those objects against an illuminated sky, and it is here that this reviewer starts to have doubts. There is no doubt that it is possible to see and to image both of those objects in daylight but what can one expect to see? The author is good enough to warn that the track record is not good but one has to question whether anything other than disappointment is likely to result from such efforts. The outer planets are then dealt with and the advice and information will be useful to those new to this aspect of astronomy.

Observing the Sun through a variety of filters is then discussed, including hydrogen alpha, beta, and even Ca II K. Much of this section might well be useful but the author seems not to be aware that whether visual use of the Ca II K filter is productive is very much a matter of the age of the observer. As one ages the lenses in one's eyes deteriorate and it is common for observers over a certain age not to be able to see any image through such a filter, while younger observers using the same equipment at the same time can see a detailed image.

Filters that can be used to image extended objects such as planetary nebulae or galaxies are then considered, followed by a useful discussion of image

manipulation using computer programs. The final 103 pages of the book, approximately 38% of the whole book, are given over to a list and then monochrome images, of a variety of extended objects, with a list of what filters might be useful to obtain colour images and what one might expect to see if they were used. To this reviewer this seems bizarre. In the earlier part of the book space and money has been found to include many colour images of the Sun, the Moon, or even sets of filters, and yet when it comes to images themselves we are presented with monochrome images with text telling what colours would be seen had colour been used. Even worse is the fact that many of these images have been obtained with the *Faulkes* telescopes (north and south and each two metres in diameter) so the results have little relevance to what observers can do with their home-based telescopes. Additionally, many of these images are bettered by those that appear almost monthly in popular astronomy magazines, obtained by observers with their own equipment.

There is another disquieting aspect of this book, and that is the number of errors. I counted 26 in the first 150 pages. These range from transposed numbers to words meaning the opposite of the one which was clearly intended. This book is part of the *Patrick Moore Practical Astronomy Series* and it is a great pity that the publishers seem to be prepared to capitalize on the name of a well-known science popularizer while at the same time being unable to provide proof-readers for the books in this series. It is not the first book in this series which this reviewer has found riddled with errors. We all make mistakes and it should be the responsibility of the publishers to correct them. Put briefly, there are aspects of this book which are both educational and entertaining but it is difficult to recommend it as a whole. — E. NORMAN WALKER.

Mars 3-D, by J. Bell (Sterling, New York; available through GMC, Lewes), 2014. Pp. 144, 23·5 × 16 cm. Price £14·99 (hardbound; ISBN 978 1 4549 1178 4).

Mars 3-D is a medium-sized hardback book the main aim of which is to showcase some of the best 3-D photos taken by the Mars rovers. There is a pair of red/green cardboard glasses neatly situated within the front cover which are thankfully large enough to fit over glasses if you wear them. The author uses the first few pages to explain the reasons behind his book, including a brief account of the Mars rovers and the people who built them, how the images were taken, and the mission parameters of each of the rovers. The following pages consist of natural or false-colour images on the left-hand page with the description below them; the main 3-D images, of which there are over 90, are on the right-hand page in a landscape format. Initially I thought this would be awkward but on flicking through the pages found it to be beneficial in viewing each image clearly. I would have preferred the entire layout of the pages to be in the landscape format as that would have prevented the constant turning of the book to read the description then turning it to view the 3-D image. Each page, while not technology-heavy, is presented to the reader using a brief explanation on how each image was obtained along with which rover took the image and a description of where it was situated on the Martian surface. The natural/false-colour photos are striking in themselves but the addition of the 3-D images makes the book an altogether different Mars experience. Not all the 3-D images are easy to discern: patience is needed on some while others just jump off the page. Included among the images are some remarkable microscopic views of the

Martian surface, stunning panoramic views of distant hills and boulder-strewn rugged terrain, all of which the rovers are experiencing. If you want to find out more about the various missions and rovers then you will find useful web links and additional resources at the back of the book.

While this book is not the sort to be used for detailed information, viewing its striking 3-D images taken by the Mars rovers and reading about the people behind them is a great way to appreciate the difficulties and wonders of the Martian surface. — HONOR WHEELER.

Encyclopaedia of the Solar System, 3rd Edition, edited by Tilman Spohn, Doris Breuer & Torrence V. Johnson (Elsevier, Oxford), 2014. Pp. 1311, 28·5 × 22·5 cm. Price £110 (hardbound; ISBN 978 0 12 415845 0).

Eight years is a long time in Solar System science and this is the interval between the second and third editions of this extremely impressive book. Since 2006 three NASA missions have visited the Moon, and China, India, and Japan have sent spacecraft too. *Messenger* is orbiting Mercury and *Venus Express* is probing the Cytherean atmosphere, a host of orbiters and rovers are investigating the astrobiological potential of Mars, *Cassini* is still imaging Saturn, *Dawn* has been orbiting Vesta and now Ceres, *Rosetta* is monitoring cometary decay, *New Horizons* is voyaging through the outer Solar System on its way to Pluto and the Edgeworth–Kuiper belt, and an army of geophysical theoreticians are modelling the magnetic, thermal, and tectonic evolution of rocky planets and satellites. As time passes, planetary flybys have been superseded by orbiters. Researchers then follow on with the landers and rovers. The hopeful amongst us look forward to sample-return missions and, in some rare cases, human exploration. And since the previous edition of this book, the number of known planets orbiting nearby stars has leapt up by an order of magnitude.

This book is lavishly and colourfully illustrated, and is accurately aimed at final-year university students and pioneering researchers. Much time has been spent on preparing relevant tables and informative graphs. It contains 57 review essays on topics varying from Europa and Enceladus to Venus: Surface and Interior, and X-rays in the Solar System. The list of the 107 contributors reads like a 'who's who' of planetary science. The emphasis is very much on what the Solar System is. Interestingly, out of the 1311 pages only 26 discuss where the System came from and even fewer are devoted to its future. Huge efforts have been made to explain observations and theories clearly and succinctly and to bring the reader up to date. I recommend the book without reservation. — DAVID W. HUGHES.

Dune Worlds: How Windblown Sand Shapes Planetary Landscapes, by R. D. Lorenz & J. R. Zimbelman (Springer, Heidelberg), 2014. Pp. 308, 28·5 × 21·5 cm. Price £90/$129 (hardbound; ISBN 978 3 540 89724 8).

Lorenz & Zimbelman nicely describe their book as "a travel guide to the research landscape". It is an impressive and beautifully crafted book, and the enthusiasm of its authors for their theme leaps out of the pages. It is not intended to be a formal textbook, but it does give a comprehensive idea of what is in fact a very broad and far-reaching field. The chapters can be read individually, and there are plenty of references given. I found my own field of interest in the Martian dust storms to be well covered, and it has also been exciting to learn more about dune fields on other Solar System bodies besides the Earth

and Mars. The existence of dunes on different bodies such as Venus and Titan enables the testing of models over a wide range of surface conditions. As the authors note in their conclusions, "Titan presents a fascinating counterpoint [to Mars] and shows that the juxtaposition of seas of liquid and seas of sand is not a combination unique to Earth".

The book consists of four principal parts. After an Introduction, the section entitled 'Dune basics' covers planetary wind patterns, the mechanics of sand transport, and the various types of dunes. The next part entitled 'Dune worlds' is a detailed and well-illustrated description of the dunes to be found upon the different Solar System bodies, and among many other things we read how the study of dunes enables a better understanding of climate changes. The next part, 'Dune studies', encompasses field studies (where it is noted how the availability of GPS has greatly assisted mapping the boundaries of geological features), laboratory modelling (including wind-tunnel work), remote sensing, and numerical modelling. The last part before the conclusions, 'Why dunes matter' covers dunes and climate, how to travel over dunes in fieldwork, and even two science-fictional dune worlds. The latter part mentions the filming of *Star Wars* at various locations.

Dune Worlds contains numerous fascinating illustrations. Many are unique to the book. One of the strangest is of the remarkable 'floating fence' upon the Algodone dune field at the USA–Mexico border, which is designed to maintain its height as the sands shift beneath it. The various images of dune fields from space are very beautiful.

I thoroughly enjoyed dipping into this book and can warmly recommend it. — RICHARD MCKIM.

Annual Review of Earth and Planetary Sciences, Volume 42, 2014, edited by R. Jeanloz & K. H. Freeman (Annual Reviews Inc., Palo Alto), 2014. Pp. 795, 24 × 19·5 cm. Price $269 (institutions, about £158), $101 (individual, about £59) (hardbound; ISBN 978 0 8243 2042 3).

Another giant achievement, with a broad spectrum of papers covering topics from Earth's core out to beyond the Solar System. Nevertheless, this year's offering is perhaps a little more focussed than usual on our own planet than what lies outside of it. There are several papers for seismologists. The book is headed up by two papers by Hiroo Kanamori, followed by a chapter on seafloor seismology — perhaps the final frontier for seismic monitoring and a challenging one at that. This chapter is complemented by one on seafloor geodesy, a discipline that poses formidable problems for technology, logistics, and cost. Nevertheless, the potential gains in knowledge are great and tantalizing, and steady progress in this difficult subject is being made. A second chapter deals with the use of Global Positioning System (GPS) observations to study the critical subject of slip along the subduction zones around Japan. The structure and anisotropy of the inner core — a small and difficult target for seismologists — follows along with a chapter on dynamic earthquake triggering. The topical subject of oil and gas is not neglected, but represented by chapters on the development of these resources from biota and their thermal maturation.

The very earliest origins and development of Earth are covered in a chapter on how the early Earth developed to become our modern world. Palaeontology is represented by chapters on herbivorous dinosaurs, phenotypic evolution, and the coupling between environment and evolution. A further chapter deals with

dinosaur growth, an interesting field in particular in the light of the currently emerging work on dinosaur embryology. At the other end of the life-cycle, apparently few dinosaurs received a telegram from the Queen. A number of chapters deal with geochemistry and mineralogy, including a chapter on the isotopes of mercury (not Mercury!) and the use of zircon U–Pb systematics for geochronology.

Moving outward from our own planet, the current status of the origin of Moon is reviewed. Not to ignore entirely the other planets, a neat chapter delves into the mineralogy of the Martian surface, and another deals with planetary reorientation.

As usual, this year's *Review* is beautifully produced on high-quality paper and with many wonderful figures and photographs reproduced in glorious technicolour. It is a highly recommended addition to the library or collection of all geophysicists and planetary scientists. — GILLIAN FOULGER.

Astronomical Data Analysis Software and Systems XXIII (ASP Conference Series, Vol. 485), edited by N. Manset & P. Forshay (Astronomical Society of the Pacific, San Francisco), 2014. Pp. 528, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 854 1).

The conference series ADASS (surely better known by its acronym than its full title 'Astronomical Data Analysis Software and Systems') is now on its 23rd incarnation. When the series started, back in 1991, astronomical computing was an acknowledged necessity, but still a rather underground activity. In 2014, 23 years later, it had become an established discipline, and when we started the journal *Astronomy and Computing*, it was more or less explicitly with the intention of providing a formal publication outlet for this now-well-defined community.

That formal outlet is important because ADASS is still very much a community event rather than primarily or only a publication outlet: it's a meeting place, gossip shop, and hiring fair, and 'everybody' goes to ADASS. That means that the contents of the ADASS volume give an accurate picture of what this community is concerned with this year, and that is most clearly articulated in the editors' division into strands of "13 invited talks, 34 oral contributions, 92 posters, 2 BoF sessions, 5 focus demos and 7 demos" (to quote the introduction). This review is therefore more a review of the typology of the discipline, in how the editors have divided this host into parts, this year.

Only one of the 'Birds of a Feather' sessions is described in the proceedings, in Part I, recording a discussion of practices for sharing source code within the discipline. This makes clear that the barriers there are not primarily technological, but about changing attitudes. The rest of the Part I talks were demos of data reduction and distribution systems, and it's clear that, even though the bulk of the specifically labelled 'virtual observatory' (VO) funding has gone, the VO is now thriving, with five out of the six demos describing VO-linked applications.

Parts II, III, IV, and VII concern themselves with updates of work in observatory operations, data management, catalogues, and spectroscopic pipelines, and illustrate the breadth and vitality of the area; *Euclid* and *Gaia* get a whole section to themselves, in Part IX. These are large software projects specific to individual data sources or archives, and many of the papers are incremental, rather than describing startling new breakthroughs; but this is very far from a defect, and illustrates one of the functions of the ADASS series

in giving developers the regular opportunity to stay up to date with how their colleagues, servicing other instruments, have pushed best practice forward this year. In contrast Parts V and VI, on visualization tools and data-analysis systems, show the extent to which this field now supports general-purpose systems, which give the users of all this data the tools to make best use of it, pulling (and indeed pooling) information from multiple sources, in a way which preserves meaning, rather than simply hauling bytes about. Tying those two clusters together is the interoperability problem that the VO was designed to address, and although it would be an exaggeration to say that the VO is pervasive in these parts, its components appear again and again in the papers as incidental but vital infrastructure.

Finally, Part VIII is a small section of papers on the mechanics of publishing, where they intersect with software systems. That includes two papers on the mechanics of publishing source code (and how astronomers can or should be induced to start doing so more than they do at present), two papers on data publication (on a smaller scale than the industrial-scale dissemination of the previous paragraph), and two on more bibliographical topics. For all the occasional lamentations here, it's worth remembering that astronomy is amongst those leading the academic world in distributing the raw materials of its scholarship to all who are interested.

This is not a slim volume — it's 500 pages of sometimes telegraphically short papers, and it wouldn't be great bedtime reading — but its length and variety illustrate the extent to which astronomical software is a diverse and thriving component of the astronomical academic community; these reports from the code-face show that the discipline is still in vigorous health. — NORMAN GRAY.

The Coronas-F Space Mission: Key Results for Solar Terrestrial Physics, edited by V. Kuznetsov (Springer, Heidelberg), 2014, Pp. 483, 24 × 16 cm. Price £117/$179 (hardbound: ISBN 978 3 642 39267 2).

The *Coronas-F* space mission, launched by the Russian Space Agency, operated from 2001 July to 2005 December. The spacecraft operated in a nearly circular orbit at a height of about 500 km, and performed a detailed high-resolution and multi-wavelength study of solar activity and its effect on the near-Earth environment during the decaying phase of solar cycle 23. The main scientific aims of the project were the investigation of the energy transfer from the solar interior to the surface, accumulation of the energy in the solar corona and its impulsive release, study of solar energetic particles, and helioseismology. The scientific payload of *Coronas-F* comprised 15 instruments performing comprehensive observations of the Sun in the entire electromagnetic spectrum from the optical to gamma-ray wavelengths, and *in-situ* measurements of the near-Earth plasma. The book presents the main and novel results of the mission, including revealing the increase in the amplitude of p-modes in the UV band, determination of the primary spectrum of the protons accelerated in flares, estimation of the total flux in the UV band and its response to the most powerful flares, first registration of coronal mass ejections in the X-ray band, investigation of the solar coronal dynamics in the X-ray band at heights up to three solar radii, revealing the high degree of linear polarization of the hard-X-ray emission produced in the impulsive phase of a solar flare, establishing the disappearance of the outer Earth's radiation belt in the main phase of magnetic storms, discovery of the hot — up to 20 million K — highly dynamical plasma structures ("coronal hot spiders") and their relationship with coronal mass

ejections, registration of the reflection from the Moon of a giant gamma-ray burst, and many others. The book also contains information about the data archive and techniques for the data pre-processing. The scientific findings summarized in the book provide the solar, heliospheric, and geophysical research communities with unique and comprehensive empirical knowledge crucial for further development of solar physics, plasma astrophysics, solar–terrestrial physics, and space weather. — VALERY NAKARIAKOV.

Atomic Spectroscopy and Radiative Processes, by E. Landi Degl'Innocenti (Springer, Heidelberg), 2014. Pp. 430, 24 × 16 cm. Price £67·99/$99 (hardbound; ISBN 978 88 470 2807 4).

This book is said "to bridge the gap between basic books on atomic spectroscopy and the very specialized publications for the advanced researcher". That is an accurate description, but it is probably rather closer to the specialized publications than to the basic books. This is a pretty advanced theoretical book and certainly not for the beginner. That said, if you already have a sound knowledge of basic spectroscopy and you are pretty good at theoretical work and quantum mechanics and special relativity, this is an excellent book — though you will have to work at it to get the most out of it.

Spectroscopy starts in Chapter 6. The first few chapters (which you should not skip) give a high-powered review of some basic physics, including electromagnetic and radiation theory, gauge invariance, Stokes parameters, Thomson and Rayleigh scattering, Bremsstrahlung, cyclotron and synchrotron radiation, creation and annihilation operators, and the Dirac equation. I list those to give a feeling for the sort of level of readership at which the book is aimed. It is assumed that the reader has a basic knowledge of relativity and quantum mechanics. One aspect that I particularly liked was the way in which the reader is at first given a classical account of a topic and then quantum mechanics and relativity are introduced. An example: when we first derive Schrödinger's equation we write $\sqrt{p^2/(2m)}$ for the kinetic energy of a particle. It is at that point that the equation is restricted to nonrelativistic (slowly moving) systems. Now let's do it again, but this time we'll write the kinetic energy as $\sqrt{(p^2 + m^2)} - m$, (we can see that $\sqrt{p^2/(2m)}$ is the first term in the binomial expansion of this) and see what happens to the wave equation, and (after some algebra!) we not only arrive at the Dirac equation, but we can see just why it is that the Dirac equation describes a particle of spin ½. The mathematics looks tough, but, if we work through it, we find that it really does take some of the mystery out of the spin, and we are now ready to start on the spectroscopy part of the book.

We start with the Bohr hydrogen atom, with an infinite nuclear mass. Then we allow the proton to move, and everything is the same as long as we replace the actual electron mass with its reduced mass. Now we are led to the Schrödinger equation and its solution in terms of spherical harmonics and Laguerre polynomials — fairly standard stuff so far. But now we move on to the Dirac equation, starting in its first-order nonrelativistic limit, and we are led to its solution *via* perturbation theory to the energy levels in terms of l, s, and j — a formula that many of us have seen, but how many of us know how to derive it? You will, if you work your way conscientiously through this text. One interesting snippet that I learned is that in the solution of Dirac's equation you cannot naïvely replace the electron mass with its reduced mass.

The alkali metals are fairly easy after we have mastered hydrogen. The next tough part comes when we have more than one optical electron. A helium atom is not like a massive star with two tiny planets moving around it. The interaction between the two electrons is every bit as strong as the forces between electron and nucleus — which makes it a rather more difficult problem. The author leads us inevitably to symmetry properties of the eigenfunctions, to Pauli's principle, and to "good" quantum numbers. Strictly speaking, L and S are "good" only for helium, though they are "good enough" for most of the light elements. Chapter 7 gives a good account of Hartree–Fock theory, Clebsch–Gordan coefficients (many authors spell Gordan wrongly — this book gets Gordan right, but slips up on Clebsch!), and angular-momentum theory. If you were faced with an examination question: "Explain what is meant by *angular momentum*", what would you write? Well, at the level of theoretical physics that we are dealing with in this book, the answer is: angular momentum **J** is an operator that satisfies the equation $\mathbf{J} \times \mathbf{J} = i\mathbf{J}$. What could be more straightforward than that? Once you have understood that and the $3j$ symbols, which the author prefers (as do I) to the Clebsch–Gordan coefficients, it is a short step to deriving the terms arising from a given configuration. One interesting trivium derived by the author is a formula telling you how many lines of calculation you need to derive the terms arising from a configuration of equivalent electrons. For f^6 it is 357. This is worth knowing before setting any exam questions. I wouldn't recommend going past p^3 or d^2 for an exam.

Next is how to calculate the energies of the terms (lots of applications of $3j$ symbols here); then spin–orbit interaction and the energies of the levels within the terms. (There is one minor temporary slip on page 217, where "term" and "multiplet" are confused.) Then there's jj-coupling and intermediate coupling, Zeeman and Paschen–Back effects, and hyperfine structure, all done well, but it is time for me to move on.

There's a good (though not easy) chapter on statistical thermodynamics (Boltzmann and Saha) with an interesting graph showing a P–T relation for a pure hydrogen plasma with different degrees of ionization; another good section on blackbody radiation. Everyone knows the relation $PV^\gamma = $ constant for a reversible adiabatic process, and what γ is for a monatomic and a diatomic gas. Quick — what is it for photons? If you are not sure, read this book.

There is plenty on intensities and profiles of spectrum lines (transition moments, Einstein coefficients, Voigt profiles), and forbidden lines (he gives details of the auroral, coronal, and nebular lines as examples), radiative transfer, limb darkening, and so on. (He says you can observe limb darkening only in the Sun, not in other stars. I don't know whether observers of eclipsing binaries would agree.) And there are appendices on several topics in physics — which I would recommend reading first before the rest of the book!

Are there any negatives? Well, I would say that the book is difficult — but that is a limitation of me rather than of the author. There is one very big black mark, though, in my opinion. The book is unrationalized cgs throughout, which will make it very hard for anyone brought up on SI. We have unnecessary 4πs and cs sprinkled through Maxwell's equations, an electric field equal to a magnetic field, equations that don't balance dimensionally, disc-shaped and needle-shaped cavities, unit magnetic poles one centimetre apart *in vacuo*, and so on. I thought all of that was ancient history. However, as long as that sort of thing doesn't worry you, the positives in the book well outweigh that negative.

I'll end with one more positive. The book is translated from the original Italian, and I have to give good marks to the translator, Giulio Del Zanna, for doing (apart from a very occasional lapse, such as 'thought' instead of 'taught', and 'precede' instead of 'precess') an excellent job. — JEREMY B. TATUM.

Radiative Processes in High Energy Astrophysics, by Gabriele Ghisellini (Springer, Heidelberg), 2013. Pp. 147, 24 × 14 cm. Price £31·99/$49·99 (paperback; ISBN 978 3 319 00611 6).

Gabriele Ghisellini's preface is remarkably informative, telling us that these lecture notes are intended as a modern successor to Rybicki & Lightman's 1979 *Radiative Processes in Astrophysics*, are intended primarily for students, that high-energy astrophysics is taken to mean "rather violent cosmic phenomena", no matter what wavelength observations reveal them, and that both strong gravity and large velocities are frequently associated with these phenomena.

Chapter 1 includes one of my favourite 'qualifying exam questions': derive the relation among the Einstein A and B coefficients; answers the burning question of what happens when you run past a temperature ("moving in a homogeneous radiation field"); and ends with its longest chapter, on active galactic nuclei, with applications of all the processes and most of the relations that have been discussed in the earlier chapters.

Ghisellini differs from Rybicki & Lightman in not providing large numbers of homework problems and solutions, though section 3.4, 'A Question', amounts to "derive the Eddington Limit for infalling and outflowing gas". This is fine. If one doesn't have one's own favourite high-energy astrophysics problems, one probably shouldn't be teaching this class.

There are some nice personal touches, including Maarten Schmidt's own report of how he came to recognize the redshift of 3C 273, and a footnote telling the reader that Martin Rees was 24 in 1966. Since the index includes names only when they are eponyms (Auger effect to Wien spectrum), I'll tell you that both are on p. 112. The discussion of special relativity is blessedly free of paradoxes (think of the life-time of cosmic-ray secondary muons, not high-speed cows trying to get both ends into a Lorentz-contracted barn). And, because the volume is divided into eight roughly equal chapters, it should make an excellent text for a quarter-long course at UC Irvine, or, I suppose, a term at Oxford or Cambridge; I don't know how long the instructional units are at the author's home institution in Milan, but probably also shorter than an American semester. In any case, I shall volunteer for the UCI radiation-mechanisms astrophysics class next time the opportunity arises, and plan on this as the primary textbook. — VIRGINIA TRIMBLE.

The Tenth Pacific Rim Conference on Stellar Astrophysics (ASP Conference Series, Vol. 482), edited by H.-W. Lee, Y. W. Kang & K.-C. Leung (Astronomical Society of the Pacific, San Francisco), 2014. Pp. 280, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound; ISBN 978 1 58381 848 0).

Marketing a conference proceedings nowadays must be increasingly difficult when many of the papers therein are already published by their authors on the Web; most of the usefulness is in providing a scholarly (though un-refereed) reference for the author. A proceedings may be defined as "A record of business carried on by a society or other organization", but since the contents of this book bear rather little resemblance to the on-line programme for the meeting

(it was held in 2013 May), this volume clearly favours a different definition. The 48 papers which it presents have been grouped under four headings: 'Stellar activities [*sic*] and atmospheres', 'Binary stars', 'Compact objects', and 'Stellar clusters' (though the first paper in the last category is entitled 'Progresses on binary stars in ...', thus rather blurring the formal categorization). In broad terms it offers a survey of current research in astrophysics by members of Asian Pacific Rim universities, who made up a very large fraction of the conference attendees.

In terms of *content*, the book covers most imaginable (and a few less easily imagined) topics in stellar physics, favouring aspects of spectroscopic or photometric variability but often with rather fewer details of the outcomes than of the preparations and observations — more like progress reports since the Ninth Pacific Rim Conference held in 2011 April. Several conclude merely with suggestions of what the new data might be persuaded to show, while one or two of the relatively few purely theory contributions would make both observers and traditional modellers squirm. Even so, it is encouraging to see so much on-going research in fields of stellar physics, keeping both older and newer equipment in high demand for observing time, and knitting the communities together through shared interests, particularly among the early-career researchers.

In terms of *presentation*, the editors seemed not to recognize that figures will come out small when reproduced in print, and that if too small (as some of them are) they will be unreadable and will not support the texts as intended. That is something of a disservice to authors. Many of the original figures were in colour, and both the text and their captions refer to colour-coding that has no correspondence in this B/W production. Some LaTeX errors have been allowed, not all the references are in the same style, and other evidence also points to incomplete proof-reading.

In terms of *readability*, how can one say it gently? Most of the authors are not native English speakers, and their struggles for expression surface on almost every page. It is highly commendable that they have managed to write coherently in a foreign language, and the English-speaking community should be more proactive with assistance. The editors do not seem to have done their job very efficiently (or perhaps they have already done much more that is not now visible?), but it does not help the authors that so many linguistic errors have been allowed to mar what are often very interesting and innovative papers. Another layer of editing should have been sought, and perhaps the blame is on the ASPCS for not requiring it.

Even so, this field is very much alive and kicking, and the book does its best to give all aspects of that research an independent voice. May such things continue to flourish! — ELIZABETH GRIFFIN.

Multi-Spin Galaxies (ASP Conference Series, Vol. 486), edited by E. Iodice & E. M. Corsini (Astronomical Society of the Pacific, San Francisco), 2014. Pp. 236, 23·5 × 15·5 cm. Price $77 (about £50) (hardbound: ISBN 978 1 58381 856 5).

Polar-ring galaxies have been of interest for very many years, largely because the presence of material (gas in particular) orbiting about two orthogonal axes in a galaxy offers the hope of being able to measure the shape as well as the depth of the gravitational potential. But radial-velocity measurements in these objects have proved difficult, the best spatial-resolution rotation curves are mostly

measured in optical emission lines, and are very expensive in terms of large-telescope time. Modern instrumentation has improved the situation, in terms of larger telescopes, more efficient detectors, and higher-multiplex integral-field units (IFUs). This volume presents the proceedings of a conference held at the Osservatorio Astronomico di Capodimonte, Naples, in late 2013, at which the latest results and ideas concerning polar-ring and related galaxies were discussed. Like all ASP conference proceedings, the hard-bound copy is well produced. Articles are prepared camera-ready, and there are a few which have proof-reading problems, and the quality of the diagrams is not uniform, but on the whole it's a well-produced volume. As well as polar-ring galaxies, other multi-spin systems are discussed, including warps in discs (of which, it is argued, polar-ring galaxies are but an extreme example), kinematically decoupled cores in early-type galaxies, inner discs, and outer haloes as evidenced from tracer dynamics. However, two key questions concerning polar-ring galaxies are posed: the question of how they are formed (mass exchange, merging, or misaligned accretion along filaments), and whether they really do tell us about the shape of the gravitational potential. Unfortunately the results of the various studies seem contradictory, and this is because the sample sizes are all still too small. We will have to wait for large samples to be probed by IFUs such as *SAURON*, *VIRUS-W*, and *VIMOS*, and other instruments in development.

Two very different articles stand out for me. The first is an argument by Pavel Kroupa that the distribution and properties of the dwarf satellites falsify the Standard Model of cosmology with exotic dark matter, and instead favour Milgrom's scale-invariant dynamics. A shorter paper by Kroupa and collaborators argues that the dynamics of polar-ring galaxies also favour Milgrom's model because the rotational velocities in the polar rings are systematically larger than those in the host galaxies. Am I convinced? This is a very fundamental question, and an awful lot has to be rethought if Milgrom is right. Much of Kroupa's argument is based around the Dual Dwarf Galaxy theorem, or a lack of observed dichotomy between tidally formed and primordial dwarf galaxies. This needs to be followed up, but in my view, neither the case for exotic dark matter nor that for scale-invariant dynamics has yet been made convincingly.

The second article which stands out, the last in the volume, concerns an art competition for local primary-school children on the theme of the shapes and colours of galaxies. This is an excellent example of an educational outreach project, and all conferences should include something like it.

Overall, this is a valuable addition to an institutional library. This kind of volume does age though, and the observational papers will no doubt be superseded over a very short time-scale. — DAVID CARTER.

The Large Scale Structures, by S. Ilić (Springer, Heidelberg), 2014, Pp. 140, 24 × 16 cm. Price £90/$129 (hardbound; ISBN 978 3 319 07745 1).

Recently cosmologists have been split, in practice, between those who study the early and the late Universe. Early-Universe cosmologists primarily use the Cosmic Microwave Background (CMB) to learn about the immediate aftermath of the Big Bang and search for evidence of cosmic inflation, primordial non-Gaussianity, and gravitational waves. Late-Universe cosmologists in general use the light from galaxies to study the growth of structure and the expansion history of the Universe, trying to understand the nature of dark matter, dark energy, and gravity itself. Of course both groups explore the same physics and

all are trying to say something meaningful about the nature of our Universe, its origins, history, and future. Nevertheless, concentration on different cosmic probes, expensive and time-consuming experiments, and even different statistical approaches can divide cosmologists in their daily work.

Stephane Ilić details in this, a print edition of his PhD thesis, some of the fascinating work that bridges the gap between both communities. He describes how we may be able to shed light on the time between last-scattering, when the Universe became transparent to light and the CMB photons were emitted, and the era accessible to modern galaxy surveys. Since its discovery in 1964 the CMB has been resolved in increasingly fine detail, most recently with the exquisite maps from the *Planck* satellite. By the time they reach us the CMB photons have cooled to a temperature of 2·73 Kelvin but tiny fluctuations in the signal across the sky, on the order of 1 in 10^5, tell us much about the physics of the early Universe.

Light from the CMB doesn't travel from redshift ~1100 to our telescopes without incident. As it passes through the gravitational field of the massive structures in the late Universe it receives an imprint. Light entering an especially dense region will gain energy (blueshift) and lose energy (redshift) as it leaves. The opposite happens with an under-dense region of space. In a universe dominated by matter these effects will cancel each other exactly but, in our Universe where the expansion of the Universe is accelerating, a photon travelling through a gravitational potential will receive a net increase in energy. This is known as the Integrated Sachs–Wolfe (ISW) effect. The detection of this effect is extremely difficult: the ISW imprints additional fluctuations on the CMB signal which are ten times smaller than the already minute primordial fluctuations. It is impossible at present to detect the individual impact of even the largest cosmic structures.

To use our data in a way that has a chance of a statistically significant detection, we need to stack the CMB signal behind clusters and voids detected in the late Universe. As the signals average together, noise and uncorrelated fluctuations drop out, leaving the imprint of the ISW effect. Ilić has done important work towards constructing robust and well-motivated stacking procedures. Even more interesting is Ilić's work on another, more unusual probe, that could be used to track the ISW signal in the CMB. The Cosmic Infrared Background (CIB) is, like the CMB, a diffuse emission, visible in the infrared across the whole sky. It originates from the "accumulated electromagnetic emissions from star-forming galaxies distributed across a large redshift range". Thus the CIB traces matter across a larger redshift range than that available in today's galaxy surveys.

The story Ilić tells is a fascinating one with much potential for future discoveries. The form of this book does it a disservice though. The work of outstanding doctoral students should be recognized but the publication of a PhD thesis in book form seems pointless. The cost puts it out of the reach of all but academic libraries and, in all honesty, there are better introductory treatments of these topics aimed at students. For those that want to see Ilić's work in particular they can get all his original papers for free on-line, and indeed the full original manuscript of this thesis. Springer, the publishers, obviously paid little attention to the book itself which is littered with typos and grammatical infelicities that any competent editor should have spotted. The final chapter, an unrelated paper on probing the epoch of re-ionization, is a natural part of a thesis but feels orphaned at the end of a published hardback.

By its very nature the book is also out of date, the thesis being completed before the publication of *Planck* measurements of the ISW effect performed, among others, by Ilić himself. If nothing else, this demonstrates what a fast-moving field Ilić is involved in, one that has the potential to open up to investigation whole eras of the history of the cosmos. — DONNACHA KIRK.

Here and There

HOW TO START AN ARGUMENT

If a degree of longitude at the equator was greater than one at the North Pole, then Newton would be proved right; if they were the same, the French position would be vindicated. — From 'How to End an Argument', *Los Angeles Times*, 2014 October 4.

WITH A PERIOD OF 200 MILLION YEARS, PRESUMABLY

His research interests revolve around Galactic structure … . — DAO Seminar Notice, 2014 October 8.