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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2015 December 11 at $16^h 00^m$
in the Geological Society Lecture Theatre, Burlington House

J. ZARNECKI, *President-Elect*
in the Chair

The President-Elect. Good afternoon, ladies and gentlemen, may I have your attention? Those of you who are very observant will realize that I am not Martin Barstow. Martin, along with our Treasurer, is jetting off to Kazakhstan at the moment, I believe, to assist Tim Peake being launched to the *International Space Station* (*ISS*) [laughter] on Tuesday, so I'm standing in for him. It's lovely to know that the Society is playing such an important part in the *ISS* project.

My first formal business is a sad one, namely to announce the recent deaths of two Fellows. First of all, Rod Davies, who was President of the Society from 1987 to 1989; and Jim Dungey, who won the Gold Medal in 1990 and of course has a Lecture named after him, who died earlier this year. So could I please ask you all to stand for a while in their memory?

Without further ado, we turn to this afternoon's programme and the first two talks are award talks, namely for the Fowler and the Winton Capital Awards; the first one is the Fowler Award Lecture to be given by Haley Gomez from the University of Cardiff. Her talk is entitled 'Can supernovae solve the dust-budget crisis?'

Professor Haley Gomez. The oft-quoted description of the cosmic-dust life-cycle assumes that stardust is predominately returned to the interstellar medium (ISM) by evolved low–intermediate-mass stars (LIMS) during their stellar-wind phase. Supernovae (SNe), or rather SN shocks, in this picture are thought to be dust destroyers, removing dust from the ISM on time-scales of ~ 10–100 Myrs. However, the time-scales needed and quantity of dust ejected by LIMS make it difficult to form significant amounts of dust in less than a gigayear. A recent detection with *ALMA* by Darach Watson *et al.*, where they discovered huge amounts of dust in a galaxy only 400 Myrs after the Big Bang, clearly suggests that a faster source of dust in galaxies is needed.

Our recent study of 26 submillimetre galaxies at redshifts 2–6 shows that this is not just a problem for the brightest, highest-redshift sources. Using multiwavelength photometry from the ultraviolet to the submillimetre to model the spectral-energy distribution of these more 'normal star-forming' galaxies, the dust mass we observe is on average 300 times more than we can predict assuming LIMS as the only source of dust. This problem has been coined the 'dust-budget crisis'. It is a simple accountancy issue: if SN shocks destroy dust, and LIMS stars are the only dust source, then we are destroying dust too quickly to replenish it *via* stars, and not forming it quickly enough at all redshifts.

One obvious question we can ask is whether SNe could be responsible for contributing to the dust budget: core-collapse or prompt type-Ia SNe could produce dust on faster time-scales. Historically, dust formation was seen directly and indirectly in young SNe (<5 yrs since explosion) and in older supernova remnants (SNR) as indicated by an increase in near-infrared continuum emission and reddening of the optical line emission. It seemed that the quantities detected in these works were negligible ($1–100 \times 10^{-6}$ solar masses). One possibility is that they could be potentially 'missing dust', since these datasets are sensitive to the bright emission from the hottest dust grains. To detect dust colder than about 100 K, we would need to observe at longer wavelengths (> 40 microns).

With the launch of the *Herschel* space observatory in 2009, we had unprecedented resolution, sensitivity, and wavelength coverage to be able to search for dust at a wide range of wavelengths (temperatures) in SNRs. A campaign was started to search for cooler dust in the ejecta of the Cas A, the Crab Nebula, Tycho and Kepler remnants, and the relatively younger SN1987A.

With *Herschel*, we were able to detect dust in the Tycho and Kepler SNRs (both type-Ia) but, by comparing with different tracers, we showed that this emission arose from the swept-up interstellar and circumstellar material, respectively. In Cas A, the *Herschel* observations revealed a cooler component of dust (35 K); when this was combined with the *Spitzer* detection of hot dust, it provided evidence for 0·1 solar masses of dust within the ejecta. Surprisingly, the dust grains are coincident with the reverse-shock-heated gas, demonstrating that dust grains can survive (or reform) after being shocked. Unfortunately the ubiquity of interstellar dust in our galaxy made it impossible to determine if dust colder than 35 K existed in the Cas A ejecta — we could not disentangle dust in the remnant from the foreground (similarly for Tycho and Kepler). Now, this is not the same as saying that there is no cold dust in these sources, rather we simply cannot distinguish it from the foreground/background emission unless it is at a higher temperature. This means that the dust masses measured in those sources are potentially lower limits, in agreement with sub-mm polarization studies of Cas A.

Our *Herschel* campaign was also able to reveal a significant quantity of dust in the Crab Nebula. Luckily for us, the Crab is located in a dust-free environment so the identification of the dust component was very clear. We combined the *Herschel* data with *Spitzer*, *Planck*, and *Herschel* spectroscopy measurements, creating a spectral-energy distribution (SED) spanning 0·1–10 000 microns. This allowed us to account precisely for synchrotron and line emission, and revealed the tell-tale signature from dust within the filaments. That provides definitive evidence that the Crab is an efficient dust factory, containing enough dust to make around 30 000–40 000 planet Earths. The lack of a pronounced reverse shock in the Crab also hints that the dust formed in the filaments could survive in the long term and perhaps contribute to the interstellar dust budget.

The final nail in the coffin came from serendipitous *Herschel* observations of SN1987A. *Herschel* detected a point source at the location of the SN, and a study of the SED led by Mikako Matsuura suggested a surprisingly large inferred dust mass of 0·4–0·7 solar masses emitting at 20 K! Later high-resolution observations with *ALMA* revealed that this large dust mass is confined to the SN-ejecta region only, *i.e.*, is freshly formed dust created in the time since the explosion. So before *Herschel*, negligible dust masses were measured in SNe, and now, by combining *Herschel*, *ALMA*, *Spitzer*, and *Planck* data, we have clear evidence that 0·1–0·7 solar masses of dust can be created in the ejecta material of nearby core-collapse SNe. The revised dust masses are 100–100 000 times more than measured in early SNe and in the pre-*Herschel* era.

Why is there such a large difference in the dust masses? Was it simply due to the longer-wavelength observations catching cold dust not seen before, or is there another reason? A new suggestion has been put forward by Christa Gall to explain this discrepancy: the different dust masses measured between SNRs and young SNe could simply be due to their age. That is, larger amounts of dust are seen in the former because those sources have had enough time to form the large dust masses. Observations of SN2010jl support this theory by showing a slow increase in NIR emission and optical extinction at early times due to dust formation; this growth rate then rapidly increases beyond about 240 days after the explosion and extrapolation from the power law agrees well with the SN1987A dust-mass measurements at 8000 days. Interestingly, theoretical models of dust formation in SNe fail to predict such a time evolution.

We're now at an impasse with dust studies with SNe (in the FIR at least) since confusion due to beam sizes hampers observations of distant or young SNe with *Herschel*, and its successor *SPICA*. Although *ALMA* breaks the resolution issue, the peak of the dust emission is not sampled, making dust-mass estimates more uncertain. In the future *JWST* will have the sensitivity and resolution to study dust in SNRs out to more than 5 Mpc but will be limited in wavelength to see only the hot dust (that is not sensitive to the dust mass). Far-IR interferometers such as *SPIRIT*/*FIRI* would allow us to reveal cool dust in statistical samples of SNe and SNRs but these are a long way off.

There is a silver lining, however: the origin of dust can be indirectly determined by comparing the dust, metallicity, stellar mass, and gas components in external galaxies. Our *Herschel* dust mapping of Andromeda at giant-molecular-cloud-complex scales provides crucial information on the dust gradient of the galaxy. We found that the dust-to-gas gradient in M 31 is steeper than the metallicity gradient, suggesting that there must be another dust source as well as stars (where one would expect the gradient to be approximately constant). The excess of dust seen in Andromeda in high-metallicity regions and the dearth at low metallicity provides support to the growing body of evidence in the literature that dust is being 'grown' in the interstellar medium. Further evidence comes from dust and gas studies of the *GAMA* fields, as observed by the *Herschel* ATLAS survey. In nearby galaxies, dust-scaling relations observed as a function of gas mass and metallicity require grain growth to be dominant. The space density of dusty galaxies out to redshifts of 0·5 also suggests that stardust must be supplemented by grain growth, outflows, and astration in order to explain the rapid evolution in the dust mass function over the last five-billion years.

So have we solved the dust-budget crisis? In the last ten years we have seen increasing evidence that supernova ejecta are efficient dust factories, made possible due to exploiting new instrumentation in the FIR and sub-mm, but we have yet to constrain their net contribution to the dust budget or gain statistically significant samples of sources. On the other hand, observations of dusty galaxies at low and high redshift provide strong evidence that stardust is, in fact, not enough: a significant mass of dust must be provided by grains growing in the space between the stars.

The President-Elect. We have a very short time for questions.

Mr. H. Regnart. I hope I'm not asking a silly question but is there any contribution that's worth considering from dust left over at star formation or emitted during the main-sequence life-time that's blown out of the stellar systems by their solar winds?

Professor Gomez. I don't think the amount of mass is that much in the systems. On the main sequence, there's not that much wind material and it's very diffuse so I don't think that would contribute much mass. One thing I didn't say is that this could be coming from high-mass stellar winds which would also be rapid. Again, the evidence is that there isn't much mass in those phases and as far as I understand, in terms of the mass budget, it's smaller than the AGB ejecta by quite a lot. That's a good question.

The President-Elect. One final question.

Dr. K. Smith. In a sort of fundamental sense, grain growth in the interstellar medium and grain growth on the late-time ejecta of supernovae are the same sort of process. It's just that the physical conditions in which they are occurring are rather different. Now, the supernovae are still going to be very hot in that state and my thought here is that it's not going to be uniform anymore. It's started interacting with the surrounding interstellar medium, and you've got all sorts of instabilities going on, so is the point where it suddenly starts producing dust the point where it starts fragmenting into hot and cold bits?

Professor Gomez. We don't know that but that's probably what's going on. I think Christa Gall actually raised the point in her paper, that it's something to do with the interaction with the surrounding material that then sends a shockwave back, and it's that that might start this rapid dust-mass increase. It's the interaction with the surrounding material that moves backwards and it might be then that you get that fragmentation that you're talking about, but we can't tell because we're just looking at extinction plus near-infrared ejecta; we're not mapping these things and resolving them. *ALMA* will be really useful since we can now at least look into the future and see what happens when the reverse shock comes in.

The President-Elect. Thank you very much — we must now move on. [Applause.]

Our second award talk is the Winton Capital Award talk and it's given by Richard Morton of Northumbria University. The title of his talk is 'Can Alfvén waves power the solar wind?'

Dr. R. Morton. Over the last few decades it has become evident that the Sun is, in fact, a very noisy neighbour. Any pretence that it only provides us with the energy for life and a gravitational mooring is now gone, with near continuous observations revealing that the Sun regularly throws out large quantities of high-energy, charged particles and twisted magnetic field into the heliosphere. The particulate output is guided along the Sun's outstretched magnetic field, which reaches out past the edges of the Solar System. As such, there are regular interactions between the debris thrown off of the Sun and the Earth, causing changes to the environmental conditions in near-Earth space, for example, geomagnetic storms or solar radiation storms. Such events have been termed 'space weather' and can have significant impact upon a technologically advanced society, degrading power-network operations, disrupting radio communications, or damaging satellite electronics, amongst other consequences. This has led to an increased interest in the monitoring and forecasting of space weather from a number of sectors including governments, armed forces, and industry.

The solar wind is the continuous particulate stream that accelerates outwards from the Sun's corona, reaching speeds of up to 700 km s^{-1}. It has been known for some time that the solar wind originates in the higher-latitude regions of the Sun, in distinct features known as coronal holes, where the Sun's magnetic field is open to the heliosphere. However, what is not evident is how the wind is accelerated to such colossal speeds, what is feeding the particulate output, and what heats the outflows to temperatures of a million Kelvin. One suggested mechanism is Alfvén waves, whose restoring force is magnetic tension. These waves are incompressible and, hence, notoriously difficult to dissipate, enabling them to transfer energy from the Sun's internal convective motions far into the extended corona and the solar wind. In order to make progress in forewarning how the solar wind streams will impact upon the near-Earth environment, understanding the role Alfvén waves play in the process of wind acceleration and heating is seen as vital.

The potential of the Alfvén waves was proposed back in the 1960s and numerous complex theories have evolved to describe the life-story of the waves, which appear to demonstrate that Alfvén waves can indeed heat the corona and power the solar wind. However, it is only over the last ten years that we have had the technological capability to probe the fine-scale magnetic structure of the Sun that supports these waves. The magnetic field is able to confine the hot, ionized plasma, defining a zoo of apparently discrete but highly dynamic magnetic structures from the photosphere to the corona — for example, spicules and coronal loops. Those features are over-dense compared to the ambient plasma environment in which they exist, forming preferential guides for the funnelling of wave energy to different regions of the atmosphere. The magnetic structure provides the conditions for a rich variety of different wave modes to exist, somewhat like the oscillatory modes of a drum — but with a greater spectrum of wave phenomena possible. As such, there are a number of wave modes that have properties similar to the classical Alfvén wave first postulated by Hannes Alfvén, which are perhaps best referred to as transverse waves due to the associated displacement of the magnetic field being perpendicular to the direction of energy transfer.

Evidence for such transverse waves was first found with the *Transition Region and Coronal Explorer* satellite in the late 1990s, observing the swaying of coronal loops following explosive activity. However, it wasn't until the mid to late 2000s that it was revealed that those waves were ubiquitous throughout the Sun's atmosphere. The basic properties of the transverse waves are currently being documented but the key will be to investigate whether they follow the paradigm outlined in many of the Alfvén-wave models designed to explain the acceleration of the solar wind.

The current story of the Alfvén waves depicted in the models suggests that the waves are excited predominantly by the turbulent convective motions that occur in the sub-surface layer known as the convection zone. A complex magnetic field bursts through the Sun's surface and pervades the atmosphere. The foot-points of those magnetic fields are, hence, embedded in the photosphere and are continually jostled by the convection. Evidence appears forthcoming to support this picture, with comparable velocity power spectra estimated from the motions of magnetic fields in the photosphere and the transverse waves in the chromosphere.

As the waves journey upwards through the atmosphere, a natural barrier to propagation occurs roughly 2000–3000 km above the surface. This barrier takes the form of the transition region, where the density drops off rapidly over a few-hundred kilometres. The transition region effectively acts as a frequency-dependent filter, restricting the flow of wave energy to the corona. While energy estimates of the transverse waves in the chromosphere and corona imply that only 5% of the observed chromospheric wave-energy flux reaches the corona, current observational estimates suggest the rate of reflection is only around 30–40%. However, recent evidence has demonstrated that some of the wave energy may be transferred by mode conversion to torsional motions before it reaches the corona. Hence, there is potentially a wealth of hidden wave energy in the corona, although the torsional motions are presently unable to be measured due to current instrumental limitations. The physical mechanism behind this energy transfer is lacking from current models of Alfvén-wave propagation, mainly due to the models' restriction to one dimension for tractability in solving the complex system of coupled equations over a large range of physical scales.

For the transverse wave energy that does make it to the corona, the waves are expected to propagate predominantly outwards in coronal holes, along a magnetic field that expands radially into the heliosphere. The current picture indicates that a radial variation in Alfvén speed associated with the varying magnetic field leads to a gradual, frequency-dependent reflection of the waves. This reflection is crucial as it enables a system of counter-propagating waves to be set up along the open magnetic-field lines, allowing for Alfvénic wave turbulence to develop. As such, the wave energy can cascade from large to small scales, enabling the dissipation of the energy, either for heating or accelerating the plasma. In 2015, I used the *Coronal Multi-channel Polarimeter* to examine the transverse waves in a coronal open-field region, and provided evidence that there indeed exists a system of counter-propagating transverse waves, with hints that the reflection rate is frequency dependent.

Unexpectedly, the results also implied that the Sun's internal acoustic modes play an important role in the excitation of the coronal transverse waves. A distinct, broad peak appears in a power spectrum that otherwise displays power-law behaviour. The peak is coincident in frequency with the expected location of maximal power for internal acoustic modes absorbed by magnetic fields in the photosphere. Again, this detail is missing from the models that describe the acceleration of the solar wind by Alfvén waves, but could have important implications for energy transfer.

While progress has been made recently in confirming some of the fundamental tenets of the currently-existing paradigm of Alfvén-wave propagation, there are a number of lines of evidence that indicate a new biography for the transfer of magnetic energy by the transverse waves is required. It is hoped that over the coming years we will be able to build a detailed description of the life-story of the transverse waves in the solar atmosphere, from their 'birth' in the turbulent rumblings of the photosphere to their eventual 'death' in the heliosphere. Only then will we be able to assess properly the role these waves play in determining the solar wind streams.

The President-Elect. We have time for just brief questions.

Professor C. Lintott. Could you say something about future datasets that might help you test some of these newer ideas? Is the *Solar Orbiter* useful or are we looking at something else?

Dr. Morton. To be honest, the data we have is rather underexploited for these studies. There's a lot of information still there that can be got out and is still very useful. We've now got a huge archive of these data that we can exploit — it's just really getting in there and doing more statistical studies. We've only really done very local studies. We're planning to do more statistical studies over an extended period of time, hopefully connecting imaging observations on the Sun with things we see further out, with data from *ACE*, *WIND*, *etc*.

Professor E. R. Priest. Of course, as well as accelerating the solar wind, we want to heat it as well. This mode-coupling is really important, it seems to me, and presumably you're going to mode couple into magneto-acoustic modes which are going to dissipate more easily. Is there enough energy in the magneto-acoustic modes to provide the heating?

Dr. Morton. You mean the observed Alfvén waves? I would say that's debatable at the moment. There are some people who have said it would, and then I've recently published some work that said not, but I still believe that we haven't accounted for all the wave energy properly. There's still something missing, especially when you look at non-thermal line widths, for example. So if you compare it to the measured swaying motion that you see, it's three or four times greater and they're supposed to represent Alfvén waves as well. So we're missing something still from imaging observations.

The President-Elect. We must move on. Thank you very much indeed. [Applause.]

The last two talks of today's meeting are related, and they are to celebrate the anniversary of William Smith. First of all, to introduce those two talks we have just a very brief presentation from Jim Bennett, who is representing the Society's Astronomical Heritage Committee.

Professor J. Bennett. I asked for a couple of minutes just to explain what's going to happen next. As you've heard, this is something organized by the Society's Astronomical Heritage Committee and we in that committee find we appreciate the two-page list of anniversaries that you find each year in the RAS diary. We thought we'd show our appreciation by trying occasionally to arrange and introduce some history and heritage into the meetings by choosing one of the anniversaries for the year and seeing if we can arrange a talk and get the Meetings Secretary to agree to include it in an Ordinary Meeting. We've been very fortunate in getting Tom Sharpe to come and speak, and then the Secretary has agreed a complementary talk by Sanjeev Gupta, which brings more astronomy into the occasion. This is the first in what we hope might be a feature. Of course, each year we have to get the Secretary to agree to this, but if you look down the list for 2016 do let me know if there's something you'd like to hear about. Mike Edmunds, who is the Chair of the Committee, would be also be happy to receive your requests.

The President-Elect. Thanks for that explanation and introduction. I would encourage people indeed to take up your suggestion and look at possible celebrations or historical anniversaries for next year. The first talk, then, is by Tom Sharpe from the Lyme Regis Museum and Cardiff University.

Mr. T. Sharpe. I used to be the Curator at the National Museum of Wales in Cardiff, where there is a substantial collection of William Smith's maps, and I have been looking into the history map in particular, and how it evolved. This year we are celebrating 200 years since the first geological map of the UK was made, by Smith. There is a copy of the map on the wall outside this lecture theatre. The curtains that cover it have been opened today and I recommend that you take a look — it really is a remarkable map. It is done on a scale of 5 miles to 1 inch and the man who made it typically travelled 10 000 miles per year, by foot, coach, or on horseback.

William Smith was born in 1769 in the small Cotswold village of Churchill. The son of the local blacksmith, he had an elementary-school education but was bright and interested in mathematics. He was taken on at age 18 by a surveyor, Edward Webb, in Stow-on-the-Wold. After a few years he was sent to near Bath in Somerset to survey coal mines, his work following that of John Strachey who had done the first survey 70–80 years earlier. Smith was then asked to survey a route for a new canal which would link the mines to the Kennet and Avon canal and then down to the Thames. It still exists in stretches. The plan was to have two branches of the canal, the northern and southern, and in the course of his work Smith found three distinct strata in the rocks — coal, a layer called red ground, and on top the stone which was used for Oxford and Cambridge colleges. During later travels elsewhere in south-west England Smith found similar strata, although he was not the first to discover it. Nicholas Steno, working in Tuscany in 1669 discovered a link between strata and fossils. Smith came up with the principle of superposition which stated that the oldest rocks were also the deepest; this idea had already been propagated by Robert Hooke, although Smith was probably not aware of it.

In 1796 Smith began to make a connection between the types of strata and the types of fossils that were found therein. This allowed strata to be identified once the fossils had been examined and classified, a principle that is still in extensive use today. Three years later he lost his job, but he knew that coal could be located as long as the related fossils could be identified. In the same year he published a list of 23 strata from coal to chalk along with the thickness of each stratum and the fossils that could be found within them. He now had enough information to plot a geology map of southern and eastern Britain. Attempts to publish the strata maps failed because the London publisher that Smith contacted, one John de Brett, went bust twice, in 1802 and 1804. In 1804 he met Sir Joseph Banks, the President of the Royal Society, who became his sponsor. In 1806 he moved to London, living not far from the mapmaker John Carey who in 1812 offered to publish Smith's map which then covered England and Wales and part of Scotland. The map is dated 1815 Aug 1, but it seems that it was not issued until the following month. It is printed on 15 sheets of Imperial-size paper and measures 8 ft 9 ins high and 6 ft 2 ins wide. It is hand-coloured by the mapmakers but also contains a cross-section showing the dipping strata from Snowdon to the Thames Basin with colours chosen to match the colours of the rock layers. Between 1817 and 1819 he published a series of geological cross-sections, a series of geological county maps (he finished about 20), and also an incomplete set of sheets illustrated from each stratum.

None of these benefitted him financially. In 1816 he was forced to sell his collection of fossils to the British Museum and he gave a catalogue to go with them. That collection largely still exists in the British Museum. In 1819 he spent ten weeks in the Debtor's Prison in London.

The ages of rock had not been established during Smith's time, other than the estimate of Archbishop Ussher of Armagh of 4004 BC. Isaac Newton found 3986 BC, and others found similar dates. But in the late 18th Century things began to change. The Comte de Buffon estimated that the Earth was at least 75 000 years old and possibly as much as 10 million. In the 1780s James Hutton, the doyen of Scottish geologists, could see no vestiges of a beginning and no prospect of an end. Smith believed that all the rocks formed at the same time but by 1806 he mentions that the age of the Earth was "large".

Charles Darwin was firstly a geologist and, assuming that the erosion rate of the Weald in southern England was 1 inch per century, had estimated that the Earth's age was 306 million years, but he dropped this estimate after the publication of the third edition of *The Origin of Species*. At the end of the 19th Century the physicist William Thompson came up with 20 to 40 million years but it was only in 1956 that we came to the currently accepted age of 4·55 billion years.

To conclude, can I point out that there is a website called www.strata-smith.com which was launched this year and which allows you to 'fly' over the map.

The President-Elect. Again we have a brief time for questions.

Professor S. Miller. As he was around at the same time as other people making their own sort of geological maps, like De la Beche and so on, how did Smith interact with them?

Mr. Sharpe. De la Beche really started in the 1830s: he's producing some geological maps in the 1820s, Pembrokeshire in 1822 and an earlier outline map of the geology around Lyme Regis where he was based, but nothing on different scales. I think very early on the Geological Society visited Smith to see what he was doing and they didn't think that using fossils and Smith's principles would actually work for making a geological map. But very quickly they realized that they *would* have to use Smith's principles to do that, and the map you see out there matches that. The map that De la Beche and the others produced from the 1830s really takes Smith's ideas and advances them. They're much more detailed maps, particularly of the older strata; De la Beche was mapping in Devon and then moved down into Cornwall, and in 1835 you get the establishment of the geological survey of Cornwall which was a big project. Smith is very vague on those areas of older rocks: Wales and the West Country, Devon, and particularly Cornwall. He's not got much of Scotland in there and really I think it's fortunate that Smith was born where he was because we are familiar with a simple sequence of dipping strata that were fossil rich. If he was born Welsh or Scottish he probably would not have done what he did.

The President-Elect. A final question?

Dr. A. Chapman. Thank you very much indeed, I certainly appreciate what you've said about Robert Hooke, who I think is a very significant figure. Two small points about historical chronologies. First of all Archbishop Ussher was not writing in a geological or consciously 'cosmological' context. He was, rather, writing as an ecclesiastical historian, and trying to date ancient human events by the best historiographical methods of the day — things like the date of the Jewish Exodus from Egypt, the building of Solomon's Temple, and so on. He calculates 4004 BC from the Biblical genealogies to establish what he saw as the commencement of human history. Ussher was not attempting to describe the age of the Earth in any geophysical sense that we would understand today. Secondly, Robert Hooke was thinking in 'geophysical' terms in his post-1664 'Earthquake Discourses' to the Royal Society, including pointing out that there were bands of geological strata at Freshwater, Isle of Wight, that were 60 feet above the high-water mark with parallel beds at Hurst Castle off the mainland coast, and wondering what had happened to the land in between. In the 1660s, therefore, Hooke was suggesting that the Earth might be very ancient, and that the Biblical narrative, commencing with Adam and Eve around 4004 BC, was the age of the human race. Could there have been a vast geological period, therefore, between 'In the Beginning', or the Creation *ex nihilo*, and the emergence of the human race? Edmond Halley also took up the idea of the 'Great Chaos', or Creation, taking place long before Biblical human history began, to give the Earth an unspecified antiquity. So the idea of 'an eternity to dispose of' before Adam and Eve, and a very ancient Earth, had certainly been floating around long before William Smith. Thanks for an excellent lecture.

Mr. Sharpe. It would be good to know more of what Smith's sources were. When he went to Debtor's Prison, all of his library was seized so we have no idea what books Smith had available to him. It would be great to know what his influences were. Thank you for that.

The President-Elect. Thank you very much indeed. [Applause.] Our last presentation is from Sanjeev Gupta, Imperial College, on 'The adventures of *Curiosity* and William Smith on Mars — a re-imagining'

Professor S. Gupta. I'm part of the MSSL/Mars *Curiosity* team, which consists of 400 scientists and 100 engineers who are guiding the robot. The aim is to answer the question 'Did life arise elsewhere?'. Smith was able to arrange his fossils in space and relative time whereas we have no fossils (yet!) to investigate.

Curiosity landed in a place which has fixed successions of rocks, and Gale Crater (150 km wide with a 5-km-high central mountain called Mount Sharp) was chosen because the rover could potentially drive from the base to the top and make a record of the Martian surface through time in one place.

At this very moment in the JPL Operations room the team are making decisions about what the rover will do over the weekend. We looked at the rocks in Gale Crater from orbital imagery in order to try and predict what sort of conditions we might expect *Curiosity* to face. When the rover landed we started by looking at rocks in the local vicinity. The rover is fitted with a huge amount of geochemical equipment but the geochemists are dependent on the stratigraphic geologists to make sense of the rocks. It is not possible to do fine-scale mapping or make extensive observations at any one site because of the long-term goal of reaching Mount Sharp. The absence of fossils between layers of rock makes geochronology very difficult.

At 6 pm there will be horse trading between the teams in the Science Operations Working Group to decide what experiments will go into the plan for the weekend, as there are limitations due to time, power, and engineering constraints. We might actually do two hours of science each day. At the moment we have some very interesting bedrock to examine, and an experiment to do geochemistry on that bedrock will be done tomorrow, and we'll take photographs to map the current terrain. We'll also look at the Bagnold dune field.

There are 17 cameras on board *Curiosity*, one of which allows us to see details as small as 1 mm. The rover has driven from the landing site east away to the mountain where you can see strata. We do not know if the strata are sedimentary or igneous in nature so the team voted by 4 to 1 to drive east. As we proceeded we encountered rounded pebbles, which are the first evidence for flowing water on the surface of Mars. Then we found sub-angular-to-rounded sand grains in a sample of rock, so as this rock was sandstone it meant that the rocks were sedimentary — a really important finding. We have found no igneous rocks at all but we have found igneous pebbles in the sedimentary rock.

We also drilled the first hole (6-cm deep) on Mars. The samples retrieved were subject to X-ray diffraction which allowed us to date the rocks. We measured the argon and potassium content and these give an original crystallization age of four billion years. Like Smith we were able to construct a stratigraphic section at the locality — we drilled through mudstone into river sandstone.

Every bit of science we do with the rover is absolutely dependent on those maps because it allows us to place the samples in context. If you don't have the map you don't have the relative chronology of each sample, and so the geochemistry and the change in geochemistry makes absolutely no sense. In the river beds we encountered we could measure direction of flow and even deduce the flow speed from simple physics.

We can take stereo-imagery from the rover and put it into a programme which allows us to view outcrops in 3D and we can geologically map these onto the outcrops. We built a digital terrain model and built the imagery on top of it. Problems with hard rocks meant that the rover's path had to be changed so that it moved only through softer terrain and we needed to map the terrain before we moved the rover. This resulted in a rather circuitous path through a whole series of valleys, one of which gave us a cross-section across the stratigraphy. The rocks here represent an ancient delta going into a lake, and so we drove south and reached Mount Sharp. We found very-fine-scale layered sedimentation indicative of standing water. Some argued that this was done by wind but this does not explain the fine scale of the layers. At present we are close to Murray Butte to look at wind-blown deposits.

The next rover will be carried on the *Exo-Mars* mission and is being built by Airbus at Stevenage. The launch is planned for 2018 with arrival at Mars in 2019. We have three possible landing sites but we will have to build the geological maps first.

The President-Elect. Time for brief questions. I'm sure there could be lots.

Dr. G. Q. G. Stanley. Fantastic, the graphics are amazing and the pictures were just out of this world. [Laughter.] One of the things that struck me was the scale with which the geology changes. It seems very much smaller — there are smaller areas and you go from one geology to another in quick succession. It's like overload for the geologists! Is it very much like that?

Professor Gupta. It is very much like that and the point is that Gale Crater was picked with the primary investigation site being outside the ellipse. That's the base of Mount Sharp. That is outside the ellipse, so up until recently we've been having to drive — just driving and driving and driving. We've been shooting pictures, and driving quickly by almost all of the outcrops, but we've slowed down now because we're on these beautiful rocks and we can investigate them. The aim of the mission has been to get to the base of Mount Sharp. What's interesting here is that these rocks are just where you're seeing the bluish-grey colours; just below that you have extensive deposits of clay minerals that have been seen from orbit. As you know, clay minerals are hydrated minerals and the excitement is to go and get to those. Getting there has been much slower than we anticipated but clay minerals indicate water–rock interaction, but also when they crystallize, they're orthogenic, they may crystallize organic matter. They may also preserve organic matter, so there is huge astrobiological interest in looking at clays. Our goal is to get there as fast as possible. That's why the geology is done very quickly.

Mr. Regnart. Where you proposed water processing to explain your observations, can you always rule out the possibility of wind processing?

Professor Gupta. We were getting pebbles that are this big [gesture]. They're rounded so there's just no way that they could be wind-blown. Sometimes we argue about the interpretation. For one of the deposits I showed you, we can't tell whether they were deposited by rivers or air because you can't differentiate. When you've got pebbles that big, it's got to be water.

The President-Elect. Time for one last question.

Dr. C. Trayner. You showed those lovely photographs of the fine-grained parallel strata that you've found down in a lake which had been carried on all the way across. What process then cut them away and removed some of it so that we can see a section through it?

Professor Gupta. That's a very interesting question. It really boils down to why is Mount Sharp a mountain in the middle of Gale Crater? There have been two really contrasting hypotheses. One of the hypotheses, which I think we've disproved, is that basically the strata that we're seeing on Mount Sharp are wind-blown deposits that have become wrapped around the central peak of Mount Sharp. Most of us on the team argue that actually what's happened is that Gale Crater got filled with sediment and then wind erosion has stripped it away over billions of years. The strata that we're looking at there are about three and a half billion years old so there's quite a lot of time for that to happen and we see plenty of evidence on other parts of Mars where craters are completely filled in, so I think that's a valid argument.

Dr. Trayner. Wind erosion, so it's not solid rock, it's just sand is it, the layers?

Professor Gupta. No, the layers are rock, but wind abrasion is enough and you can see this very clearly on Earth.

The President-Elect. Thank you very much to all of our speakers. [Applause.] I will finish by inviting you all to a seasonal drinks reception in the RAS library. And finally, I give notice that the next monthly Open Meeting of the Society will be on Friday the 9th of January 2016. Happy Christmas to everybody.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2016 January 8 at $16^{h}\ 00^{m}$
in the Geological Society Lecture Theatre, Burlington House

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

Mr. S. Kirk. Good afternoon, ladies and gentlemen. This is a first for us as I imagine it is for you. We are 'Time Will Tell Theatre'. Two years ago, we were approached by a member of your Council, Mandy Bailey, and asked about the possibility of creating a piece of work to commemorate what is a very significant anniversary, the first time that women were admitted as Fellows and Associates rather than honorary members of the RAS. So here we are, we have created a piece of work, it's called "The way to the stars" and we hope you enjoy it.

[There followed a 30-minute dramatic presentation of the role of women in astronomy from the earliest times until 1916 when the RAS first admitted women into full membership. The actors, attired in Edwardian costume, were Kathy Hipperson, Lucy Charles, Tracy Russell, Simon Kirk, and Simon Norbury. The script was written by Simon Kirk with assistance from Mandy Bailey, Sian Prosser, and Mike Edmunds.]

The President. I'd just like to say what a wonderful and unique way that was of celebrating this important anniversary. Please give them all a thoroughly massive round of applause again. [Applause.] And before he escapes, I think we should also thank Mike [Edmunds] and Mandy [Bailey], who engineered this for us. [Applause.]

I'm not sure how to follow that [laughter] but I will try. Firstly, I'd like to say it's so great to see such a full house to celebrate this important occasion for us. Diversity is important in the Society and clearly we've come a long way, but obviously there is still work that we need to do and I would like to see more improvement over the next few years. I'll step down later in the year but I know it will carry on within the Society. I'd like to draw your attention to another part of the celebration, if you haven't seen it: there is a wonderful display of photographs of current female Fellows to be found in Burlington House. It really does show what a fantastic community we have now, after 100 years. I was thinking as we listened to the presentation that it's about time we had a Society song. I look forward to rehearsing it and singing it at the end of each Ordinary Meeting. [Laughter.]

To coincide with the celebration that we've been undertaking today and hopefully throughout the year of the 100th anniversary of the admission of women to the Fellowship of the Royal Astronomical Society, I'm very pleased to announce that the Society will launch a new medal later this year. This will be named the Annie Maunder Medal after the solar physicist who was one of the earliest Fellows of the Society, and the medal will be awarded for outreach. I've got a few further details that have been passed on to me and I'd like to read them out because I think it's important to illustrate the importance of the medal and the background to it. The descendants of Annie Maunder have given us permission to use her image on our medal and have asked us to mention that the great-great granddaughter of E. W. Maunder (Annie Scott Dill Maunder's husband) has just had an award named after her called the Dr. Katherine Giles Award to support media training for scientists. So there's clearly still a lot of activity going on amongst the descendants of Annie Maunder and relations. This aims to improve scientific-media skills, encouraging scientists to speak to journalists and in so doing improve the reporting of science within the UK, which I know has improved a lot in recent years but clearly we could do more. Dr. Katherine Giles was a NERC research fellow and lecturer working in the centre for polar observations and measurement at UCL. I think you will know some of the story here because she was killed tragically a couple of years ago, and her research until her death in an accident in 2013 led to a greater understanding of the complex interactions between sea-ice cover, wind patterns, and ocean circulation. So two great awards to record the contributions of two brilliant scientists.

It's now my pleasure to announce the 2016 RAS Awards and it's always great to do that, to celebrate the achievements of the Fellowship of the Society. I'm pleased to say that the Gold Medals will be awarded to Professor John Barrow from Cambridge, who will receive the Astronomy Gold Medal, and Professor Philip England from the University of Oxford, who will receive the 'G' Gold Medal. Now I know John is in the audience, but I think we should give them both a round of applause. [Applause.] Thank you. I'm going to read the rest of the list and perhaps we'll have another round of applause at the end in case we have some of the medallists here. The Chapman Medal is awarded to Professor Philippa Browning from the University of Manchester, the Eddington Medal is awarded to Professor Tony Bell from the Rutherford Appleton Laboratory, the Herschel Medal to Professor James Dunlop from the University of Edinburgh, and the Price Medal to Professor John Tarduno from Rochester, New York. The Jackson-Gwilt Medal for instrumentation is awarded to Professor Bruce Swinyard, somebody I knew very well as an observational astronomer, but posthumously because sadly he passed away recently. The Patrick Moore Medal will be awarded to Mr. Steve Bush from Sackville School in West Sussex. For the Fowler Awards, the 'A' Award will go to Dr. Andrew Pontzen from UCL and the 'G' Award to Dr. Sarah Badman from the University of Lancaster.

Winton Capital Awards go to Dr. Ralph Schoenrich from the University of Oxford, who receives the 'A' Award, and the 'G' Award goes to Dr. Dali Kong from the University of Exeter. There is only a 'G' Group Award this year and that goes to *EISCAT*, the *European Incoherent Scatter Radar System*, and that's led by Dr. Craig Heinselman who is the current director of the *EISCAT* scientific association, while the current chair of the *EISCAT* council is Professor Ian McRae. The Service Award for Astronomy goes to Professor Alan Wells from the University of Leicester, and the 'G' Award goes to Professor Peter Styles from the University of Keele. I haven't finished, there's still more to come. [Laughter.] The Honorary Fellowships, which this year are all 'A', go to Professor Joergen Christensen-Dalsgaard from the Stellar Astrophysics Centre in Denmark, to Professor Neil Gehrels from the Goddard Space Flight Center, and to Professor Alvio Renzini from the National Institute of Astrophysics at the Astronomical Observatory in Padova in Italy. The George Darwin Lecturer will be Professor Michael Kramer from Bonn and the University of Manchester at Jodrell Bank. The Harold Jeffreys Lecturer will be Dr. Jenny Collier from Imperial College London. The James Dungey Lecturer will be Professor Betty Lanchester from the University of Southampton. And last but not least, the Gerald Whitrow Lecturer will be Dr. Neil Turok from the Perimeter Institute in Canada. I think that's a fantastic array of recipients that represents the diversity and quality of the Society, and I think we should give them all a round of applause. [Applause.]

So on to our speakers' programme and our two speakers this afternoon are really going to have a hard act to follow, but first I'd like to invite our RAS 2015 Group 'G' Award winner, Professor Louise Harra from UCL, without chaperone [laughter], to talk about 'Exploring solar activity with the *Hinode* spacecraft'.

Professor Louise Harra. In 2015, the *Hinode EUV Imaging Spectrometer* (*EIS*) team won the RAS Group Achievement Award. This is a brief summary of the science that has been produced from data from the *Hinode* spacecraft with an emphasis on the results from the *EIS* instrument. *EIS* is a spectrometer that observes in the EUV waveband. It uses four different slits in order to create spectrally pure images of the Sun by either 'rastering' the narrow slits across the target on the Sun or by using wider slits that allow images to be taken by losing some spectral resolution. The instrument was built and is now operated by a consortium based in the UK, US, Japan, and Norway. The Japanese spacecraft was launched in 2006 September, previously known as *Solar-B*, and was christened *Hinode* (meaning 'sunrise' in Japanese) after its first successful orbit. *EIS* has performed flawlessly for over 9 years — and in the words of Jon Culshaw at the NAM dinner in 2015, "it sounds wonderfully impressive". The *Hinode* spacecraft also has two other instruments – the first-ever solar optical telescope in space (the *Solar Optical Telescope*, *SOT*), and the X-ray telescope that images the Sun in the higher-energy régime. The number of refereed publications using *Hinode* data is close to 1000, with 14 nations across the world and 12 institutes in the UK making use of the data. Around 80 PhD theses have made use of *Hinode* data.

EIS is producing high-spatial- and spectral-resolution data simultaneously in the EUV waveband. When the first full spectra were analyzed a wide range of spectral lines were found, ranging from He II to high-ionization stages of iron. Indeed, what surprised us is that although we thought we understood this wavelength range, 40% of the spectral lines seen were new.

Since launch, observations have been made during the extended solar minimum, and the current solar maximum. This solar cycle has been particularly interesting — the longest solar minimum to have occurred in over 100 years, sparking fears in the media that the Sun's dynamo had stopped working! From the early days of the mission, the *Hinode* team ensured that observations were made of the polar regions. The poles provide us with insight into the global magnetic field that defines the activity cycle — and having a view of how the Sun's polarity changes is key. These consistent observations revealed small-scale magnetic fields at the poles with the *SOT* data. The magnetic fields were tracked and it was found that the north pole started reversing well before the south pole. The solar magnetic field changed in an asymmetric fashion coming out of the recent extended minimum. It is known that the polarity change is driven by the active regions on the disc dispersing with time. The active regions are tilted relative to the equator, and the magnetic field in the lagging part of the regions slowly move towards the polar regions, leading to a polarity reversal. The 'streams' of magnetic field can clearly be seen in the magnetic butterfly diagram. One of the scientific questions that *EIS* data could address was whether these streams change the coronal dynamics at the poles. The long-term observations made allowed us to explore this. Viewing the poles spectroscopically reveals a new world. The images show us bright points, jets, and a diffuse corona. The spectroscopic data show us something else — we see regions of strong dynamics with no intensity enhancement. The 'secret' world at this small spatial scale was tracked over seven years. It was found that although the global magnetic field and the sunspot-activity levels were changing significantly, the level of dynamics at the poles did not change. This result has an impact in both understanding how the fast solar wind is formed and understanding the all-important solar dynamo.

One of the intriguing scientific questions for us to understand is where the slow solar wind comes from. The slow wind fluctuates with speeds of 200–600 km/s. It is mostly focussed around the activity belt, and multiple sources and theories have been proposed to explain it. Our new world of spectrally pure, high-resolution data from the corona has shown consistently that in each and every active region observed there is always a part of it that has weak intensity, but with strong blue-shifted plasma. This is usually at the edge of the active region between regions where the magnetic field is drastically changing its connectivity. These regions are hot and dynamic with flows of up to 200 km/s being seen. The flows change rapidly with time. Of course, this is all very well, but we need then to know if this plasma can actually leave the Sun and make its way into the solar wind, and travel through the heliosphere. This is where it becomes tricky. Our measurements of the solar wind are currently made mostly at 1 AU. During this passage it can change significantly. We have our spectroscopic weapon of measuring the abundances. This has been done, and those regions with strong blue-shifts have been found to have abundances consistent with those of the slow solar wind measured at 1 AU. We need to understand the physical processes of how the solar wind propagates in more detail.

A final scientific question to explore is that of the driver of solar flares. Magnetic reconnection is one process that has been put forward to explain the energies observed in flaring. The model has many observations that are consistent with it. *EIS* data were able to show spectroscopically that there is turbulence both right above the magnetic loops and the plasma inflow. Those observations are expected by the reconnection model. The trigger itself is not so clear. Flares have been analyzed where small-scale dynamics are seen in regions away from the actual flare site. The trigger does not need to be where the flare is.

We have made a lot of discoveries using this wonderful mission — only a few have been touched on here and *Hinode* is likely to continue working for many years to come with a healthy set of instruments. But what is the future beyond *Hinode*? *Hinode* was radical as it had an optical telescope producing fantastic data of the photosphere and chromosphere and understanding very-small-scale magnetic fields, but there is a leap to measurements in the atmosphere from those being made in the corona. There is a critical 'gap' in our coverage of the solar atmosphere. And worse, this 'gap' is much larger for spectroscopic data — with there being no such data in the chromosphere or transition region. Another issue is the mismatch between the datasets in the different instruments with different spatial resolutions. This is a function of how we can measure at different wavelengths and it is a challenge to do it differently. The next Japanese solar mission, *Solar-C*, will aim to crack that problem. Technical solutions have been worked on and developed over the past eight years or so. The designs end up with a set of three instruments that track through the whole solar atmosphere spectroscopically and with consistent resolutions. In addition, they not only measure the magnetic field in the photosphere, but also in the chromosphere, allowing a proper 3-D view of the magnetic field for the first time. Combined, these will allow us to measure and then model how magnetic fields are created and how they drive solar activity at all levels that ultimately creates the heliosphere that we exist in. It is tough technically but worth the challenge! A mission that will be launched much sooner is the ESA/NASA *Solar Orbiter* mission. This will be launched in 2018 and is currently at the peak of the building phase. It will have an elliptical orbit reaching as close as 0·28 AU from the Sun — just inside the orbit of Mercury. It will be the first time such delicate remote-sensing telescopes have gone so close to the Sun. Again it is a technical challenge and one that the UK has embraced with its partners over many years. The UK is involved in four of the instruments and is building the spacecraft. So we will get up close to the Sun and the instruments will allow us to 'touch' and 'see' the solar wind. In addition, the mission will move out of the ecliptic, allowing the first-ever view of the poles with both remote-sensing and *in-situ* instruments. This will allow us to understand those elusive polar regions, giving us an insight into how the solar-activity cycle works. The future is exciting!

The President. Louise has kept very nicely to time, so there's time for a few questions.

Dr. Lyndsay Fletcher. This observation that you made of the non-thermal broadening in the larger area around the flare — what do you think is going on there? Have you got an interpretation for this? It's quite surprising to me.

Professor Harra. The non-thermal velocity had its ends at the edge of the dimming region. Our interpretation was that that was where the flux rope was that we couldn't see before it was activated, and that we were seeing something in the turbulence that we couldn't see in the intensity.

Dr. Fletcher. But why should the flux rope be turbulent before an eruption? That was really my question.

Professor Harra. Dynamics! It has to get its energy from somewhere so there's a build-up before it goes. It is showing dynamics as opposed to turbulence as such.

The President. Anybody else? You've obviously answered everybody's questions today. Let's thank Louise again. [Applause.] The final presentation this afternoon is Professor Paul O'Brien, also without chaperone, from the University of Leicester, who is going to talk about the 'The STFC Exoplanet Science Review'.

Professor P. T. O'Brien. It's a great pleasure to have been invited to summarize the findings of the 2015 STFC Exoplanet Science Review. I had the privilege to chair the review, in my capacity as Chair of the STFC Astronomy Advisory Panel, ably assisted by the other panel members, namely Chris Arridge, Stephen Lowrey, Richard Nelson, Don Pollacco, David Sing, Giovanna Tinetti, and Chris Watson. Excellent administrative support was provided by Michelle Cooper and Sharon Bonfield from STFC. Since the last such UK review, led by Mark McCaughrean in 2007, the exoplanet area has grown tremendously. It is extraordinary to realize that within a generation we have gone from zero to thousands of known exoplanets.

The UK community is now large and broad in terms of the range of its activities. To give just a few examples, the UK *WASP* facility has provided the bulk of the exoplanet discoveries for which spectroscopic characterization has occurred due to the targeting of bright stars. UK groups head about 25% of the observational radial-velocity publications which provide data to enable studies of planetary migration and evolution. The UK also has led roles in theoretical studies and many other activities. This breadth of activity comes at a time when the UK is investing in future facilities, such as the *Next Generation Transit Survey* (*NGTS*) and *PLATO* (the ESA M3 mission). To ensure some focus and prioritization which matched, as well as possible, the views of the community, the review panel consulted widely. We used an on-line questionnaire, white-paper submissions, a town meeting, and provided access to a draft report (which we also presented at the 2015 UK Exoplanet meeting in Warwick). These procedural activities took place in early 2015, followed by submission of the final review report to STFC in 2015 April, followed by a discussion with the STFC Science Board.

The review made a large number of recommendations supporting four main aims. The details are available on-line at http://www.stfc.ac.uk/files/exoplanet-science-review-2015/.

The primary aims are: (*1*) To support the 'transit roadmap'. With the UK support for *NGTS* and *PLATO* the UK now has a path from ground- to space-based discovery of transiting exoplanets. These exoplanets will permit detailed atmospheric characterization and greatly enhance our understanding of how exoplanets form. Aligned with this aim is support for high-performance computing facilities, particularly DiRAC, and provision of community access to radial-velocity data. (*2*) To develop a better understanding of planetary atmospheres through observations and theoretical research. Around the transit roadmap are common-user facilities the UK should support that have spectroscopic instruments capable of detecting planetary-atmosphere signatures. (*3*) To understand the structure of discs and the formation and evolution of planetary systems. Beyond detecting planets and understanding their physical properties (*e.g.*, bulk compositions, atmospheric dynamics, and chemistry), a major scientific goal is to understand planet formation and planetary-system evolution. (*4*) To determine the frequency, mass distribution, and origins of orphan and cool planets. This aim includes providing support for the *Euclid* microlensing survey and exploitation of *GAIA* data.

Finally, the review concluded that support is needed for long-term technology development, including supporting teams early in the selection process to enhance UK leadership roles.

We were very impressed by the dynamic nature of the field and by the enthusiasm of the community. However, it is clear that the funding outlook will likely not permit all desires to be met. The aim of the review was to provide some context and suggest key areas, such as support for the transit facilities. We hope that that helps STFC and UKSA to help the community. One day someone will be standing here at the RAS giving a talk on the discovery of an Earth-like planet, which has clouds, rain, and wind. Clearly the UK community is ideally qualified to study such an object!

The President. We have a few minutes for questions, if there are any.

Professor S. Miller. I think that looks like a very exciting report in what is in my view an extremely exciting field. Did you have a look at all at supporting the individual scientists and scientific groups? I'm thinking in particular of making use of the European Research Council where I know on your panel both Giovanna [Tinetti] and David [Sing] have got ERC fellowships, and whether there's anything that can be done to support UK applications to the ERC a bit more from the community as a whole.

Professor O'Brien. It's an interesting idea, assuming we stay in the EU. [Laughter.] It's a general problem, and certainly at our institution, getting the manpower available to help you write proposals is a lot of work and there's a kind of art to it: you have to know the jargon; likewise in this country for writing fellowship proposals. The community in a sense, and this is true across astronomy, should be supporting itself. People should be saying, "well, I've just got one, I'll help you get one", because they're not in competition any more. What some people said we should be doing is perhaps targeting some funding at particular scientific areas — saying, "well, we're going to do exoplanets so let's carve out some fraction of the budget". I was opposed to that, and I think most people are opposed to that. I think we should stick to the way we have of funding the best science, and in that process the exoplanet community is doing alright. I didn't show the plot of the fraction of funding in the UK that's going to the community but it is doing relatively well.

Dr. R. Clegg. Paul, congratulations on a good review — very worthwhile. The large range of areas covered, unless the community is huge, suggests to me a large number of very small research groups around the country. I just wondered if the Panel had looked at that at all, especially in terms of development and co-ordination of the UK effort, instrument building, and so on?

Professor O'Brien. That's why we think there should be some focus in future. The community has had a period of exponential growth, as it were, and that can't be sustained in any funding climate. So the community is going to have to decide. Of course there is room for individuals to do some theoretical work, say, or join an overseas observing team, and so on, but we can't fund everything. In terms of funding facilities to find planets, for example, the transit method we favoured over, say, direct imaging due to current agency investment. Some people might want to put a lot of money into building an instrument to do something else. We said no, we should prioritize supporting what we called the transit roadmap. So, there is some change that's going to have to come to the community but we didn't think that it was for us really to start ordering academics as to what research they should be doing. Rather we've given advice to the Research Councils and told them what we think the primary scientific goals should be.

Dr. P. A. Daniels. I'm Paul Daniels, and I'm the President of the Guildford Astronomical Society and I can confirm that it is possible to detect exoplanet transits with small instruments because we detected two or three exoplanet transits with a modest instrument. Is there anything in your road map to co-ordinate amateurs to help you with some of the transits on brighter stars?

Professor O'Brien. This is an area where there is a role for smaller facilities. In particular, one of the things that is hard to do is confirm transit candidates. You find lots of candidates and then what do you do? Telescopes which are slightly bigger than the discovery telescopes, the telescopes that are half-metre, or one-metre-sized, which some amateur astronomers do have, are ideal for that. I think there certainly is a role, and I believe that the transit community should publish its candidate list so you can follow up that way, confirm them, and then those are targets for the really big telescopes because you don't want the really big telescopes to have to chase a hundred possible things, you want maybe five or ten. That step between the candidates and the detailed work needs smallish-sized telescopes where certainly there would be a role for the amateur community.

Dr. Daniels. I was also thinking you could do follow-up work with the timing of transits.

Professor O'Brien. You could do the timing. They don't normally publish the candidates unless they've seen several transits because of course a star itself can vary, as we heard earlier for the Sun, for example. So the candidate list is very large but not perfect. There's been some recent work to suggest that the *Kepler* transit list, for example, could be polluted by 40% false positives. That may be 20% but it's several tens of per cent and you've got to filter that down or otherwise you're just wasting very-large-telescope time.

Professor F. W. Taylor. You mentioned orphan planets but I didn't quite catch how you define what those are or what you think you can do with them?

Professor O'Brien. Yes, I'm not the expert, of course, but there are orphan planets in the sense that there are planets that appear to be adrift. Just like orphan brown dwarfs.

Professor Taylor. Can you detect them?

Professor O'Brien. You can in principle detect objects that are small but it's very hard to detect an object that's not producing much light itself. So it's certainly not a big area of astronomy. I'm sorry I'm not expert enough to answer your question fully. They are inferred from microlensing surveys. Where you draw the line, of course, between planets and brown dwarfs is unclear. Take that plot I showed at the start, made from data from an exoplanet website; I made a similar plot myself the other day that had thousands of objects up to thousands of Jupiter size and I thought, well that can't be right. I asked my exoplanet colleagues and they said no, anything bigger than about two Jupiters is either not real or not a planet. Of course, where you draw that line is an interesting question. There are studies of brown dwarfs, and Martin will know one of his postdocs is working on irradiated brown-dwarf atmospheres, where you can study atmospheres that look like planet atmospheres. It's an example of a role to be found for things that you might not immediately think of as related.

The President. We're probably going to have time for just one more question after that.

Professor Harra. I was just wondering was there any discussion of looking at the impact of stellar flares or stellar coronal mass ejections on the exoplanets?

Professor O'Brien. You mean mass extinction and all that sort of stuff?

Professor Harra. The impact on whether you can sustain life there through the radiation levels.

Professor O'Brien. Yes, there is work going on particularly in the radio to try and look at that sort of thing, magnetospheric effects and so on. I can't say it's a big area in the UK at the moment. But yes, the number of stellar flares may have an impact on predictions for life. Of course, this is not a very-well-determined number in general. But yes, certainly those very close-in objects, some of which might be gas giants, but if they're close-in rocky terrestrial-type objects, then it's quite a hostile environment for life if you have a magnetospherically active star.

Professor Harra. We tried to work our way through studying solar flares and CMEs to see whether we can detect stellar coronal mass ejections as well, which may be useful when you look at that.

The President. We've got time for one more question. In the spirit of what we're celebrating today I'm going to let Jane have the last word.

Dr. Jane Greaves. You wouldn't otherwise, would you? [Laughter.] Given how hard it was to get STFC to back transit work a decade ago, and now transit work is 'woohoo' in the big report, do you think we're backing the wrong horse again? Should we go for a better horse? [Laughter.]

Professor O'Brien. Well, one of the reasons *NGTS* is being backed of course is that the hardware has been paid for largely by universities. It's a challenge for the agencies now that a lot of universities have such similar projects. Although we're not that rich, if you have enough universities putting in a few hundred thousand pounds each, you can do something quite significant on the ground. So the *NGTS* hardware is being paid for by university groups; Leicester has put in £300 K, for instance, and then STFC is bombarded with requests for operational help. So it's a challenge for agencies to know what to do then because they've been blindsided by groups saying "Well now you've got to give us some money because we've spent our money". That's a real challenge for agencies. You don't want to deflect them from what they want, but should support what the community wants to do. What was reassuring in this report was that the community backed *NGTS*. So although most institutes are not involved directly, they backed the exploitation of *NGTS* and we got a clear message that *NGTS* is exactly the facility STFC should have built to find planets around bright stars.

The President. Sadly, we have to draw things to a close; as you probably know, we have to finish early this afternoon. So I'd like to thank our performers and speakers again. [Applause.] And remind you that the drinks reception in the RAS Library follows immediately after this meeting and you've got even more time to drink than usual. [Laughter.] And finally, I'd like to give notice that the next monthly A&G Open Meeting of the Society will be on Friday 12th February 2016.

SPECTROSCOPIC BINARY ORBITS FROM PHOTOELECTRIC RADIAL VELOCITIES

PAPER 248: HD 76115, HD 149955, HD 163528 B, AND HDE 239027

By R. F. Griffin
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This paper, like so many recent ones in this series, presents orbits for four moderately faint stars; all of them are at quite high declinations (~50°–75°). They were all observed in the course of the 'Clube Selected Areas' programme. Only the first two were actually programme stars, however; the other two were first measured just as a result of the observer's curiosity concerning other stars seen in the fields of ones that were genuinely on the programme, but when their radial velocities proved to be variable they 'had' to be observed as a matter of routine to establish their orbits. The four stars are all single-lined.

HD 76115 is an $8^{m}\cdot7$ star at a declination of 75°; it is in Clube Area 3 (which largely surrounds the celestial pole), and like all 'Clube' stars its *HD* type is K0. It was, however, considered at one time to be a carbon star, but then the correctness of that assignment appeared to be in doubt, and no final conclusion seems to have been agreed. It has an orbit of low eccentricity with a period of some 3½ years; despite the very large mass function, more than 0·7 $M_{\odot}$, the radial-velocity traces show no evidence of the secondary object.

The other three stars are all in Area 2, which is centred at about $17^{h}\ 30^{m}$, +60°*. HD 149955 has an orbit of modest eccentricity with a period of just over 1000 days that is determined to better than a day. The faint ($10^{m}\cdot8$) visual companion to HD 163528 has been known for 93 years to have a high proper motion; it actually has its own designation as Wolf 1392 and was observed in its own right by *Hipparcos*. It has a low-eccentricity orbit whose period of about 85 days is known to within about 12 minutes. HDE 239027, a star in the field of the Clube star HD 180635, is bright enough, at $9^{m}\cdot1$, to have featured in the Selected Areas programme, but was ineligible through (*a*) not being in the main *Henry Draper Catalogue* and (*b*) being of type K5 and not K0. It has an 8-month orbital period that is determined to little more than an hour, with a tiny but definitely non-zero eccentricity. If the very small proper motion (the parallax is unknown) is taken to imply that the principal star is a giant, the mass function suggests that the secondary may be a star of near-solar type.

*The declination is unfortunately misprinted in ref. 2.

Introduction

Apart from the actual star identifications, the *Introduction* to the previous paper[1] in this series could almost equally serve for this one. The stars treated here all arose from the 'Clube Selected Areas' survey, whose principal results (the radial velocities of more than a thousand stars, all of *HD* type K0 and confined within one or other of 16 systematically arranged small 'selected areas' all at Galactic latitudes ±35°) have long since been published[2,3]. Few of the programme stars had ever been measured for radial velocity before, and in the course of the programme many previously unrecognized spectroscopic binaries came to light. Orbits for about 50 of them have already been published by the writer of this paper, and a somewhat similar number still remain for the future; it will be appreciated that it can take longer to document an orbit than it does to make a relatively few measurements of a star whose velocity proves to be constant. (Writing it up is more demanding, too!)

HD 76115

HD 76115 is a star a little brighter than the ninth magnitude, to be found at 75° declination in a corner of Camelopardus near the boundaries of Draco and Ursa Major, so it is in principle visible (albeit with modest optical aid) by most of the people in the world whenever the sky is clear at night. The region is devoid of conspicuous stars, but there are a few that are bright enough to be in the *Bright Star Catalogue*; the best guide to HD 76115 is the $5^{m}\cdot 5$ star HR 3216, about 2°·5 preceding.

The star was observed by *Hipparcos*, which gave its magnitudes (after transformation to the normal system) as $V = 8^{m}\cdot 73$, $B = 9^{m}\cdot 75$. The spectral type was given as K0 in the *Henry Draper Catalogue*, and the fact of its inclusion there with that type and a magnitude within the range $8^{m}\cdot 5$–$9^{m}\cdot 5$, together with its position in the sky within one of the designated Areas, caused it to be included in the writer's 'Clube Selected Areas' programme[2]. The (revised[4]) *Hipparcos* parallax is 2·60 ± 1·08 arc-milliseconds, equivalent to a distance modulus of about 8 ± 1 magnitudes, so the object is evidently of giant-star luminosity.

In a 1958 paper, Vandervort[5] included HD 76115 in a survey of *The magnitudes, colors and motions of the stars of spectral class R*. He attributed the discovery of HD 76115 as an R-type star to Vyssotsky (unpublished) at the Leander McCormick observatory of the University of Virginia, where Vandervort himself was a graduate student at the time. The type listed by Vandervort was R0. The R stars are described in the *Introduction* to each of the volumes of the *Henry Draper Catalogue*. It is useful briefly to record here that their principal spectral characteristics are analogous to those of K types, but with the additional feature that they exhibit molecular absorption bands due to C_2; in the violet part of the spectrum, to which stellar spectroscopy was often restricted in the days when photography was the usual method, the principal bands are the 1–0 and 2–0 bands of the $B^3\pi$–$A^3\pi$ system, the 'Swan bands'[6]. The R types are defined in such a way that the strength of the Swan bands increases rapidly through the sequence, from 'just detectable' at R0 to overwhelming already at R5; over the same range the stars get rapidly redder, such that the spectrum can be seen down into the near-UV shortward of the *H* and *K* lines at R0 but can hardly be traced below the very strong λ4216-Å *CN* band by R5. HD 76115, with its modest colour index of only just over one magnitude, is one of the earliest and bluest of the 98 stars in Vandervort's table of R-type stars — there are only five that are (slightly) less red.

Long before Vandervort's work, a proposal had been made by Keenan & Morgan[7] in 1941 to supersede the R-type classification scheme by 'C' types, which recognized in the 'carbon-star' spectra the involvement of two largely independent variables — temperature and carbon abundance — and accordingly called for the specification of two independent numerical sub-divisions of the C class for every spectrum. This present paper must not be allowed to degenerate into a review of spectral classification, but it is noted here that Yamashita *et al.*[8] offered such a classification of HD 76115 (the star did not feature in Keenan & Morgan's own paper), as C3,0$^+$. C3 is a temperature type, roughly equivalent to K0, while the second number is intended to represent (though only qualitatively) how unusually conspicuous carbon and its compounds are in the spectrum — in this case, evidently, not very! In fact the classification reported in that reference was not a new one but was quoted from Yamashita[9], a reference not retrieved for HD 76115 by *Simbad*.

The degree of carbon enhancement indicated by the number 0$^+$ is clearly small, and most subsequent authors have not corroborated it at all. Thus Stephenson, who in 1989 published a 160-page monograph[10] entitled *A General Catalog of Cool Galactic Carbon Stars, Second Edition*, included HD 76115 only in a relatively small addendum (his Table 2), entitled *Stars that have been published as carbon stars but probably or definitely are not*. Its entry there calls HD 76115 a '4150 star', and there are *Notes* on it in that addendum* that say, "Candidate star seen or classified by me on a blue objective-prism plate", and "Classified by me from slit spectrogram." The designation '4150 stars' appears to have originated with Miss Roman[11], who used it to describe stars whose λ4200-Å *CN* band was unusually strong†. Bergeat *et al.*[13] classified HD 76115 as 'K0 CH:', thus contributing another half-hearted suggestion that any deviation from a normal K0 type might involve slightly enhanced carbon abundance. *Simbad* actually has a note in its entry for HD 76115, immediately after the listing of the basic data of position and magnitude, saying, "notes: ● Is mot [*sic*] probably NOT a carbon star".

Radial velocities and orbit of HD 76115

The only radial velocity published for HD 76115, as far as the author is aware, is the +18·0 km s^{-1} given by Yamashita[9], in whose listing the star is identified as BD +75° 355; since no date is given, that velocity‡ cannot be used in the discussion below of the star's orbit. There is a note against the entry for the star in Yamashita's paper, saying, "Located close to +75° 348; hence, a physical relation of some kind might be anticipated. However, the spectrum is normal, and the velocities seem to be different." HD 76115 is +75° 355, which might give the impression of being 'close' to +75° 348, but in fact the stars are well

*Difficult to locate! — the addendum itself is on pp. 208–212 but the notes were eventually located on p. 64!

†But hardly anything is as simple as at first it promises to be! Keenan[12] objected to the term as being "rather ambiguous, for some objects designated as '4150 stars' in the literature (*e.g.*, γ Cep) actually do not have very strong CN bands." In extenuation, however, it may be remarked that although Miss Roman did say, in referring to her classification of certain late-type stars as '4150 stars', that the CN band whose head is at λ 4216 Å is "too strong for the strength of the hydrogen lines and of λ 4077", she also said that "they are recognized on low dispersion by the fact that the λ 4150 region of CN is too strong compared with the region more to the red.".

‡Reprehensibly 'improved' to +18·00 km s^{-1} in the *IAU Information Bulletin*[14].

over a degree apart. At the distance of HD 76115, of order 400 pc although not at all well determined, the linear separation would be something like 8 pc (say 25 light-years) even in the unlikely event that the two stars are at the same distance from us, so the idea of physical association is really a non-starter. Moreover, the one velocity available[9] for +75° 348 was +63 km s^{-1}, far from HD 76115's +18, although with only one measurement for each star there could be a remote chance that the discrepancy *might* arise from the duplicity of one or both objects.

The writer's first radial-velocity observation of HD 76115 was made on Christmas Eve in 1997 at Haute-Provence and was near –15 km s^{-1}; the author was not aware at that time of Yamashita's result, so he did not realize then that the star is a spectroscopic binary. The next observation was not made until 2003 April, at Cambridge, when the velocity was found to have changed to +18 km s^{-1}, as was shortly confirmed by another measurement. From 2005 to 2013, HD 76115 featured regularly in the Cambridge observing programme, and 46 velocities were obtained in total. They have been adjusted by +0·2 km s^{-1} from the 'as reduced' values in an effort to put them more accurately onto the zero-point often adopted in this series of papers, 0·8 km s^{-1} higher than the 'IAU'[14] and Haute-Provence[15] zero-points, in deference to the trend of 'chromatic discrepancies' noted in the writer's work on the 'Redman K stars'[16]. Analogous chromatic adjustments have been made to the Cambridge *Coravel* velocities in the same way in the cases of the other stars treated below, but without the issue being discussed again explicitly each time. The observations of HD 76115 are set out, together with the initial Haute-Provence measure, in Table I, and readily yield an orbit, whose elements are given in the first numerical column of Table V towards the end of this paper, and which is plotted in Fig. 1. The orbital period of nearly four years is seen to be established almost to a day;

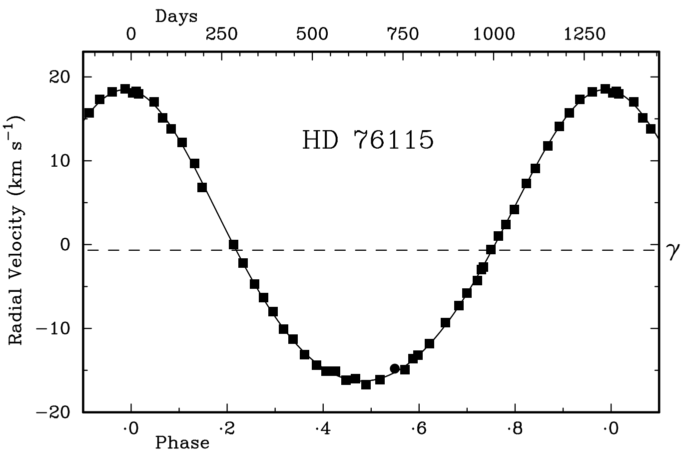

FIG. 1

The observed radial velocities of HD 76115 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. All but one of the observations were obtained with the Cambridge *Coravel* and are plotted as filled squares; the very first measurement, from the Haute-Provence *Coravel*, appears as a filled circle at phase ·55 and was given the same weighting as the rest in the solution of the orbit. The same plotting conventions are used in the other figures in this paper.

TABLE I

Radial-velocity observations of HD 76115

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

Date (UT)	MJD	Velocity km s⁻¹	Phase	(O–C) km s⁻¹
1997 Dec. 24·09*	50806·09	−14·8	$\bar{2}$·549	+0·4
2003 Apr. 2·89	52731·89	+18·1	0·004	−0·3
18·85	747·85	+18·0	·016	−0·1
2005 May 14·94	53504·94	−13·6	0·587	+0·2
27·89	517·89	−13·2	·597	+0·1
Nov. 19·21	693·21	−3·0	·730	−0·1
25·19	699·19	−2·7	·734	−0·2
Dec. 15·14	719·14	−0·6	·749	+0·3
2006 Jan. 26·03	53761·03	+2·4	0·781	−0·1
Feb. 18·02	784·02	+4·2	·798	−0·2
Mar. 22·93	816·93	+7·3	·823	+0·1
May 21·89	876·89	+11·8	·868	−0·1
Oct. 27·23	54035·23	+18·6	·988	+0·1
Nov. 26·23	065·23	+18·3	1·011	+0·1
2007 Jan. 14·04	54114·04	+17·0	1·047	+0·3
Feb. 7·03	138·03	+15·1	·066	−0·4
Mar. 2·04	161·04	+13·8	·083	−0·3
Apr. 1·96	191·96	+12·2	·106	+0·3
May 5·91	225·91	+9·7	·132	+0·5
Oct. 19·19	392·19	−4·7	·258	0·0
Nov. 12·20	416·20	−6·3	·276	+0·2
Dec. 8·15	442·15	−8·0	·295	+0·2
2008 Jan. 6·18	54471·18	−10·1	1·317	−0·1
Feb. 2·10	498·10	−11·3	·338	+0·1
Mar. 5·10	530·10	−13·1	·362	−0·2
Apr. 6·90	562·90	−14·4	·386	−0·2
Dec. 7·20	807·20	−14·9	·571	−0·4
2009 Feb. 12·08	54874·08	−11·8	1·621	+0·1
Mar. 27·99	917·99	−9·3	·655	+0·3
May 3·91	954·91	−7·3	·682	+0·1
26·90	977·90	−5·8	·700	0·0
Dec. 1·22	55166·22	+9·1	·842	−0·1
2010 Feb. 6·02	55233·02	+14·1	1·893	0·0
Mar. 5·01	260·01	+15·7	·913	0·0
Apr. 2·91	288·91	+17·3	·935	+0·3
May 6·89	322·89	+18·2	·960	+0·1
2011 Jan. 10·13	55571·13	+6·8	2·148	−0·6
Apr. 6·96	657·96	0·0	·213	+0·1
May 2·90	683·90	−2·2	·233	0·0
Dec. 18·25	913·25	−15·1	·406	−0·2
2012 Jan. 13·17	55939·17	−15·1	2·426	+0·4
Feb. 11·04	968·04	−16·2	·448	−0·2
Mar. 7·92	993·92	−16·0	·467	+0·2
Apr. 5·93	56022·93	−16·7	·489	−0·4
May 14·91	061·91	−16·1	·519	−0·1
2013 Feb. 7·08	56330·08	−4·3	2·721	−0·5
Apr. 5·86	387·86	+1·0	·765	+0·3

*Observed with Haute-Provence *Coravel*; weight 1.

the eccentricity, though small, is thirty times its standard error, allowing the epoch of periastron to be determined within about a week despite the orbit being nearly circular.

The radial-velocity semi-amplitude of some 17 km s^{-1} is remarkable for a late-type star having a period of years; correspondingly, the mass function given by the orbit, at just over 0·7 $M_{\odot}$, is disconcertingly large. If the star whose radial velocity has been measured, whose luminosity we know from the parallax to be no greater than that of a normal giant, is attributed a mass of 2 $M_{\odot}$, then to fulfil the mass function its companion must, as a minimum, have a mass of about 2·4 $M_{\odot}$. The only possibly plausible model seems to be one in which the inclination is near 90° (to avoid pushing the mass of the companion object higher still), and for that object itself to be a multiple system. If we deemed it to consist of an equal pair of 1·2-$M_{\odot}$ objects, they would need to be of type about F8 V, with $M_V \sim 4^{\mathrm{m}}\cdot 0$ each, which might just escape detection in competition with the primary that is three, possibly four, magnitudes brighter, but the room for manœuvre in designing a system that accords with the known facts and yet remains single-lined is very small.

HD 149955

This star is to be found in Draco, by imagining a line drawn from 19 to 18 Dra (two 5$^{\mathrm{m}}$ stars nearly 2° apart) and prolonging it for half that distance. Its magnitudes have been provided by *Hipparcos*, at $V = 8^{\mathrm{m}}\cdot 72$, $B = 9^{\mathrm{m}}\cdot 61$. The (revised, and unusually precise) parallax[4] is 3·04 ± 0·54 arc-milliseconds, leading to a distance of about 330 ± 60 pc (modulus about 7$^{\mathrm{m}}$·6), and thus to an absolute magnitude near +1, with a 1-σ uncertainty of about half a magnitude. The star is evidently, therefore, a giant; its colour index would be consonant with that of a star whose type is somewhat earlier than the K0 given in the *HD*, about G6 III.

Alone among the stars treated in this paper, HD 149955 has already featured in the writer's publication[2] of radial velocities in the 'Clube Selected Areas'. There are no other papers that say anything of sufficient interest about the star to warrant re-telling in any detail here; of the six papers known to *Simbad*, one is my own[2], another includes my result in a tabulation, two propose small and unexceptional values for the interstellar extinction (0$^{\mathrm{m}}$·17) and polarization (0·000%) and two are those extraordinary listings noted obliquely in previous papers.

The author made two radial-velocity measurements of HD 149955 with his original photoelectric spectrometer[17] at the 36-inch telescope at Cambridge about 45 years ago. The two velocities differed only by 0·7 km s^{-1}, an amount that could easily be ascribed to observational uncertainty, so the binary nature of the star was not apparent. It only came to light when, in the context of renewed interest in the 'Clube Selected Areas', after the observation of the previously inaccessible far-southern Areas[3] in the course of a number of visits to use the ESO *Coravel*, the writer concerned himself once again with the northern Areas. He made fresh observations of the stars there, and discovered the binary natures of certain objects whose duplicity had not previously been recognized. One of them was HD 149955; it turned out that the two early velocities happened by misfortune to be phased about halfway up the ascending side of the velocity curve and halfway down the descending side. The discovery of the velocity variations was thereby withheld from the observer for the time being, and was deferred for more than 30 years! In the course of the years 2002–2014, however, 49 radial velocities were obtained of HD 149955 with the Cambridge

Coravel, and the binary nature of the star became apparent at the very first one. At a declination of 64° the star is in principle circumpolar, but the form of the telescope mounting and the configuration of the *Coravel*, not to mention a large new building cavalierly sited immediately to the north of the telescope and reaching almost to the angular altitude of the celestial Pole, prevent observations being made at hour angles greater than about 6 hours. All the same, the star has been observed in the evening sky on dates up till November 26 and in the morning from January 13; as the orbit has a period of 'only' about 1000 days and has been seen round four times since systematic observations began, there has been little difficulty in obtaining tolerably uniform phase coverage. The radial-velocity traces, like those of HD 76115, show 'dips' of normal depth for a star of its putative type.

Table II sets out the available radial-velocity observations of HD 149955; they readily yield the orbit whose elements appear in the third column of Table V (towards the end of this paper) and which is plotted in Fig. 2. The orbital period of just over 1000 days is determined so accurately that there will be no ambiguity in the cycle count to future observations provided that the star is not henceforth neglected completely for more than a thousand years. The modest velocity amplitude leads to a mass function of less than a hundredth of a solar mass, so it is not surprising that no sign has been seen of the secondary component of the system, whose signature in radial-velocity traces would in any case be likely to be permanently blended with that of the primary, adding to the difficulty in detecting it. The r.m.s. velocity residual of 0·20 km s^{-1} is representative of the best performance of the *Coravel*, sustained over quite a long period of time and including observations made in conditions not conducive to maximum accuracy, including extreme hour angles both east and west.

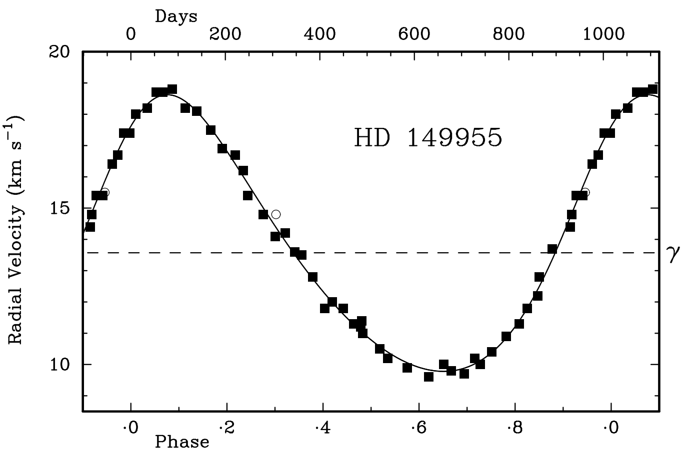

FIG. 2

The observed radial velocities of HD 149955 plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The first two observations were made more than 30 years before any of the others, with the original Cambridge spectrometer[17]. They are plotted as open circles and have been weighted 1/10 in the solution of the orbit; the rest were made with the Cambridge *Coravel*.

TABLE II

Radial-velocity observations of HD 149955

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

Date (UT)			*MJD*	*Velocity* *km* s^{-1}	*Phase*	*(O – C)* *km* s^{-1}
1970	Aug.	3·97*	40801·97	+15·5	$\overline{12}$·946	−0·4
1971	Aug.	1·04*	41164·04	14·8	$\overline{11}$·302	+0·4
2002	Sept.	8·92	52525·92	11·2	0·478	+0·1
		10·92	527·92	11·4	·480	+0·4
		12·84	529·84	11·0	·482	0·0
	Oct.	18·76	565·76	10·5	·518	−0·1
	Nov.	4·76	582·76	10·2	·534	−0·2
2003	Mar.	3·22	52701·22	10·0	0·651	+0·2
	May	8·02	767·02	10·2	·716	+0·2
	June	13·07	803·07	10·4	·751	0·0
	Aug.	9·96	860·96	11·3	·808	−0·1
	Oct.	18·78	930·78	13·7	·877	+0·4
	Nov.	26·73	969·73	14·4	·915	−0·3
2004	Mar.	2·22	53066·22	18·0	1·010	+0·1
	Apr.	15·12	110·12	18·7	·053	+0·2
	May	19·06	144·06	18·8	·087	+0·2
	June	15·02	171·02	18·2	·113	−0·2
	Aug.	7·98	224·98	17·5	·166	−0·1
	Sept	1·90	249·90	16·9	·191	−0·1
	Oct.	25·83	303·83	15·4	·244	−0·4
	Nov.	26·73	335·73	14·8	·275	−0·2
2005	Jan.	13·27	53383·27	14·2	1·322	+0·3
	Mar.	12·22	441·22	12·8	·379	+0·1
	Apr.	22·11	482·11	12·0	·419	0·0
	May	15·06	505·06	11·8	·442	+0·2
	June	7·04	528·04	11·3	·464	0·0
	Sept.	27·85	640·85	9·9	·575	−0·2
	Nov.	12·78	686·78	9·6	·620	−0·2
2006	Mar.	1·23	53795·23	10·0	1·727	−0·1
	Apr.	26·07	851·07	10·9	·782	0·0
	June	8·97	894·97	11·8	·825	0·0
	July	4·01	920·01	12·8	·850	+0·3
	Sept.	20·93	998·93	15·4	·927	+0·2
	Oct.	4·90	54012·90	15·4	·941	−0·3
		24·80	032·80	16·4	·961	0·0
	Nov.	18·77	057·77	17·4	·985	+0·2
2007	July	13·00	54294·00	16·7	2·218	+0·3
		29·90	310·90	16·2	·234	+0·2
	Nov.	15·76	419·76	13·6	·341	+0·1
2008	Oct.	11·84	54750·84	9·8	2·667	0·0
	Nov.	7·79	777·79	9·7	·694	−0·2
2009	June	24·03	55006·03	14·8	2·918	0·0
	Aug.	18·89	061·89	16·7	·973	−0·1
	Sept.	12·84	086·84	17·4	·998	−0·2
2010	July	17·97	55394·97	14·1	3·301	−0·3
	Sept.	11·84	450·84	13·5	·356	+0·3
	Oct.	30·75	499·75	+11·8	·404	−0·5

TABLE II (*concluded*)

Date (UT)	*MJD*	*Velocity* *km s⁻¹*	*Phase*	*(O – C)* *km s⁻¹*
2012 Aug. 1·93	56140·93	+18·2	4·034	–0·1
Sept. 3·91	173·91	18·7	·067	+0·1
Nov. 14·73	245·73	18·1	·138	0·0
2014 Nov. 5·77	56966·77	+12·2	4·847	–0·2

*Observed with original Cambridge spectrometer; weight 1/10.

HD 163528 B (*Wolf 1392*)

HD 163528, an $8^{m}\cdot5$ star of HD type K0, is one of the stars that was added to the 'Clube' programme in Area 2 when the northern Areas were arbitrarily enlarged to provide numbers of stars per Area comparable with those that prevail in the much richer southern hemisphere. Although most of Area 2 is in Draco, HD 163528, which is towards the southern border of the enlarged Area, is in the north-following corner of Hercules. It is a little over one-quarter of the way from the 2^{m} star γ Dra towards ι Her, which is some 6° south-preceding. HD 163528 does not itself create much excitement for a radial-velocity enthusiast, who does, however, find interest in a faint companion about 80″ distant in position angle about 292°. The present writer first observed it merely out of curiosity, just as a possibly measureable star seen in the finding field rather close to a genuine programme star; a subsequent literature search, however, revealed that attention had been drawn to it as long ago as 1923 by Wolf[18], who included it in a list of 45 'proper-motion stars' in the vicinity of γ Dra. Other observers took notice of (or repeated) Wolf's discovery, which led to the star's appearance in Luyten's *NLTT* catalogue[19] of proper-motion stars*, and subsequently to its inclusion in the *Hipparcos* programme as HIP 87614.

The (revised)[4] parallax of the companion is $4\cdot93 \pm 1\cdot85$ milliseconds of arc, giving the distance modulus as about $6^{m}\cdot5$ though with an uncertainty of about a magnitude. The *Hipparcos/Tycho 2*[20] *V* and *B* magnitudes are $10\cdot77 \pm 0\cdot08$ and $12\cdot10 \pm 0\cdot23$, respectively, making the colour index abut $1^{m}\cdot3$, though with substantial uncertainty. The numbers just recited do not seem to add up to a plausible model for the star. The distance modulus and apparent magnitude combine to suggest an absolute magnitude between 4 and 5, such as would belong to an early-G main-sequence star; but the colour index then ought to be about $0^{m}\cdot6$, and even allowing for the uncertainty of measurement and the likelihood of some reddening the observed value seems hard to reconcile with that expectation.

The radial velocity of the faint star was first measured with the Haute-Provence *Coravel* in 1998, and not again until a Cambridge measurement was made in 2007. There was a major discordance, which somehow was allowed to rest until 2011, when a third measurement in August of that year disagreed with both the previous ones. That at last galvanized the transfer of the object to the spectroscopic-binary programme; it soon proved to change velocity on a short time-scale, and the 85-day orbit had become apparent by the close of the

*As no. 45654 in *Simbad*, but that number is not in the *NLTT* itself and appears to be a running number assigned by *Simbad* to the successive stars in the *Catalogue* up to and including that one.

observing season at the turn of the year. There are now 37 Cambridge velocities as well as the initial Haute-Provence one; they are listed in Table III and result in the orbit whose elements are included in Table V and which is illustrated in Fig. 3. The orbit is quite well determined, with its period known to a standard error of only 12 minutes, and the eccentricity is a modest 0·14, differing from zero by more than 20 standard deviations. The γ-velocity is quite different from

TABLE III

Radial-velocity observations of HD 163528 B

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

Date (UT)	*MJD*	*Velocity* *km s*$^{-1}$	*Phase*	*(O – C)* *km s*$^{-1}$
1998 July 25·97*	51019·97	−58·5	$\overline{56}$·514	−0·1
2007 Aug. 6·00	54318·00	−31·5	$\overline{17}$·248	+0·3
2011 Aug. 8·98	55781·98	−50·5	0·442	+0·9
Sept. 29·83	833·83	−32·9	1·051	−0·5
Oct. 18·83	852·83	−33·5	·274	+0·6
19·83	853·83	−35·8	·286	−0·6
22·79	856·79	−39·0	·321	−0·4
26·81	860·81	−43·5	·368	+0·1
Nov. 9·75	874·75	−60·4	·532	−0·5
19·76	884·76	−69·5	·649	−1·5
27·76	892·76	−69·3	·743	+0·6
Dec. 3·73	898·73	−67·6	·813	−0·6
5·77	900·77	−65·0	·837	0·0
2012 Jan. 3·73	55929·73	−26·8	2·177	+0·7
May 28·09	56075·09	−58·3	3·885	+1·0
July 23·97	131·97	−61·2	4·553	+0·5
Aug. 20·96	159·96	−60·5	·881	−0·7
29·88	168·88	−41·8	·986	+0·4
Sept. 6·90	176·90	−29·2	5·080	+0·3
13·91	183·91	−27·5	·163	−0·3
Nov. 5·82	236·82	−69·2	·784	−0·5
2013 May 7·12	56419·12	−53·1	7·925	−0·1
June 3·09	446·09	−31·8	8·242	−0·5
21·98	464·98	−53·0	·464	+0·5
July 1·04	474·04	−62·9	·570	+0·2
5·02	478·02	−66·1	·617	+0·2
7·00	480·00	−67·3	·640	+0·3
25·96	498·96	−61·3	·863	+0·9
Sept. 16·92	551·92	−55·4	9·485	+0·2
Oct. 5·83	570·83	−69·7	·707	+0·1
28·78	593·78	−44·4	·976	−0·5
Nov. 29·79	625·79	−42·8	10·352	−0·9
Dec. 4·72	630·72	−47·6	·410	+0·4
2014 July 23·96	56861·96	−26·8	13·126	+0·4
Oct. 7·84	937·84	−37·2	14·017	−0·1
8·92	938·92	−35·6	·030	−0·4
2015 July 6·04	57209·04	−28·3	17·202	+0·3
18·00	221·00	−41·6	·343	−0·7

*Observed with Haute-Provence *Coravel*; weight 1

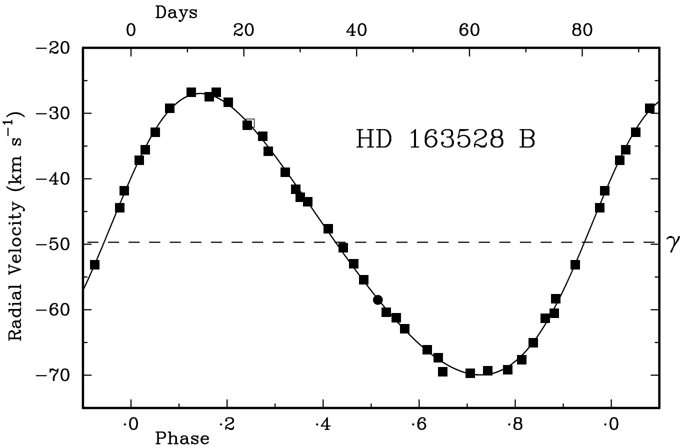

FIG. 3

The observed radial velocities of HD 163528 B (Wolf 1392) plotted as a function of phase, with the velocity curve corresponding to the adopted orbital elements drawn through them. The first observation, obtained with the Haute-Provence *Coravel* in 1998 (phase ·51), is plotted as a filled circle. All the other observations were made with the Cambridge *Coravel*; an early one which more than doubles their time-base is plotted with an open symbol.

the velocity of the 'visual primary' star, HD 163528 itself — not surprisingly, because the different proper motions already showed that the two stars were nothing to do with one another apart from lying nearly in the same line of sight.

The nature of this relatively faint system is none too certainly elucidated here, but if indeed the primary is a star of about solar type, as may be suggested in the paragraph next but one above as well as by the depth of the 'dips' seen in radial-velocity traces, then the mass function demands a secondary with a mass not much less than 0·6 $M_{\odot}$, corresponding to that of a main-sequence star of very-late-K type, whose absolute magnitude would be about 8·5, something like four magnitudes fainter than the primary, so its non-appearance in radial-velocity traces need not occasion any surprise.

HDE 239027

This *Henry Draper Extension* star was observed, like Wolf 1392 above, simply because its proximity to a genuine 'Selected Areas' programme star drew the writer's attention to it. It is just over 5′ of arc, at position angle 225°, from the programme star HD 180635, which itself is about 24′ almost due south of the 5^{m} K star 54 Dra. *Simbad* knows of no references to it at all in the literature, although the star has entries in a number of catalogues, including, obviously, the *Henry Draper Extension*[21]. The *Tycho 2*[20] magnitudes for it are $V = 9^{m}{\cdot}11$, $(B - V) = 1^{m}{\cdot}54$, and the *HDE* spectral type is K5, agreeing with the colour index. Stars of such a colour and type give very fine and deep dips in radial-velocity traces, and this one is no exception.

The star's radial velocity was first observed in 2002, with the Cambridge *Coravel*; possibly because of a book-keeping oversight it was re-observed on the very next night. There was no reason to expect it to be of particular interest, and since it was in any case not really on the observing programme it did not get observed again for four years, but it gave then (2006 December) a velocity quite different from the initial pair. The season when HDE 239027 is accessible to the telescope was then nearly at an end, and no further observations were obtained that season. The next measurement, made in the following August, agreed with the 2006 one, so it did not animate the enthusiasm that it would have done if the 245-day interval that had elapsed since the preceding measure had been recognized as the orbital period, to within less than a day! Observations of the star were not resumed until 2011, but were then organized at a more consistent frequency of about two a month; the orbital period was soon established, and in the ensuing few years the phase distribution of the observations was largely evened out.

The number of observations now stands at 43; they are shown in Table IV, and lead to the orbit whose elements appear in the final column of Table V. At first sight the velocity curve (plotted in Fig. 4) looks to the eye to be a sine wave, implying a circular orbit. The computed eccentricity, however, though very small at 0·038, is well over ten times its formal uncertainty, so the orbit does deviate definitely, even though only slightly, from a circle. (The actual eccentricity is just twice that of the Earth's orbit round the Sun; few people notice *that*, let alone do they realize that perihelion occurs very close to the northern-hemisphere *winter* solstice!)

Most K-type stars down to any given apparent magnitude are giants, whose frequency relative to dwarfs increases towards later types, because the giants

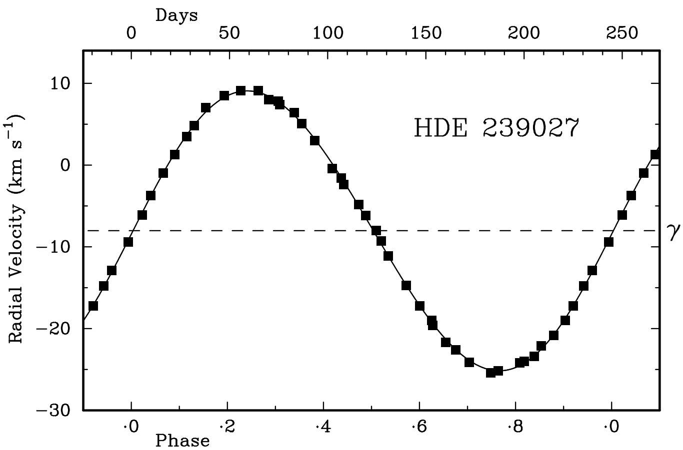

FIG. 4

The observed radial velocities of HDE 239027 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*.

TABLE IV

Radial-velocity observations of HDE 239027

All the observations were made with the Cambridge Coravel

Date (UT)	*MJD*	*Velocity* *km s^{-1}*	*Phase*	*(O–C)* *km s^{-1}*
2002 Sept. 10·05	52527·05	+7·8	$\overline{13}$·306	+0·1
10·94	527·94	+7·4	·309	−0·2
2006 Dec. 3·74	54072·74	−19·0	$\overline{7}$·625	+0·2
2007 Aug. 6·01	54318·01	−19·6	$\overline{6}$·628	−0·2
2011 July 30·01	55772·01	−14·7	0·573	0·0
Aug. 19·09	792·09	−21·7	·655	−0·4
Sept. 10·93	814·93	−25·4	·748	−0·3
14·93	818·93	−25·2	·764	0·0
27·93	831·93	−24·0	·818	+0·2
Oct. 18·88	852·88	−19·0	·903	−0·2
Nov. 27·80	892·80	−1·0	1·066	0·0
Dec. 3·75	898·75	+1·3	·091	−0·2
9·78	904·78	+3·5	·115	−0·2
28·78	923·78	+8·5	·193	+0·2
2012 June 29·06	56107·06	−14·8	1·942	+0·1
July 23·05	131·05	−3·7	2·041	+0·1
Aug. 19·97	158·97	+7·0	·155	+0·5
Sept. 6·91	176·91	+9·1	·228	+0·1
15·86	185·86	+9·1	·265	+0·2
Nov. 5·91	236·91	−4·8	·473	+0·2
14·78	245·78	−8·0	·510	+0·6
2013 June 16·06	56459·06	+3·0	3·382	−0·2
25·07	468·07	−0·4	·418	−0·6
July 1·05	474·05	−2·4	·443	−0·3
12·04	485·04	−6·2	·488	+0·2
20·00	493·00	−9·3	·520	+0·4
Aug. 26·96	530·96	−22·6	·676	0·0
Sept. 2·96	537·96	−24·1	·704	−0·2
Oct. 5·84	570·84	−23·4	·839	−0·1
15·92	580·92	−20·8	·880	−0·1
25·86	590·86	−17·2	·920	0·0
Nov. 12·77	608·77	−9·4	·994	−0·2
19·80	615·80	−6·1	4·022	−0·2
2014 May 31·08	56808·08	−24·2	4·809	+0·3
June 11·09	819·09	−22·1	·854	+0·4
July 7·02	845·02	−12·9	·960	+0·2
Aug. 17·94	886·94	+4·8	5·131	−0·1
Sept. 24·95	924·95	+8·0	·286	−0·4
Oct. 7·85	937·85	+6·4	·339	+0·3
11·81	941·81	+5·1	·355	0·0
31·76	961·76	−1·6	·437	−0·1
Nov. 24·75	985·75	−11·1	·535	0·0
Dec. 10·75	57001·75	−17·2	·600	0·0

actually become slightly more luminous whereas the main-sequence luminosities fall rapidly with advancing type. We might well rely on that statistical argument, which is backed up by the strength of the 'dips' seen in radial velocity traces, to believe that HDE 239027 is a giant star; the interest of that is simply so that we might enter an *ex cathedra* estimate of, say, 2 $M_{\odot}$ into the expression for the mass function (whose value is about ⅛ of a solar mass) to obtain a minimum value for the mass of the secondary, which comes out close to 1 $M_{\odot}$. That suggests a ΔV of something like 5 magnitudes between the components, and goes some way to reassuring us over the non-appearance of any secondary 'dip' in the radial-velocity traces.

TABLE V

Orbital elements for HD 76115, HD 149955, HD 163528 B and HDE 239027

Element	*HD 76115*	*HD 149955*	*HD 163528 B*	*HDE 239027*
P (days)	1324·1 ± 1·1	1016·6 ± 0·9	85·145 ± 0·008	244·59 ± 0·05
T (MJD)	54051 ± 7	54073 ± 8	56084·9 ± 0·6	56121·1 ± 3·6*
γ (km s^{-1})	−0·67 ± 0·04	+13·57 ± 0·03	−49·69 ± 0·10	−8·03 ± 0·04
K_1 (km s^{-1})	17·38 ± 0·06	4·42 ± 0·05	21·49 ± 0·15	17·12 ± 0·06
e	0·103 ± 0·003	0·185 ± 0·010	0·143 ± 0·006	0·038 ± 0·003
ω (degrees)	5·3 ± 1·8	320·6 ± 3·0	293·6 ± 2·8	269 ± 5
$a_1 \sin i$ (Gm)	314·8 ± 1·1	60·8 ± 0·6	24·91 ± 0·17	57·53 ± 0·21
$f(m)$ ($M_{\odot}$)	0·711 ± 0·007	0·00867 ± 0·00027	0·0851 ± 0·0018	0·1271 ± 0·0014
R.m.s. residual (wt. 1) (km s^{-1})	0·25	0·20	0·56	0·25

*T_0 = MJD 56183·21 ± 0·13

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REVIEWS

Moonshots and Snapshots of Project Apollo, by J. Bisney & J. L. Pickering (University of New Mexico Press, Albuquerque), 2015. Pp. 272, 31 × 23·5 cm. Price £48·95 (hardbound; ISBN 978 0 8263 5594 2).

Can it really be almost half a century ago that man first set foot on another world, in what was, in my view, the greatest triumph of exploration in history? And equally astonishing, since that time, and in spite of the enormous technological advances of the last 50 years, how can it be that we don't yet have a foothold on Mars? Of course, it all comes down to politics. The 'race' to the Moon was driven not so much by mankind's curiosity about our nearest neighbour in space but rather by ensuring that 'the West' got there before 'the East', demonstrating some kind of 'superiority'. And now all 'our' efforts seem to be directed to fighting amongst ourselves and rapidly wrecking this 'Pale Blue Dot' on which we live.

So it's rather nice to remember those halcyon days when, although the political motives may not have been very pure, the actual events of the late 1960s and early 1970s were exciting and space was seen to be where the action was. And I can think of no better tribute to those times than this magnificent volume of 'snaps' taken of Project Apollo and its follow-up in *Skylab*. This coffee-table tome contains a treasure trove of photos of the men involved in those missions (and occasionally their wives and children) together with their vehicles in various stages of assembly, during lift-off, and in space. Not just the astronauts are featured here but lots of the personnel working at the various spaceflight centres and the launch facilities; many photos are in colour and scattered amongst them are images of the certificates, plaques, stickers, and other memorabilia, such as the lunar rovers' 'license plates' provided by Boeing (although not actually flown). Each mission has a chapter to itself, containing a brief description on how it unfolded, and each photo within those chapters has clear, explanatory text (with a list of acronyms at the end of the book for those not up to speed on such matters).

Not all the memories are happy ones, and the book starts with *Apollo 1* in which the three astronauts tragically died in a fire on the ground. *Apollos 7–17* were fortunately free of such disasters although *Apollo 13* did have problems and never made it to the Moon, a story brilliantly portrayed in the film of the same name. And most of us above a certain age will remember 1969 July 20 when Neil Armstrong and Buzz Aldrin stepped onto the lunar surface; I was at the Lick Observatory where (so far as I can remember!), shortly after that date, Joe Wampler and Joe Miller detected reflections of laser light from the retro-reflectors left on the Moon's surface, by using the 120-inch telescope (proof, if ever one needed it, that the whole show was not simply staged in a film studio).

With the termination of the Apollo programme, some of the hardware was adopted for use in *Skylab*, a precursor to the *International Space Station*, to demonstrate the possibilities of living and working in space. *Skylab* missions 1–4 are documented here together with the Apollo–Soyuz Test Project, a rather pleasing collaboration in view of the rivalry which started the whole process going.

This is a wonderful souvenir of an inspirational time. Sadly I doubt if such a book will be forthcoming from a programme to put humans on Mars before I'm pushing up the daisies. — DAVID STICKLAND.

Hollyweird Science: From Quantum Quirks to the Multiverse, by Kevin R. Grazier & Stephen Cass (Springer, Heidelberg), 2015. Pp. 308, 23·5 × 15·5 cm. Price £19/$24·99 (paperback; ISBN 978 1 3 319 15071 0).

Ah, Hollywood! The spiritual home of such gems as *Star Trek, Stargate, Battlestar Galactica, 2001: A Space Odyssey, Star Wars, The Day the Earth Stood Still*, and *Armageddon*. Those media classics all have scientific foundations. And the way science is portrayed in the media is important. It is not only a significant indicator of the way science and scientists are valued in society, it also plays an important (and much overlooked) role in encouraging and inspiring young people into STEM education and careers.

The two questions at the heart of this book are "just how sound does media science have to be?", and "how accurately do the media portray the science profession?" The authors have certainly done their homework. Grazier, who has spent many years working at NASA's Jet Propulsion Laboratory in California, and Cass, a well-known New York science-and-technology journalist, have clearly spent months if not years in the cinema or stuck in front of the TV. They seem to have had huge fun thoroughly and critically delving into the films and television programmes. And not only have they investigated the end-products, they have also interviewed many of the people responsible for producing science-fiction programmes. It is clear that these screenwriters and film and TV-programme makers are the first to admit that they are not scientists and, as such, have a rather limited idea about the motivations and methods of the typical boffin.

There again, to quote Brian W. Aldiss, "science fiction is no more written for scientists than ghost stories are written for ghosts". But the science is significant, and, within the bounds of the entertaining fictional story it has to be as near-right as possible, or at least not so completely unbelievable that people switch off and walk away in disgust.

Grazier and Cass are clearly fans of the genre. The media subtleties of heat and temperature, mass and weight, energy, force and power, gravity and radiation are investigated in detail. Much is made of the problems of scale and time, quantum mechanics, the uncertainty principle, radiation sickness, the form of the atom, and the production of energy. It is obvious that moving about the Universe is a problem for human beings with their limited life spans. The book thus delves into the mysteries of such topics as faster-than-light travel, time dilation, time travel, tachyons, suspended animation, wormholes, parallel universes, and hyperspace. Astronomy is writ large and the advantages of terraforming other planets and producing Dyson spheres are considered.

This is a fascinating, informative, and entertaining book. It is well illustrated, well referenced, and extremely thought-provoking. I will look at the media in a new light. It made me wonder about the importance of Captain Nemo (Jules Verne; *20,000 Leagues under the Sea*) in encouraging me to become a scientist. Or was I just looking for a Julie Christie (in Fred Hoyle and John Elliot's *A for Andromeda*) or a Dr. Christmas Jones (in James Bond's *The World is not Enough*)? — David W. Hughes.

A Numerate Life, by A. A. Paulos (Prometheus, Amherst), 2015. Pp. 206, 22·5 × 15 cm. Price $17 (about £11) (paperback; ISBN 978 1 63388 118 1).

Professor Paulos — mathematician, academic, and communicator — already has a strong literary reputation as well as one in mathematics, with at least one best-seller (*Innumeracy*) to his credit. One might suppose that there can be only a limited number of hues that a mathematician can select in order to paint his or her subject for easy assimilation by the non-professional, but this new book does not disappoint in any way. What is nominally an autobiography, at least from the title, turns out to be an engaging meander through snippets of Life, its encounters, challenges, opportunities and mysteries, that proves overall to be exactly the kind of autobiography that its creator says is mathematically unlikely. According to Paulos, maths — at least in the form of statistics — colours everything we think we recall, bends our memories, distorts our impressions, favours our friends, and plays down our weaknesses, and moreover he proves each such claim by intriguing number-based examples. Over and over again one sees oneself mirrored in those experiences, and cannot but admire the writer for his total honesty, candour, and frankness. Whether or not we've been down those side-lanes ourselves, here's someone who can teach us to honour the truth, to laugh at the ridiculous, and to discern unhesitatingly which is which.

Paulos speaks feelingly about his being absorbed by "the beauty, the elegance and the power of mathematics" which he began to discover at a quite tender age and now shares with us, offering some sage advice, some brute facts, and some disarming peeps at the Emperor's new clothes. It has to be said, however, that the book does not contain any astronomy, so it may not really deserve a place in this *Magazine*. But don't let that deter you; for anyone — numerate, innumerate, or without even the faintest flicker of interest in numbers — this book is a darned good read. — ELIZABETH GRIFFIN.

François Arago: A 19th Century French Humanist and Pioneer in Astrophysics, by J. Lequeux (Springer, Heidelberg), 2015. Pp. 334, 24 × 16 cm. Price £90/$129 (hardbound; ISBN 978 3 319 20722 3).

Dominique François Arago (1786–1853) — who went by the name François — was one of the giants of European physical science during the first half of the 19th Century. Yet his life was lived out not only within a period of rapid scientific and intellectual change, but also, in France, against a backdrop of regular political disruption: from a childhood and early manhood during the Revolutionary and Napoleonic period, to the Revolutions of 1830 and 1848, with lurches between Bonapartist, Bourbon, and Republican political régimes. And Arago was involved in the politics of his day, being of Republican inclination, and at times even holding high office in government amidst the swings-and-roundabouts politics of the age.

At the heart of James Lequeux's excellent biography, however, is Arago's physical science, encompassing as it did an enormous range: the study of light, electromagnetism, geodesy, astronomy, geophysics, meteorology, applied physics, and even engineering — for during Arago's latter years, when the first railways were built in France, the great physicist inevitably came to be involved with aspects of railway engineering and safety.

One thing I found especially fascinating was Arago's work, in the pre-spectroscopic era, as a 'Pioneer in Astrophysics'. This began in 1811, when he was working on the physics and chemistry of polarization. Partly in the context of Sir William Herschel's work on sunspots and speculations about the solar interior, Arago examined the Sun with his polarimeter, and found that its light was not polarized, suggesting that the solar surface consisted of burning incandescent gases. Had the surface been solid or liquid, he would have expected it to exhibit polarization. This predicated various possibilities for the nature of the solar interior, which would be elucidated by later generations.

Indeed, the very nature of light itself engaged much of Arago's thought, and Chapter 4 is devoted to his attempts to measure accurately its velocity using new high-precision technologies, such as beam-splitters and rapidly rotating mirrors — work which would be taken further by Léon Foucault and Hippolyte Fizeau.

What comes over in Lequeux's book, moreover, is how very differently structured French science was from that of England. For whereas British science was organized around self-funded private gentlemen and the private Royal, Royal Astronomical, and other Societies, the French Academy (or Institut) was very much a product of the state, and highly bureaucratized. I therefore much appreciated Lequeux's detailed account of the structure and working practices of the Academy, along with Arago's standing within it.

Arago, furthermore, was a major pioneer of what we would now call outreach, or 'the public understanding of science'. With his drive for 'Astronomie Populaire' and "mania for giving lessons" (p. 273) at the Observatory and Collège de France, Arago got through to very large audiences, and began to educate the Parisian public in science — forming a parallel, in fact, to the many private lecturers active around Great Britain at that time, who too aimed at the same noble objective.

François Arago is a fine, scholarly work, fully footnoted, with a detailed bibliography. The layout and exposition are clear, making it easy to locate specific researches. It is very well written and easy to read. I thoroughly enjoyed this book and learned much from it, and warmly recommend it to everyone interested in early-19th-Century astronomy and physics. What a pity that such a valuable book should be priced at £90! — ALLAN CHAPMAN.

The Muleskinner and the Stars, by R. L. Voller (Springer, Heidelberg), 2016. Pp. 241, 24 × 16 cm. Price £26·99/$34·99 (hardbound; ISBN 978 1 4939 2879 8).

Good grades in school exams, a first-class honours degree, a topical and robust PhD thesis, productive years as a post-doc, and an eventual professorship — these are surely the steps needed to ascend the greasy pole to the top jobs in astronomy today. But it wasn't always thus. This fascinating book charts in detail the very different path taken by one of the 20th Century's most productive scientists: Milton La Salle Humason.

From a small town in Minnesota, the Humason family moved to Los Angeles when Milton was 10 years old, and it was there that he remained for the rest of his eighty years. With a love of the outdoor life, Milt (as he was generally known) got to know every inch of the Mount Wilson area and decided early on that that was where he wanted to be. Thus he became aware at the outset of Hale's project to build an observatory atop the mountain, and very soon decided that he wanted to be a part of it. Dropping out of high school, Humason found his niche with the teams driving mule trains loaded with equipment up to the summit of Mount Wilson (a so-called muleskinner, which fortunately didn't seem to involve any skinning of mules), later becoming a general handyman on the project. After a short time away from the mountain, running a farm and earning enough respectability to enable him to marry, Milt returned to the observatory and showed his capabilities as an all-rounder, as a night assistant and then, through his work with the likes of Walter Adams and Seth Nicholson, as a very capable observer on the 60-inch and 100-inch telescopes. Finally, of course, he found fame working with Edwin Hubble on the programme — eventually with the 200-inch telescope — to measure the redshifts of extragalactic nebulae, thus demonstrating the expansion of the Universe.

This is a splendid story, about a very 'can-do' man, a tale nicely fleshed out by snippets of history of the times — social, political, and astronomical — which give it context. Humason seemed to be universally popular on the mountain, working with a rather disparate collection of individuals such as Hubble, Baade, and Zwicky, where the need to pour oil on troubled waters was often required. Certainly the author is a great admirer of Humason, and that is reflected in the occasionally repetitive and enthusiastic text. Strangely, each of the eleven chapters (plus extensive prologue) is prefaced by a short abstract, as though each was meant to stand alone; this too creates some repetition. Scattered throughout are snaps from what might be a family album, and they add nicely to this valuable history. — DAVID STICKLAND.

Astronomy's Limitless Journey, by G. Hasinger (University of Hawaii Press, Honolulu), 2015. Pp. 209, 23·5 × 15·5 cm. Price $19·99 (about £13) (paperback; ISBN 978 0 8248 5362 4).

This is a book by an expert and enthusiastic astrophysicist aimed at a wide readership of those interested in his subject. Originally in German and fluently translated by the author himself, it provides in 188 pages of text a comprehensive description of what is out there (and indeed all around us), how it got there, and how it may end.

Opening with a review of "the main actors of the universe — dark energy, dark matter and baryons", the author then covers in proper sequence the Big Bang and its immediate aftermath, the development of a cosmic web of galaxies, the formation and progress of stars, our increasing awareness of exoplanets and of black holes, and in conclusion a review of possible cosmic endings.

Over the years I have read many similar books, and this one has the obvious appeal of recent information gleaned from constantly improving investigative techniques. The author is generous with his historical as well as his factual information, and I particularly appreciated his description of modern supercomputer simulations as well as enjoying his insider's explanation of how it all went pear-shaped for the quondam planet Pluto.

While the author admits that new discoveries tend to open up new puzzles, he is reasonably confident that the increasing depth and detail of astronomical research is steadily moving us towards a proper comprehension of the cosmos; but bearing in mind his premise, quoted above, that dark energy, dark matter, and baryons are the main actors in the cosmic plot, there is clearly much still to be worked out. I think Hilaire Belloc made a relevant point when, writing about the microbe, he said:

> All these have never yet been seen —
> But Scientists, who ought to know,
> Assure us that they must be so …
> Oh! Let us never, never doubt
> What nobody is sure about.

One of the merits of this book, and similar books before it, is to excite in the reader not just a wish to know more but rather an urge to the constructive analysis of current belief. Classical astronomy provided a comfortable field of study, with majestic dimensions and a pleasing logicality. The baryon is literally and figuratively hard to comprehend, and its introduction into astronomy, together with dark energy and matter, has created something uncomfortably arcane.

It is all too easy for complex mathematics and high academic qualifications to lead to bewilderment rather than clarification, and Dr. Hasinger in effect acknowledges that some degree of general comprehension must be maintained when on page 47, after he has introduced his readers to multiverses and their possible ramifications, he hastily exhorts them not to slam the book shut and give up physics for ever.

I am reluctant to mention common sense in this context (Hasinger quotes Einstein's definition of common sense as "the sum of the prejudices gathered during the first eighteen years of your life") but I have always taken emotional comfort from Dr. Samuel Johnson's put-down of Bishop Berkeley — on being told by Boswell that the learned Bishop's argument about the unreality of matter was so profound as to be incapable of refutation, Dr. Johnson "struck his foot against a large stone till he rebounded from it, saying 'I refute it thus!'". (Pleasingly, this anecdote does have a degree of relevance to this review, for Hasinger mentions in his book that Einstein was much influenced by the Mach principle, and Ernst Mach himself was much influenced by Bishop Berkeley.)

Do not think from this that the book obliges the reader, like Alice's Red Queen, to believe six impossible things before breakfast. It in fact keeps everything as simple as is possible without patronizing the reader, and does not, for example, touch upon Alain Aspect and spooky action at a distance. Its subtitle is *A Guide to Understanding the Universe* and with the reservations noted above I can heartily recommend it as such.

The book has 27 interesting and well-presented colour plates, and also contains more acronyms than I have ever previously come across in a textbook. Each new astronomical project appears to require several acronyms for ready reference, and a glossary of them would be a helpful addition.

At the end of the book, the author has, rather unusually, taken up four pages to speculate about God. This is because the book is derived from lectures which the author regularly gives to general audiences and in which he frequently encounters God-related questions. It is not inappropriate for a book covering life, the Universe, and everything to end in this way, and I found the author's handling of the subject sensitive and sensible. — COLIN COOKE.

The Lost Constellations, by J. C. Barentine (Springer, Heidelberg), 2016. Pp. 506, 24 × 17 cm. Price £24·99/$44·99 (paperback; ISBN 978 3 319 22794 8).

"For centuries the nomenclature of the sky was subject to a kind of Wild West mentality", writes author John Barentine in this entertaining rummage through the contents of the celestial reject pile. Until the IAU formalized matters in the 1920s, astronomers could, and did, create new constellations to commemorate animals, instruments, and inventions they considered worthy of heavenly recognition, or to flatter a patron or monarch. These included a cat, a reindeer, a hot-air balloon, a printer's workshop, and a harp for King George III.

Over the years, dozens of new constellations were added to star charts by astronomers keen to leave their mark on the sky. Most of those novelties, shoehorned awkwardly between existing figures, had few supporters and only a limited lifespan. For this book, Barentine has blown the dust off 27 that attained at least some degree of currency before being consigned to the astronomical attic.

In 1789, for example, the Hungarian-born astronomer Maximilian Hell introduced two constellations commemorating the 20-ft and 7-ft telescopes of William Herschel. Unfortunately Hell had seen neither telescope, and his depictions of them were woefully inaccurate. Herschel's fellow-German Johann Bode, who had bought one of the 7-ft telescopes and knew what they looked like, adopted the smaller of the two Herschelian constellations in his *Uranometria* atlas of 1801, but Lacaille's generic Telescopium was already established in the southern hemisphere so further such instruments were superfluous.

Perhaps best-known of the constellation discards is Quadrans Muralis, the wall-mounted quadrant, because its name lives on in the Quadrantid meteor shower which radiates from the area that it once occupied. Invented in 1795 by the French astronomer Joseph Jérôme Lefrançois de Lalande to commemorate the instrument used at Paris Observatory for transit observations, it had a better case than most for survival. But, like all the constellations introduced after Lacaille's visit to the Cape in the 1750s, it too ended up on the scrapheap.

For each of his 27 deceased constellations Barentine gives its origin and history, numerous useful illustrations from various atlases and charts, a less-useful discussion of its iconography, and a concluding note outlining its decline into obscurity.

Overall the book is well written, although (almost inevitably with a Springer book) in need of some editing and proofreading. There are references throughout the text to a Volume 2 that is not yet published, so perhaps there are more delights to come from Dr. Barentine's cabinet of constellation curiosities. — IAN RIDPATH.

The Total Skywatcher's Manual, by Linda Shore, David Prosper & Vivian White (Weldon Owen, San Francisco), 2015. Pp. 272, 24 × 18·5 cm. Price $29 (about £20) (paperback; ISBN 978 1 61628 871 6).

This volume is, according to its back cover, "the ultimate, up-to-date guide for stargazers, comet-spotters, and planet-seekers". It is "brought to you by the Astronomical Society of the Pacific, the world's largest astronomy education organization". Although the book can be purchased, it is more obviously available as a premium for a donation to the society. A smaller donation brings you an ASP lapel pin that says "celebrating Pluto 2016". Check their website, www.astrosociety.org to see how much is required for each and, perhaps, to make a donation. I'm not quite sure what one is supposed to celebrate — ten years not a planet, perhaps? An up-front confession of conflict of interest: I have been a sporadic donor to the ASP for many years, generally to honour a specific colleague, as was the case this year.

Now, what is in the book? A total of 298 "skills and tricks for exploring stars, planets & beyond", divided into 'Naked eye astronomy tips', 'Telescopes and other tools', and 'Advanced techniques'. There is enormous variety, which gets off to a slightly poor start in "01 Meet the Universe" with images of "local supercluster" which does not look at all like Laniakea, and "observable universe" which looks even less like the standard cosmic web. The endpoint is "298 Build an Awesome Observing Chair". In between come some favourite constellations, choosing eyepieces, lunar surface features, astrophotography (with editing techniques, not film or plates), a guide to sketching galaxies and nebulae, light pollution, Drake's equation, and capsule introductions to famous astronomers of the past from Thales to Sir Bernard Lovell.

If you should want to "run" a Messier marathon, Shore *et al.* explain that you should choose the night of the new moon in late March, at mid to low Northern latitudes. They don't mention cloud cover, but minimal would probably be a good idea. I have not fact-checked more than a sliver of the names, figures, and connections mentioned, but there are oddities, some of which probably arise from translating into popular units. The Sun, for instance, is 8 light-minutes away from us, the Sagittarius dwarf at 70 000 light-years (both right to one significant figure), but the Crab Nebula is at 6523 light-years, which is probably also correct to one significant figure.

The last, main-text page is a disclaimer, explaining that the book is for an adult readership and for entertainment value only (no horoscopes, I suppose) and that you should make sure you have adequately researched all applicable risks. Good advice, of course, but sad that our litigious society has made such things necessary as an accompaniment to so many beautiful photographs. — VIRGINIA TRIMBLE.

Celebrating Science: Putting Education Best Practices to Work (ASP Conference Series, Vol. 500), edited by G. Schultz, S. Buxner, L. Shore & J. Barnes (Astronomical Society of the Pacific, San Francisco), 2015. Pp. 296, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 884 8).

The time-scales of producing a bimonthly magazine like *The Observatory* mean that I am reading these conference Proceedings as the unseasonably warm Christmas of 2015 deteriorates into a wet and seasonally dismal January of 2016. However, you may well be actually reading this review in the relevant issue of *The Observatory* as daffodils flourish on Welsh hillsides or indeed during an unseasonably wet summer for which England is well known. This preamble is relevant as these conference Proceedings had to compete with a bounty of splendid books to be read over the Christmas holidays, which also touched on teaching and understanding science. The competitors for my time were, in order: Hugh Aldersey-Williams' poetic, thematic account of the life of Thomas Browne (*The Adventures of Thomas Browne in the 21st Century*, Granta books), David Waltham's splendid counter-blast to the view that the Universe is teeming with life, *The Lucky Planet* (Icon Books), Sarah Bakewell on the life of Montaigne (*How to Live*, Vintage books) — like Browne, Montaigne had a nuanced approach to knowledge — and finally most widely relevant, Tom McLeish's *Faith and Wisdom in Science* (Oxford University Press). McLeish deals with issues of the accessibility and acceptability of science and points out a problem in the etymology of the word science itself. Science from the Latin root, I know (*scio*), compares unfavourably with the older phrase "natural philosophy" the roots of which lie in the Greek for love (*philia*) and wisdom (*sophia*). Who would not prefer a lover of wisdom of natural things to a bombastic know-it-all? And that, fundamentally, is the problem being addressed by the educators at this conference — you can only wish them luck.

It has to be said at the outset that the conference organizers do not help their cause. The initial section on the plenary sessions wallows in the very essence of bombastic 'know-it-all', as all six papers in this section are nothing more than CVs detailing the glorious past achievements of the authors and panel members, with no additional teaching material and little in the way of a summary of the panel discussions.

Section two, which covers 23 of the papers presented at the workshops, fares better, as there are many interesting presentations dealing with the problems of teaching science — or more generally STEM subjects — sometimes leavening the mix with "Art" to get the acronym STEAM. The section begins with a paper exploring the concept of different cultures through role play — a difficult subject to convey in text. The cultures being dealt with in this case were artificial constructs designed to highlight communication gaps between scientists and the rest of the population.

Several papers described efforts to use libraries and on-line resources to assist in promoting STEM subjects — one with the catchy title of 'Dark skies, bright kids' (DSBK) also pointed out a seemingly often-overlooked view that "excitement doesn't always correlate with learning". Contributors from NASA were in the vanguard of descriptions of on-line resources, and several papers detailed web sites which are available to provide extensive teacher and pupil aids — NASA Wavelength, for example. I must admit that the few sites that I sampled did not inspire — but it could be that learning-over-excitement thing again.

A couple of the more interesting papers dealt with the coming 2017 eclipse (Sunday August 21) across the contiguous United States of America — both in its potential exploitation as a teaching opportunity and also in the detailed practicalities and likely difficulties that may be encountered in seeing it. Pasachoff, in an effort to counter the views of some overly safety-conscious health organizations, is unequivocal in his plea to get out there and view from the path of totality, helpfully providing cloud-cover charts along the centreline. Fraknoi, in a following paper, points out that the path of totality, although effectively coast to coast, is only about 60 miles wide and does not touch any metropolitan areas, creating a predominantly rural event. Thus the simple business of finding sufficient hotel rooms, food, or even parking space for the expected hundreds of millions of visitors is likely to be problematical. The issue of providing sufficient safe eclipse-viewing glasses is also covered, with the suggestion to canvas support from organizations used to dealing with large numbers of people daily — McDonalds, Starbucks, *etc.*; maybe even the producers of Corona beer, who must be overjoyed at their luck at the amount of free advertising it will get.

NASA, with its huge budget, leads the way in providing educational resources, the effectiveness of which it also monitors — noting in passing that national conferences (such as this one) have a pretty low impact in terms of meeting educators' needs; local meetings are better. Some of the NASA initiatives look particularly interesting — Airborne Ambassadors, for example, looks fun for the participants: "competitively selected" two-person teacher teams get to ride in the converted 747 that is the *SOFIA* infrared airborne observatory. One teacher was so inspired by the event that in spite of an all-night observing run, which took off from NASA Armstrong (named for Neil Armstrong and based at Edwards Air Force base in California), immediately on landing many hours later, she got out her laptop to conduct a video conference with her school that was just starting its day in New York. When it works, inspiration is great stuff — as Montaigne probably almost said or as the author actually said "it bridges the distance between astronomers in the air and people on the ground". Not all teacher-inspiring efforts are so high-tech; the workshops covered themes as diverse as communities of practice in which best teaching practices are devised/discovered and shared; the nature of science — what does it encompass?; and the use of music — music inspired by astronomy to inspire students. Many papers came with a statistical analysis of how effective a teaching strategy had been, *e.g.*, the effectiveness of digital planetaria in overcoming scientific misconceptions (very effective), the extent to which non-scientific beliefs hinder scientific learning (hardly at all) — strong support of science seems to co-exist with susceptibility to non-scientific thinking; a detailed paper by Impey & Buxner on this warrants a very close reading. The final paper in this section deals with on-line classrooms and the concept of using student test results in an interactive loop to fine-tune the on-line teaching content to trap and correct any misconceptions through the use of "side tasks". I can't help wondering how long before this process reaches its chilling conclusion and is automated. The interactive loop is seen as an improvement over the more well-known massive open on-line courses (MOOCs) which although succeeding in attracting high enrolment numbers have a rather poor success rate in terms of students completing the course. The authors contend that simply putting a traditional lecture/exam course on-line does not achieve the success rates of active learning.

The final section covers 22 of the 55 posters presented at the conference. Starting where the workshop sessions left off, in the same sort of area of on-line pedagogy, the first paper simply lists a series of astronomy lectures made available on YouTube: the Silicon Valley Lectures (funded by an anonymous benefactor). There then follow a few posters describing the monitoring of the effectiveness of various teaching initiatives by NASA and other organizations, three of them using exactly the same introductory paragraph but using different permutations of the six authors. The majority of these papers are couched in the hard-to-read prose of management consultants and is dry-as-dust stuff; if you want excitement as well as learning then I recommend the Silicon Valley Lectures. The one I have sampled so far, Robert Kirshner on the runaway expansion of the Universe, was excellent, and particularly fitting to close this review as, unlike the statistical evaluation of student "Likert" sheets, it describes the motivation for astrophysics research as not for material gain, technological advancement, defence, or even health; it is research simply for sheer unalloyed joy of using physics to find stuff out — and joy was a characteristic that was missing from much of these proceedings.

However, in spite of the extensive use of acronyms and education/management jargon, if you are involved in teaching astronomy or just have an interest, then these proceedings are worth at least a skim through for ideas or maybe only to harvest from the large number of websites available to provide free teaching resources. And, by the way, I also heartily recommend my alternative Christmas reading listed in the first paragraph. — BARRY KENT.

The Impact of Discovering Life Beyond Earth, edited by S. J. Dick (Cambridge University Press), 2015. Pp. 356, 23·5 × 16 cm. Price £19·99/$29·99 (hardbound; ISBN 978 1 107 10998 8).

If everything beyond the magnetosphere is astronomy, then extraterrestrial life, astrobiology, and so forth clearly belong to us, and astronomers have been writing about the topic since long before Shklovsky & Sagan's 1966 *Intelligent Life in the Universe*, who and which, however, are not indexed in the present volume. In fact, most of the chapter authors come from other communities: history and philosophy, mass communication, theology, animal behaviour, risk communication, medical and biological topics, anthropology, psychology, and political science. Apart from editor Steven Dick himself, those you are most likely to have heard of (or, anyhow those I know!) are Seth Shostak (of the SETI institute), Eric Chaisson (author of many textbooks), and Guy Consolmagno (meteoriticist, and director of the Vatican Observatory).

Possible impacts mentioned are destruction of terrestrial human life or at least civilization (think Cortés and the Aztecs, Pizarro and the Incas); the solving of all our problems by a superior species; mild cognitive dissonance for some, but not all religions; and total boredom (all right, already; Mars has water!!!). Among UCI freshmen in recent years, this last reaction has become so common that trying to teach 'Life in the Universe' ceased to be worth the struggle. Black holes work better for the moment. There is, in other words, no consensus. For instance, Douglas Vakoch shows some drawings meant to convey the concept of altruism to aliens who would have to be roughly at our level of development, while Clement Vidal thinks the most likely encounters will be with microbial life or Kardashev Type II civilizations (who use the entire energy output of their home star). This lack of consensus is present despite the volume and the conference on which it is based involving only a western, indeed American, perspective, apart from one Israeli author (Iris Fry, retired from Tel Aviv and Haifa) and comments on Buddhism and the nature of the Universe by a father–son pair (who, however, in the text, describe themselves as "I"), John and Julian Traphagan.

My favourite question and answer come from Consolmagno, "Would you baptize an alien?" Seeing the chapter title, my instant response was "infant baptism, no; adult baptism after suitable preparation". His instant answer to a reporter was "Only if they ask". "They", while ungrammatical, is a clever way around having to decide among he, she, and it in this context. The chapter actually addresses, for the most part, why, for a believer, it is not a silly question and why the answer cannot be a firm yes or no. A third-generation atheist myself, I nevertheless find the question and Consolmagno's answer interesting, but it is not in any obvious way astronomy. — VIRGINIA TRIMBLE.

Practical Optical Interferometry, by D. F. Buscher (Cambridge University Press), 2015. Pp. 267, 25 × 18 cm. Price £39·99/$64·99 (hardbound; ISBN 978 1 107 04217 9).

For some years, interferometry at visible and near-infrared wavelengths held a reputation as being an arcane and technically challenging field appealing mostly to tinkering specialists who like the challenge of making difficult things work. More recently, though, the discipline has generally been tamed and a wide variety of remarkable results, including images of stellar surfaces, environs, and systems, have shown just how powerful optical interferometry is at addressing long-standing questions of stellar formation and evolution. Continuing sensitivity developments are likely to extend broadly interferometry's reach to extragalactic objects, importantly expanding the technique's constituency to the dominant sub-species of astronomers.

Until the appearance of this book, interferometry novices have largely relied on Peter Lawson's *Principles of Long Baseline Stellar Interferometry*, which is an edited collection of notes from NASA's 1999 Michelson Summer School back when NASA was in the interferometry business. That remains a fine resource that had the added benefit of being free of charge, but it lacks the uniformity of coverage of principles and practicalities that one would hope for from a textbook written entirely by an expert. David Buscher does not disappoint in this regard. He is among the top tier of interferometrists internationally and has exploited his experience in creating this new invaluable resource for those who might want to build interferometers themselves or better utilize ones to which they have access.

The author wisely stays true to the implications of his book's title and refrains from relating the history of optical interferometry or reviewing its scientific contributions. Except for indicating how the current handful of interferometers approach specific problems that naturally arise in the book, Buscher also refrains from detailed descriptions of each of those complex instruments. He does provide a supply of references that point the reader to such details. The writing style is excellent and thoughtful in anticipating questions that would arise in the minds of students who are endeavouring to understand a field that can be obscured by experts either less experienced or less caring about demystifying interferometry. Indeed, this benefits not only from Buscher's technical expertise but also from his years of teaching. *Practical Optical Interferometry* is a wonderful resource that fulfills a long-standing need for advanced undergraduates, graduate students, and postdocs enticed by the prospects of sub-milliarcsecond spatial resolution. —HAROLD A. MCALISTER.

Revolution in Astronomy with ALMA: The Third Year (ASP Conference Series, Vol. 499), edited by D. Iono, K. Tatematsu, A. Wootten & L. Testi (Astronomical Society of the Pacific, San Francisco), 2015. Pp. 364, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 882 4).

These are the Proceedings of a conference held in 2014 December for the mm/sub-mm community to present the latest results from *ALMA*. Reviewers for *The Observatory* tend to be ambivalent about the value of conference proceedings, but I generally welcome them as providing useful surveys of particular topics easier to navigate than the primary literature. Most of the value lies in the longer review articles, but the short contributions give a sample of current work and point to papers worth looking out for in the journals. The Proceedings reviewed here contain rather few reviews: we have full-page photographs of Pierre Cox showing an image of HL Tau in his introductory talk, Meredith Hughes reviewing gas and dust in "Circumstellar Disks", and Christine Wilson summarizing the conference — but not the texts of their contributions! Of the reviews that *did* make it into the Proceedings, I particularly enjoyed those by Susanne Aalto ("Galaxies and Galactic Nuclei ..."), which includes a handy summary of useful molecular lines, Nami Sakai ("Protostellar Disk Formation Traced by Chemistry"), and Valentín Bujarrabal ("First *ALMA* Observations of Evolved Stars"). The use of different molecules to map processes deep inside the protostar L1571 (Sakai) is spectacular, as is the molecular and dust mapping of the HH212 protostar in the immediately following contribution by Codella *et al.* The great sensitivity of *ALMA* allows spectroscopy of distant sources, such as the ISM of the $z = 0{\cdot}89$ galaxy in front of PKS 1830-211 (Muller *et al.*), which shows isotopic ratios differing from their solar/terrestrial values, while the high resolution allows monitoring of the relative strength of two of the lensed images of the background blazar. The contributed papers provide a window to a variety of spectacular results which could stimulate non-specialist readers to consider *ALMA* for their own investigations.

Some of the papers cite arXiv preprint numbers, sometimes but not always identified as such, following the journal references of papers which have already been published in final form. This could be a nod to Open Access, useful to readers who cannot access the published versions, but the preprint and published versions are seldom identical. Which version did the authors have in front of them when working on their paper? The differences might be minor emendations by the copy editor, corrections at the proof stage, or significant changes if the preprint was not the accepted version of the paper.

These Proceedings have come out commendably quickly — they were published fewer than 12 months after the meeting, but at a price: no index, a scattering of typos and $\LaTeX$ errors, missing references, and many of the figures reproduced so small that their axes are unreadable. Such figures may be impressionistic, but they are not scientifically useful. Grumbles aside, these are valuable Proceedings but of shorter half-life than many, given the rapid development of the subject: they could have been published on-line. For a more permanent record, speed of publication could have been sacrificed to allow more of the reviews to be included and the editing to be tightened. — PEREDUR WILLIAMS.

Physics and Evolution of Magnetic and Related Stars (ASP Conference Series, Vol. 494), edited by Yu. Yu. Balega, I. I. Romanyuk & D. O. Kudryavtsev (Astronomical Society of the Pacific, San Francisco), 2015. Pp. 358, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 872 5).

This volume contains the review papers and contributed papers of the 9th international conference on magnetic stars held in Nizhny Arkhyz, in the Caucasus mountains, near the Special Astrophysical Observatory. Magnetic-star research these days encompasses the entire main sequence plus magnetic white dwarfs, magnetars, and pulsars. Many of the 50 researchers attending were from Russia but several were from, *e.g.*, Czech Republic, Canada, Slovakia, Sweden, Chile, Italy, Germany, Belgium, and India. The review papers in particular provided much to think about. Most of the evidence points to the magnetic fields of Ap stars, Bp stars, O stars, and WD stars being frozen-in 'fossil' oblique-dipole and quadrupole fields that may be varying only on long evolutionary time-scales. In most parts of the main sequence about 5–10% of stars are magnetic and their fields have been mapped in many cases. Detailed study shows that individual Ap stars have periods that, in the most slowly rotating objects, are of the order of 300 years, and there is nothing to exclude the possibility of periods of 1000 years (G. Mathys). The 'BOB' survey of B fields in OB stars by another collaboration has found fields in a few stars of late O and early B type. The MiMeS collaboration has found or confirmed fields in several O stars, and the analysis of polarization in the O7 V star θ^1 Ori C shows that that star has a mainly dipolar field inclined to the rotation axis by about 42°.

The fraction of magnetic white dwarfs (MWD) is a few per cent, with fields ranging from several kG to 1000 MG. They also have mainly dipolar fields, and some of them seem to show no rotation. The origins of most of those strong fields is suggested to be due to flux conservation during the evolutionary reduction of the radius of a magnetic Ap star, though possibly not all MWDs have fossil fields (G. Valyavin).

The observations of magnetic stars began with the work of H. W. Babcock in the 1940s and '50s with photographic measurements, using Zeeman analyzers at the coudé spectrographs at Mt. Wilson and Palomar Observatories. Those techniques have been superseded by the new generation of spectropolarimeters that can measure the Stokes parameters, such as *FORS* at ESO's *VLT*, *HARPSpol* at ESO La Silla, *NARVAL* at Pic du Midi, and *ESPaDOnS* at the *Canada–France–Hawaii Telescope*. Magnetic measurements of T Tauri stars and Herbig Ae/Be stars have also been undertaken. Nearly all the field-measurement results discussed in this conference are from instruments such as those.

Most of the papers are in very clear English, for which the editors deserve high praise. A couple of the papers were, unfortunately, not of that standard and I had to spend time working out what the authors really meant. But on the whole the standard of production is excellent. This book provides a useful summary of current research in this important field and belongs in every library of research universities, and the price is within the reach of individual researchers. — MIKE DWORETSKY.

Living Together: Planets, Host Stars, and Binaries (ASP Conference Series, Vol. 496), edited by S. M. Rucinski, G. Torres & M. Zejda (Astronomical Society of the Pacific, San Francisco), 2015. Pp. 418, 23·5 × 15·5 cm. Price $88 (about £58) (hardbound; ISBN 978 1 58381 876 3).

The conference which this volume records took place in Litomyšl, Czech Republic, the birthplace of binary-star, lunar (*etc.*) astronomer Zdenek Kopal, whose centenary provided the occasion for the meeting. One hundred and twelve participants came from 25 countries on the customary six continents (and I am still hoping for a symposium with a delegation of penguins from Antarctica). Of those, about 30% were from the Czech Republic and Slovakia and a somewhat smaller percentage of women (based on names, for garments worn in conference photographs have converged between genders beyond disambiguation). Among them were two of Kopal's three daughters, Zdenka Smith (now at NOAA, Boulder, Colorado) and Georgiana Rudge (of San Jose, California). They must be about my age, since their parents married in 1938 and mine in 1939, but are rather better preserved, judging from a full-length photo of the pair. Third daughter, Eva, appears only in the introductory chapter by Michal Křížek, unless she is disguised as Eva Plávalová of Bratislava.

The SOC chair and senior editor, Slavek Rucinski (of Toronto) describes the underlying question addressed by the conference as "How do stars manage angular momentum?". Since nearly all the contributions mention stars with companions and/or rotation they ought to be heading in the right direction. Getting rid of angular momentum (and magnetic-field flux) is also essential in star and planet formation, so it is annoying that what was probably the keynote talk on formation of binary stars and planets appears only as an abstract. The absence of any sort of index precludes casual search for additional information on the topic.

Several of the review talks do, however, provide very interesting factoids. Matthew Bate on origins of the statistical properties of binary systems reveals that the correlations of binary incidence, distribution of separations, primary masses and mass ratios do not tell us which is the underlying, fundamental property. Jerome Orosz points out that 15–20% of the *Kepler* eclipsing binaries (more than 2000 total) have close-in tertiary companions. Gregory Feiden confesses that standard stellar-evolution theory is insufficient to explain the most basic correlation for low-mass, main-sequence stars: the mass–radius relation (I think that means that theory and observation do not agree, by –4 to +10 %, scattered randomly from 0·2 to 1·0 solar masses). Magnetic fields and stellar activity can reconcile models to data, but (the author notes) this does not mean that they are the right answer.

John Southworth presents a wealth of information on transiting planets, but my favourite sections are on the Rossiter–McLaughlin effect. Why not McLaughlin–Rossiter? Because, although the two papers appear in the same volume of *Astrophysical Journal* (**60**, 1924), Rossiter is on page 15 and McLaughlin on page 22. As for the effect, it is a distortion of the measured radial velocity of a rotating star when another star or planet sequentially blocks one side, the middle, and the other side, by up to 50 m/s for planets *vs.* 13 km/s for Beta Lyrae. From these data comes the surprising fact that not all exoplanets orbit in their hosts' equatorial planes; indeed some are even retrograde to their stars.

A recent and exciting discovery is the orbiting of planets in or around binary star systems. Yes, it happens, both for a planet around relatively close star pairs (William Welsh on *Kepler* data) and for a planet around one star in a wider pair (Eva Plávalová and Nina Solovaya on HD 120136Ab using the very challenging Eggleton code). Ah! But would you want to live there? Paul Mason and colleagues have examined what happens to a planet 1·47 AU from a pair of solar-mass stars with $a = 0{\cdot}015$ AU ($P = 11{\cdot}4$ days) and find the habitability conditions to be comparable to those on Earth or better. But there is a price to pay (by the star, anyhow). Jorge Melendez of Sao Paulo, and colleagues, have looked hard at 16 Cyg ABb. Relative to A, B is deficient in refractory elements by about 1·5 to 6·0 Earth masses, just what would be needed to form the initial rocky core for the giant planet 16 Cyg Bb. But it was, however, the rapidly moving 61 Cyg, in which several mid-20th-Century astronomers thought they had found a giant planet, in case you were tempted to cry "Eureka! They were right!" — VIRGINIA TRIMBLE.

The Formation and Disruption of Black Hole Jets, edited by I. Contopoulos, D. Gabuzda & N. Kylafis (Springer, Heidelberg), 2015. Pp. 264, 24 × 16 cm. Price £90/$129 (hardbound; ISBN 978 3 319 10355 6).

This is a volume which arose from a one-day session on black-hole jets which took place at the European Week of Astronomy and Space Science in Rome, in 2012 July. The book is a pleasant surprise in that each of the ten contributions it contains is a serious mini-review about one facet of the field, rather than the two-page summaries which often appear in conference proceedings. Furthermore, there is a good mix of theory and observations, and even some attempt to see where they may overlap. Theoretical foundations are laid by Lynden-Bell and expanded upon (in arguably less-certain directions) by Tcheckhovksoy, Vlakhis, Punsly, and Contopoulos. These focus largely on the likely magnetic origin of relativistic-jet launching and collimation, and speculate on the connections to black-hole spin and accretion flows. The contributions themselves present an interesting snapshot of current theoretical ideas on black-hole jets and, although inevitably rather subjective, are well written.

The observational state of the art, for both stellar-mass and super-massive black holes, is presented in chapters by Gallo, Hardcastle, and Gabuzda, and possible physical origins for the observed accretion-ejection phenomenology are discussed by Kazanas and Kylafis & Belloni. These are good reviews, largely capturing the current observational picture and attempts to understand it. It is interesting to note that the empiricists are rather more tentative in drawing firm conclusions than the theoreticians, but also how much of the observational details remain poorly understood (if at all).

Overall, this volume contains a nice mix of theoretical ideas combined with solid observational reviews. I would recommend it for someone wanting to gain a quick snapshot of the field. I would, however, also recommend that in the interests of getting the broadest possible picture this is not the only book in the field that they read. — ROB FENDER.

Magnetic Fields in Diffuse Media, edited by A. Lazarian, E. M. de Gouveia Dal Pino & C. Melioli (Springer, Heidelberg), 2015. Pp. 623, 24 × 16 cm. Price £153/$229 (hardbound; ISBN 978 3 662 44624 9).

Magnetic fields and turbulence are universally present within astrophysical objects ranging from the intracluster medium down to star-forming regions. This book covers a broad spectrum of topics associated with both processes, such as techniques for observing magnetic fields, magnetic fields in star-forming regions and galaxies, and magnetic diffusion, acceleration, and reconnection. All of them have seen substantial progress in the last several years and the authors of each chapter, who are all experts in their fields, succeed in conveying these recent successes to the reader without neglecting to provide the necessary background information.

I particularly enjoyed the chapter on magnetic reconnection in astrophysical environments by Lazarian, Eyink, Vishniac & Kowal. In that chapter, the basic physics of magnetic reconnection, *i.e.*, Sweet–Parker and Petschek reconnection, is discussed and then extended to take into account magnetohydrodynamic turbulence. The main reason to invoke the presence of turbulence is to enhance the magnetic-reconnection rate to realistic values, but a further extension can be made towards turbulent reconnection in weakly-ionized plasmas. In that case, magnetic reconnection provides an effective diffusion of the magnetic field at rates that exceed those due to ambipolar diffusion (which is also covered in the book, by Zweibel), and has potentially far-reaching implications for the conventional theory of star formation.

While I singled out one chapter, the others are equally interesting and informative. I recommend this book to anyone interested in magnetized and astrophysical plasmas, but specifically to graduate students, postdocs, and even academics working in the fields of star formation, the interstellar medium, and galaxies, as this book contains all of the information needed for a thorough understanding of magnetic fields in diffuse media. — SVEN VAN LOO.

Collisionless Shocks in Space Plasmas: Structure and Accelerated Particles, by D. Burgess & M. Scholer (Cambridge University Press), 2015. Pp. 356, 25 × 18 cm. Price £99·99/$150 (hardbound; ISBN 978 0 521 51459 0).

Collisionless-shock phenomena constitute some of the most important dynamical processes in space plasmas, and this fine new addition to CUP's series in *Atmospheric and Space Science* delivers a comprehensive review of the field. Written by two of the most respected experts on shock physics, this superbly produced monograph takes the reader from the basic phenomenology of shocks in fluids to a lucid and detailed account of the most recent research. Emphasis is on physical principles throughout, but the presentation also benefits from results of computer simulation, as well as comparisons between theory, computer modelling, and experimental data. The authors have been directly involved, over the past few decades, in a number of key satellite missions that have explored the Earth's magnetosphere, the solar wind, and heliosphere, and their experience in interpreting data from such missions is manifest in the descriptions of the interplay between theory and experiment. The quality and quantity of the graphical detail concerning the output from both computer simulations and spacecraft instrumentation is particularly impressive.

The comprehensive treatment includes shock structure, particle dynamics in shock electric and magnetic fields, ion and electron acceleration mechanisms and heating, instabilities, and the role of wave dispersion in limiting shock development. The earlier chapters treat plane shocks, but a later chapter deals with large-scale shock structure, such as bow shocks, where curvature plays a role. There is also a short appendix on computer simulation techniques that includes reference to the important issue of initialization strategies.

The authors, together with the publishers, are to be congratulated for producing a book that is such an enjoyable as well as an informative read. It should prove an ideal source of information for post-graduate students of space-plasma physics and astrophysics, as well as being a high-quality reference work for professionals in these and related fields. — TERRY ROBINSON.

Seven Brief Lessons on Physics, by C. Rovelli (Allen Lane, London), 2015. Translated from the Italian by S. Carnell and E. Segre. Pp. 93, 18·5 × 11·5 cm. Price £6·99/€7·15 (hardbound; ISBN 978 0 241 25596 6).

I normally don't read translations. If I can read the original, I prefer that. If not, considering that I will never be able to read all the books I want to, I would rather avoid the risk of a bad translation. (Not all bad translations are apparent when reading just the translation, so the potential for wasting time is great.) Exceptions are books friends have given or lent me, when the author has personally authorized the translation, or when I have a special reason. One special reason is that the author is Carlo Rovelli. From his technical papers (written in English), my impression is that he is one of the most interesting physicists alive today. Thus, my interest in reading his latest popular book trumped any potential doubts about the translation (which, as far as I can tell, is very good; the author himself thinks that it is even better than the original[1]). (Even if I ever learn enough Italian — neither a language I know well nor one I am learning — to read it, by then it will be too old for me to review in these pages.)

The seven lessons cover General Relativity, quantum mechanics, the structure of the Universe, elementary particles, quantum gravity, black-hole thermodynamics, and us. "Lessons" sounds perhaps too strict; these are essays, illuminating not only the topics but also Rovelli's personal connections to them. Of course, detail is lacking, but rather than being superficial, each chapter distils the essence of its topic. There is one equation in the book: not $E = mc^2$, but rather Einstein's field equation $R_{ab} - \frac{1}{2}Rg_{ab} = T_{ab}$. There is some astronomy in the first chapter, involving the confirmation and applications of General Relativity; there is more in the one on the structure of the cosmos, which includes, in addition to the usual suspects, Rovelli's hero Anaximander (about whom he has written an entire book[2]).

While the first four chapters discuss common topics in popular-science books, the next three are somewhat unusual: Chapters 5 and 6 because they discuss cutting-edge areas (in which Rovelli himself works — few if any other popular-science books mention Planck stars), and the last chapter because it is concerned with humans — not as animals and thus just another part of the Universe, but as beings with souls (a concept which Rovelli is able to convey without any trace of mysticism). Many books describe scientific discoveries (long) after the fact, perhaps leading to a too cut-and-dried view. By including current topics with which he is familiar, Rovelli gives the reader a glimpse of what scientists really do.

Weinberg[3] dismisses much of what is often thought of as Ancient Greek science as "poetry", by which he means that it doesn't conform to the modern definition of science, even if there is some superficial resemblance; in other words, "style without substance". On the other hand, much of the scientific literature is, or is perceived to be, "stuff without style", either because the latter is deemed to be unnecessary or because it is visible only to experts. In this short book, Rovelli cannot really enable the uninitiated reader to see through the jargon to the inner beauty, but he does provide some motivation for doing so, the reward being beauty like that which we can perceive in other areas of our experience. (Whether, as Rovelli claims, it takes less effort to appreciate Einstein's field equation than a late Beethoven string quartet, I leave as an exercise to the reader.) Rovelli's book is not just an exposition of what science is about, but, in a positive sense, is poetry as well. Even Weinberg would probably like it.

This little book was a bestseller in Italy and has been translated into more than thirty languages. It's easy to see why: it is short enough that those in the intended readership ("those who know little or nothing about modern science") don't have to make a big commitment to read it; it is well written; it provides a compact overview of the main areas of fundamental research in physics. Perhaps most important, it conveys well *why* those working on fundamental physics do what they do.

Most readers of this *Magazine* will not learn much, if anything, new from it (though it is still worth a read), but it is an ideal introduction for anyone who wonders what we do and why we do it. — PHILLIP HELBIG.

References

(1) C. Rovelli, personal communication.
(2) C. Rovelli, *The First Scientist: Anaximander and His Legacy* (Westholme, Yardley, PA, USA), 2011.
(3) P. Helbig, *The Observatory*, **136**, 82, 2016.

Here and There

CARELESS EXOBOTANY

As many as half of all natural history specimens in some of the greatest institutions are probably wrongly labelled, according to experts at Oxford University ... . They found that when specimens from the same planet are sent to different museums, they are often given different names by the in-house experts. — *Weekly Telegraph*, 2015 November 25, p. 8.

THE BIG CRUNCH COMETH

… over this enormous galaxy cluster [the Virgo Cluster] — about 10 light-years across … — *A&G*, 2015 December, 56, no. 6, p. 6.7.

AND BEYOND OURS

Major Peake said that the view from the cupola, a windowed segment that offers 365-degree vistas, was "way beyond my expectations". — *The Times*, 2015 December 19, p. 43.