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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2018 December 14 at 16^{h} 00^{m}
in the Geological Society Lecture Theatre, Burlington House

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

The President. Good evening, ladies and gentlemen. I am afraid I have some unhappy events to report. I will ask you, in a moment, to stand in memory of two of our Fellows and Honorary Fellows who passed away in recent months. First of all, Michael Thompson, who was the Deputy Director for the National Center for Atmospheric Research, and a very notable solar physicist who worked at Imperial College and at Sheffield. Secondly, Riccardo Giacconi, who was a Nobel Laureate, and who can reasonably be described as the originator of X-ray astronomy and the science that, in the end, observationally discovered black holes. Can I ask you to stand for a few moments in their memory. Thank you.

I think we can now proceed to the Ordinary Meeting and I am very pleased to invite Professor Jim Wild, of Lancaster University, to give us the James Dungey Lecture for this year, 'Space weather: living with our star'.

Professor J. A. Wild. [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*.]

The President. Jim, thank you very much indeed. We did actually ask you here to cheer us up, but anyway... [laughter]. Time for a few questions.

A Fellow. My passion is chasing the aurora, so one thing that I always look at are predictions of coronal holes, coronal mass ejections, and so on. One thing that it does not seem possible to predict is the polarity of the solar wind. Is that something you might look forward to in the future — say there is a coronal hole opening up, and it has a nice southward component?

Professor Wild. That would be nice if we could do it. The question refers to the fact that as a coronal mass ejection, for example, is fired out from the Sun, it may be hurtling towards Earth. Depending on the orientation of the magnetic field bundled up inside it relative to the Earth's magnetic field, it could be very geo-effective or not at all. It could have a big impact or not. We can try to measure it *in situ*: as it flies over a spacecraft between the Earth and the Sun, we can measure it with magnetometers on board. That will typically give us thirty minutes' flight time, so we get thirty minutes' warning. Really, "Mr President you have to turn off the power grid, you have got thirty minutes" is not very helpful. And the power companies would like four weeks' notice; well, they are not going to get that either, although several days is useful. Trying to predict the polarity of the magnetic field inside a coronal mass ejection is in theory possible. There are some physical phenomena you could measure to remote-sense that, but we are nowhere near doing it practically yet, but it is a kind of holy grail of forecasting.

Professor Kathy Whaler. You have concentrated understandably on the extreme events, but there is insidious and continuing degradation of the insulation of power systems and damage to satellite chips and things like that. On what do you think we should concentrate?

Professor Wild. Is it an either/or question?

Professor Whaler. I don't know. That's another important thing to think about.

Professor Wild. It's hard to say, because trying to quantify the damage of some of these things is difficult, and at the end of the day it is probably money that talks — how much is it going to cost to replace a transformer, how much of its lifetime is eroded. We have seen examples in recent years where there have been events which haven't been large enough to damage a transformer, but over a course of months when the Sun was particularly active in 2003 there were several transformers that slowly went downhill and had to be taken out of service. There is definitely a cost to that. I am guessing that is the kind of thing you could more easily fit inside a business continuity plan, where you would have to keep checking and fixing these things. But I think it is very industry specific as well. If you have got some sectors like the railways, where they have got huge problems with regular weather or terrorism or leaves on the line, it is quite hard to push this stuff into any of the top ten things they need to worry about. It would be something big they would worry about I think. I don't think there is a one-size-fits-all.

The President. Let us thank Jim again for an excellent Dungey Lecture. [Applause.] Our next speaker is Professor George Efstathiou, from the Kavli Institute for Cosmology at Cambridge. He is the team leader for the winner of the RAS 'A' Group Achievement Award. He is going to talk to us on 'The *Planck* legacy: inflation and the origin of structure in the Universe'.

Professor G. P. Efstathiou. [No summary of this talk had been received at the time of going to press.]

The President. George, that was a very interesting talk indeed. I think we can afford time for two questions.

Reverend G. Barber. From the point of view of the scientific method, is there not another problem? And that is over the past roughly forty years, since the first beginnings of inflation, the Standard Model requires inflation, dark matter, and dark energy. And yet, none of these have been discovered on a laboratory scale, so we do not actually know what physics we are talking about. Is that a problem?

Professor Efstathiou. Of course it is. The fact that this model fits the data, and we know parameters very accurately and so on, means some people might say "cosmology is finished", but it isn't. There are these huge open problems, and we could be very wrong. So there's all to play for.

Mr. N. Jeffrey. You talked about the measuring problem of inflation. Would you not get an equivalent problem in the very late times with dark energy, and would those people use that as an argument against dark energy, for example?

Professor Efstathiou. Yes, it is interesting. I agree you have the same type of problem with late-time dark energy, so there are, I am sure you know, real conceptual problems with infinite de Sitter space. So, yes, we add that to the list of fundamental problems.

The President. I think we should stop there, but George you obviously need more grant funding. Let us thank George again. [Applause.]

Our last talk this evening is from Professor Mike Edmunds from Cardiff University and the title is 'Christmases past: the best popular astronomy books ever'.

Professor M. G. Edmunds. Books are a popular present, and at this season recommendations are often welcome. The death earlier this year of Stephen Hawking prompted reflection on the extraordinary success of his *Brief History of Time*, and then to thoughts of what were the other great popular astronomy books in history. Both adjectives — great and popular — need some explanation. Is popular to be judged from the number of copies? Numbers of editions? Should the numbers be normalized to the literate population at the time? Inevitably this is going to be something of a personal choice. I have, for reasons of personal safety, excluded any living authors. What makes a book great? Science is rarely a literary genre, with some notable exceptions. Common to the books that are chosen here are grand themes, stylish and clear writing, and a vocabulary appropriate to its readership.

The *Brief History of Time* has to go on our shortlist. First published in 1988, it remained on bestseller lists for years, with total sales in excess of nine-million copies and translation into many languages. To avoid alienating his readers, Hawking was careful to use only one equation — I expect you can guess which one! Undoubtedly sales were boosted by his inspirational overcoming of his physical state, and the attraction of brevity in dealing with such a large subject. Nevertheless it has been somewhat unkindly suggested that a Hawking Function $f(n)$ should be defined, where $f(n)$ is the fraction of readers who read beyond page n in the book and the only known function to tend to zero faster than the exponential. The book's success does certainly demonstrate a welcome strength of popular aspiration to fathom the Universe, however modest the actual achievement. That desire is underlined by our next choice, Carl Sagan's *Cosmos*. That wide-ranging "story of cosmic evolution, science and civilisation" — again a grand theme — arose out of a TV series with a claimed 500-million viewers worldwide, and the book itself selling over five million. It propelled Sagan into a popular-science guru.

Next on the list is Arthur Koestler's *The Sleepwalkers* from 1959. He acknowledged that it was "a personal and speculative account of a controversial subject", and it is the spirited, imaginatively-told story of Copernicus, Kepler, and Galileo. Professional historians hated it, since it is full of inaccuracies and occasionally polemic, but it is still a great and stimulating read. As we are now back in the 1950s, we must include *Frontiers of Astronomy* by Fred Hoyle. Having honed his narrative skills on early 1950s' radio, Fred produced a book which inspired a whole generation of astronomers, and was remarkably popular in the USA too. Its Steady State theory is dated now, but the writing is full of insight into his way of thinking. It reminds us too of his classic output of exceptional science fiction.

Passing back to the inter-war years, it would be tempting to include either James Jeans' *The Mysterious Universe* (1930) or Arthur Eddington's *The Expanding Universe* (1933), but although well-known they don't quite reach the heights of popularity. That cannot be said for our next choice, Agnes Mary

Clerke's *A Popular History of Astronomy during the Nineteenth Century*. It was first published in 1885 and went through extensively revised and expanded editions to 1902. She was a friend of William and Margaret Huggins, and spectroscopy is a major theme in the book. It was published in the UK, USA, and Germany and acclaimed as a "model of style". Again we note the importance of readability in courting popularity.

Earlier in the 19th Century Mary Somerville's *On the Connexion of the Physical Sciences* went through some eleven editions between 1843 and 1877, selling in excess of 15 000 copies. It offered no equations and 500 pages of astronomy, physics, chemistry, geology, and meteorology. Its dates nicely bracket the publication of two classics in other spheres: *The Origin of Species* and *Middlemarch* — the latter at least being able to borrow metaphor from its readers' astronomical knowledge.

An absolute must for our list is Galileo's *Sidereus Nuncius* or *Sidereal Messenger*, rushed into press in a couple of months in 1610, with its account of the first observations through the telescope. Here we find the mountains on the Moon, deep star fields, and in particular the night-to-night dance of the moons of Jupiter — exciting even today. Which could not really be said of the fundamental, but hardly popular, *de Revolutionibus Orbium Coelestium* (1543) of Copernicus — labelled as the "book that nobody read" by Koestler, a claim somewhat negated by Owen Gingerich's wonderful bibliographic study. Copernicus' earlier pamphlet *The Commentariolus* was much shorter but contained the important ideas, and might have been much more popular — but probably fewer than a hundred copies were made.

Before revealing the 'most popular' book, we ought to go back to the classical world around 280–260 BC. The *Phaenomena* or *Things that Appear* by the Greek poet Aratus is a verse account of the constellations, rising and setting of stars, the celestial sphere, and weather lore. Following in the tradition of Hesiod's *Works and Days* it was based on earlier astronomical texts, and was translated into Latin by Cicero, among others. This was essential and popular reading for the intelligentsia for generations. It even included a version of "red sky at night, shepherd's delight..."

The palm of popularity I have to award to *de Sphaera* by John of Sacrobosco — who was probably born in England in the late 12th Century. This short book of some 9000 words covered similar subjects to Aratus' *Phaenomena*, with some leavening quotes from Virgil and Ovid, and was written in Paris around 1230 AD. The first manuscript copies are known from around 1240, it was the first printed astronomy book (in Ferrara 1427), and went through 200 editions until 1673 — 430 years after its composition. In print for over 200 years, and from around 1500 AD translated from its Latin into several European languages. Paper cut-out moving models (*volvelles*) adorned later editions, which were often heavily rewritten and augmented. It had become a staple of a liberal arts education, and its longevity and widespread distribution (here interpreted as popularity, normalized in some sense by its contemporary world) is unlikely to be surpassed.

Of the nine books highlighted here, five were by what might be thought of as professional astronomers, four by popularizers or poets. There are many other candidates for choice. I hope to expand and illustrate this talk in a paper to be submitted to *Astronomy and Geophysics* in the New Year.

The President. Well, Mike, I think we have time for just one question.

Mr. H. Regnart. I can be so brief that there could be another question. Two suggested additions: Bronowski's *Ascent of Man*, and Eddington's *Nature of the*

Physical World.

Professor J. D. Barrow. I believe the biggest selling popular astronomy book, certainly of modern times, probably of all time, has sold over 28 million copies between 1973 and 1990 and published by Bantam, the same publishers as Stephen Hawking's *Brief History of Time*, was the *Late Great Planet Earth* by Hal Lindsey; it is one of those Creationist–Astronomy volumes, which totally dwarfs everything else in the popular-science world.

The President. Well, that is not good news is it? [Laughter.] Thank you very much. Can I announce that the next Open Meeting will take place on 11th of January 2019. Can I wish you all a very pleasant and happy Christmas holiday. I look forward to a copy, like all of you will, of Sacrobosco's *de Sphaera* in the Christmas stocking.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

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

The President. Good afternoon everyone and welcome to the Open Meeting of the Royal Astronomical Society. My next duty is a very pleasant one — to announce the winners of this year's RAS awards.

This year the winners of the Gold Medals are Professor Margaret Kivelson of the University of California Los Angeles (G), and Professor Robert Kennicutt of the University of Arizona and the Hagler Institute for Advanced Study at Texas A&M University (A). The Chapman Medal for Geophysics goes to Dr. Tom Stallard of Leicester University. The Eddington Medal is awarded to Professor Bernard Schutz, University of Cardiff. The Herschel Medal goes to Professor Nial Tanvir of the University of Leicester. The Jackson-Gwilt Medal is awarded to Professor Anna Scaife at the University of Manchester.

Moving on to the Fowler Awards, the winners are, on the Astronomy side, Dr. Baojiu Li of Durham University, and on the Geophysics side, Dr. Ingo Waldmann (University College London). The Price Medal for Geophysics goes to Professor Catherine Johnson from the University of British Columbia. The Winton Award for Astronomy goes to Dr. Blake Sherwin of the University of Cambridge and the Geophysics Award is given to Dr. Timothy Craig at the University of Leeds. The Group Achievement Award for Astronomy goes to the Galaxy Zoo Team and for Geophysics goes to the *Cluster* Science and Operations Teams at MSSL, RAL, and the University of Sheffield. The Service Award in Astronomy goes to Professor Donald York at the University of Chicago and that for Geophysics is given to Professor Katherine Whaler of the University of Edinburgh.

The George Darwin Lecturer will be Professor Christine Done of Durham University. Honorary Fellowships have been awarded to Professor Sierd Cloetingh at Utrecht, Dr. Glenn Orton at NASA JPL, and Professor Ralf

Bender at the Max Planck Institute for Extraterrestrial Physics. The Harold Jeffreys Lecturer will be Professor Francis Nimmo of the University of British Columbia, and the James Dungey Lecturer will be Dr. Mark Clilverd of the British Antarctic Survey [applause].

We now come to the science part of our programme. I am going to invite Dr. David Jess from Queen's University Belfast, who is the 2018 Fowler (Geophysics) Award winner, to present a talk on 'Waves, shocks and heating in the Sun's most powerful magnetic fields'.

Dr. D. Jess. Observations of sunspots are by no-means a new phenomenon, with some of the first scientific studies dating back to the advent of the telescope in the early 1600s. The magnetic properties of sunspots were uncovered by Hale (1908), who employed the physics of Zeeman splitting to deduce the high magnetic-field strengths that are embedded within sunspot atmospheres. More recent high-resolution observations have shown that magnetic-field strengths on the order of 6000 Gauss can be observed in the dark umbral cores of sunspots. In this talk I will discuss how these powerful magnetic fields play an important role in the thermalization of wave energy propagating outwards from inside the solar interior.

The observations I utilize are from the *Dunn Solar Telescope* situated at an elevation of 2800 m in the Sacramento Peak mountains, New Mexico, USA. This facility contains a wealth of instruments designed to capture high-speed dynamics in the solar atmosphere from the near UV through to the far infrared. Such instruments include the *Rapid Oscillations in the Solar Atmosphere* (*ROSA*), *Interferometric BI-dimensional Spectrometer* (*IBIS*), and the *Far InfraRed Spectropolarimeter* (*FIRS*), which allow high-speed images, spectroscopy, and spectropolarimetric Stokes profiles to be captured at frame rates exceeding 30 per second. As such, the data volume is impressive, with around 5 TB/hour captured when all instruments are operating simultaneously.

The purpose of multiwavelength observations is so we are able to piece together the various layers of the solar atmosphere like a giant jigsaw puzzle. It allows us to observe the cause-and-effect processes occurring from the depths of the photosphere through to the transition-region boundary, spanning many thousands of kilometres in geometric height. Through examination of the chromospheric Ca II 8542 Å spectral line, we find that our sunspot observations are replete with impulsive brightenings, repeating in a quasi-periodic fashion approximately every three minutes. These signatures are commonly referred to as umbral flashes, and represent the non-linear development of shock fronts at the core of sunspot umbrae. Here, the acoustic-wave energy flux that propagates upwards along the magnetic-field lines experiences a dramatic density decrease with geometric height. The waves attempt to conserve their energy flux by increasing their amplitudes, but eventually the velocities reach supersonic speeds and cause the formation of shocks, providing a localized thermal increase on the order of several hundred K.

However, what was not expected was the generation of shocks at the outer edges of the sunspot umbra, where the dark background meets the much brighter penumbral plasma. Here, the magnetic-field lines are much more heavily inclined, some by up to 80 degrees with respect to the solar normal. As such, the density decrease felt by the propagating magneto-acoustic waves is much less than would be experienced at the central core of the umbra where the magnetic-field lines are mostly vertical. Therefore, the traditional shock-development scenario is not as relevant for these perimeter brightenings. To uncover the underlying physics, it becomes necessary to probe the physical plasma properties that promote such shock behaviour, and to do this we require inversion routines applied to our spectral and spectropolarimetric data.

The application of the Caisar, Nicole and Hazel inversion routines allowed pixel-by-pixel maps of the magnetic-field strength, temperature, and density to be calculated as a function of atmospheric height. Employing these parameters, we were able to trace locations where the plasma's magnetic and gas pressures are approximately equal — the so-called $\beta = 1$ region, where wave coupling and conversion is at its most efficient. Interestingly, at atmospheric heights corresponding to the lower chromosphere, the balance between magnetic and gas pressures overlapped precisely with the umbra–penumbra boundary. As a result, within this region the conversion between all types of wave mode (fast, slow, Alfvén) is at its most efficient, providing an opportunity for the ubiquitous slow magneto-acoustic modes to couple into more-elusive fast- and Alfvén-type waves.

The final avenue is to explore the velocity signatures of the observed plasma motions. However, this is a challenging aspect, since the spectral characteristics of the developing shock front are superimposed on top of the quiescent sunspot background. This creates a two-component spectral model, which must be treated with care in order to extract robustly the key signatures associated with the shock front alone. By subtracting a time-averaged quiescent profile from the two-component spectrum, the residual spectral shape allowed fitting to be performed on the isolated shock front. Following this approach, we found that the shocks developing around the periphery of the sunspot umbra had an intermixing of upwards and downwards motions (contrary to the entirely upward motions of traditional umbral flashes at the centres of sunspot umbrae), with velocity amplitudes on the order of several km sec^{-1}. These motions hint that the magneto-acoustic modes had in fact coupled into Alfvén-type waves as they propagated through the region.

To examine whether Alfvén waves are able to assist with the creation of plasma shocks, it was necessary to map the Alfvén speed across the diameter of the sunspot to see whether the propagating waves encountered any particular velocity gradients. Utilizing the magnetic-field strengths and densities output by the Nicole inversion routine, we first spatially mapped the Alfvén speeds in our field of view. Next, a two-dimensional Savitzky–Golay derivative filter was employed to calculate the spatial derivative of the mapped Alfvén speeds. Here, it was found that the umbra–penumbra boundary also exhibited a prominent negative Alfvén speed gradient. In this regime, the magneto-acoustic waves would have coupled into elliptically polarized Alfvén waves, where the induced non-linear pondermotive forces create density perturbations that resonantly amplify in the layer and steepen into shocks, giving rise to the tangential velocity signals perpendicular to the magnetic-field lines. This is consistent with the observational evidence provided by a combination of high-resolution imaging, spectroscopy, and spectropolarimetry.

Hence, these observations provide new evidence for the mode coupling and shock development of wave motions embedded within sunspot atmospheres. Of course, we were fortunate to sample the localized heating against the cool background of the sunspot atmosphere, but this opens up the question as to whether Alfvén-driven fast-mode shocks exist in other magnetic structures, for example, magnetic bright points that make up a fraction of the solar surface at any given time. If so, can we detect them against the brighter solar background, and what implications does this hold for supplying energy to the outer reaches of the solar atmosphere? This avenue of research is something we are now beginning to investigate.

The President. That was really great, thank you. Open for questions?

Professor Lyndsay Fletcher. Thank you so much, David. I am sorry, this is a slightly technical question. The thing you did where you subtract the normal absorption profile from the overall line profile and then worked with the bit that is left. Is that tantamount to saying the bit that is left is optically thin, and is that a good approximation?

Dr. Jess. Yes. That is perhaps one of the challenges that we have. With some of the signatures we are not sure about are the movement of the optically thick component *versus* the movement of a bulk plasma. Now, what we genuinely feel is that because the background plasma is relatively steady, we think then that there is some component of 'optical thinness' to the shocking material, if you will. Indeed, we have seen profiles that are very difficult to fit accurately; they are very broad and they almost merge into the deepest parts of the absorption profiles. It has been a challenge to do such fitting on a pixel-by-pixel basis, or even a flash-by-flash basis. Hence we just wanted to examine them as a statistical sample and there may indeed be a better approach to do it, but the sample we had was over half a million individual cases and we thought with that in mind, the results seemed to be fairly self-consistent. I appreciate there is a little bit of ambiguity sometimes in the profiles.

The President. This very high resolution, both spatially and spectrally, really needs a ground-based instrument at the moment. Is that true?

Dr. Jess. The capabilities for observing these events can of course be placed in space as well. I think the real problem is getting the data down again to the Earth. Trying to achieve 5 TB per hour is going to be impossible, unless we manage to track a big ethernet cable up to the spacecraft. Data transfer is the problem we are going to have for such high-resolution studies, but hopefully in the future we might have other ways of solving that.

The President. David, thanks, that was a great talk. [Applause.] Our next speaker is Amelie Saintonge from University College London who will talk to us on 'Probing galaxy evolution with dust and gas'.

Dr. Amelie Saintonge. [No summary of this talk had been received at the time of going to press.]

The President. Amelie, thank you very much indeed. You dismissed mergers fairly early on in your talk; is that because you think they don't have anything to do with this, or do you think it is just too difficult to deal with?

Dr. Saintonge. I put that statement there because the merging of two small galaxies clumping and forming a big galaxy is vital for some things, but we have plenty of evidence to show that it is not the thing that regulates the growth and star formation.

Mr. M. Hepburn. Have you considered the role of neon? It is a relatively abundant element and it is the only element which approximates to the physical properties of molecular hydrogen. If a galaxy gets older then there will be more neon there, and might this not affect the efficiency of the condensation of stars?

Dr. Saintonge. There are a vast number of different molecules and atoms that in principle we can use to study the composition of these galaxies. Unfortunately, because in this case we apply this to distant galaxies, we can observe nothing but the brightest few tracers.

Mr. Hepburn. You have to use carbon monoxide because you can detect it. What I was saying is there are a vast number of marker molecules, but only one approximates to the low-temperature behaviour of molecular hydrogen and it is very difficult to detect. I was just hypothesizing a mechanism by which increasing amounts of neon affects the efficiency of condensation of stars, because stars fundamentally are formed from molecular hydrogen. If that is contaminated by increasing amounts of neon, would not that affect the efficiency?

Dr. Saintonge. Possibly. It is not something I can comment on based on these observations.

The President. That sounds like a very good answer. Thank you, Amelie, very much indeed. I would now like to introduce the Michael Penston Thesis Prize winner, Dr. Sownak Bose from the Harvard Smithsonian Center for Astrophysics, who is going to talk on 'Cosmology beyond cold dark matter'.

Dr. S. Bose. The study of cosmology is entering a fascinating stage in its development. The observational facilities available to astronomers to conduct large surveys of galaxies are reaching unprecedented sensitivity, unlocking the potential to discover a wealth of new phenomena in the context of galaxy evolution. A comprehensive census of the faintest and earliest galaxies that form may enable us to pin down properties of the elusive dark-matter particle — thought to comprise the bulk of the mass density of the Universe, and the building block for galaxy formation, yet whose phenomenology remains a fundamental mystery to our cosmological paradigm. With this in mind, the need for a synergy between theoretical predictions and observational data has never been more necessary.

The highly successful standard model of cosmology is built upon two fundamental assumptions: that structure formation proceeds hierarchically through the gravitational collapse of cold dark matter (CDM), and that the late-time expansion of the Universe is dominated by dark energy in the form of the cosmological constant, Λ. One of the great facets of the ΛCDM model is that it is predictive in nature, a feature that has been exploited to compare the theoretical predictions of this model with the observed temperature fluctuations in the cosmic microwave background and the large-scale clustering of galaxies, two non-trivial tests that the ΛCDM paradigm has passed with flying colours. More recently, hydrodynamical simulations of galaxy formation have been performed at scale to produce increasingly realistic galaxy populations for the first time.

While this is all very well and good, there does remain a rather big elephant in the room: that despite many decades of extensive, expensive detection experiments, no particle that could be a CDM candidate has yet been discovered. How sure are we that we are truly looking for the dark matter in the right place?

This situation begs the need for well-motivated alternatives to CDM, which may originate from different mechanisms to the traditional CDM particle, whilst still retaining the success of the CDM model in predicting the statistics of structure formation. One such example is that of the sterile neutrino, originally introduced by particle physicists as an explanation for flavour oscillations exhibited by Standard Model neutrinos. Tantalizingly, a particular variant of the sterile-neutrino hypothesis could additionally serve as the dark matter, with properties akin to CDM on the largest scales, but markedly different on smaller, more non-linear regimes. Interest in sterile neutrinos has increased dramatically in recent years, following the detection by two independent groups of an unidentified X-ray line at 3·5 keV in the spectrum of galaxy clusters and dwarf galaxies. The authors claim that this line is not associated with any (known) atomic emission line, and may instead be the spectral signature of the decay of a sterile-neutrino dark-matter particle with a rest mass of 7 keV. If true, this would be remarkable — at last, perhaps, a glimmer of light from the dark sector of the cosmos.

Motivated by these observations, we sought to investigate the properties of galaxy populations predicted by sterile neutrinos, with a view to quantifying the manner in which they are distinct from that predicted by CDM. To be able to track faithfully the evolution of structures in the non-linear regime — where differences between dark-matter theories manifest themselves most prominently — we resort to large *N*-body simulations of structure formation. To this end, we ran the *Copernicus Complexio* (COCO) suite of simulations of CDM and sterile-neutrino cosmologies. Comprising over 13-billion resolution elements in each cosmological model, COCO is one of the largest and highest-resolution studies of sterile-neutrino dark matter ever undertaken.

The simulations, which are evolved over the entire history of the Universe using supercomputers, immediately reveal a number of interesting differences in the manner in which structure formation proceeds in the sterile-neutrino universe compared to a CDM universe. Most strikingly, the formation of the first structures — so-called dark-matter 'haloes' — is delayed in a universe dominated by sterile neutrinos, compared to one dominated by CDM. This owes itself to the fact that sterile-neutrino particles have close to relativistic thermal velocities soon after their birth. The ensuing free-streaming motion of these particles inhibits gravitational collapse over some characteristic scale, delaying the formation of low-mass dark-matter haloes (typically of the order of 10-billion solar masses and below). As these dark-matter haloes eventually become the seats for galaxy formation, this naturally results in a delayed start to the formation of the first galaxies. In addition to this, the abundance of the low-mass dark-matter haloes (the hosts of 'dwarf' galaxies) is heavily suppressed in the sterile-neutrino universe. On the other hand, the abundance of massive, rich clusters of galaxies is identical to that in CDM. This scale dependence of structure formation is the defining feature of the sterile-neutrino model (and, indeed, of the general class of 'warm' dark-matter models, of which the sterile neutrino is an example). The traditional CDM particle, in contrast, undergoes no free-streaming and exhibits no characteristic scale as a result.

Given the paucity of galaxies at early times, it may be possible to constrain the nature of sterile-neutrino dark matter using observations of the early Universe. One such inference has been made by the European Space Agency's *Planck* satellite, in constraining what is known as the 'Epoch of Reionization'. This is a period in the very early Universe (when it was less than a billion-years old), during which the starlight from the first galaxies began to ionize the neutral hydrogen gas in the cosmos. The duration and epoch by which this transition from a neutral to an ionized Universe is complete is strongly dependent on the galaxy population that has formed by this early time: if a particular dark-matter model forms too few galaxies to reionize the Universe in time, this would spell trouble for the theory. Through our modelling, we found that, remarkably, the sterile-neutrino models have no trouble at all completing reionization by the redshift inferred by *Planck*, despite the delayed start to the galaxy-formation process. This rather counter-intuitive result is made possible by the fact that galaxies form *more efficiently* in a universe made of sterile neutrinos than one composed of CDM. In other words, a galaxy of a given mass today will have assembled its stellar content more rapidly than is possible within CDM. Future space-based observatories like the *James Webb Space Telescope* (*JWST*) will provide us with unprecedented access to galaxy populations in the early Universe; it will be incredibly interesting to verify what other imprints this different star-formation history will leave on the primordial galaxies and if, indeed, they can tell us something about the way galaxies form, and the implications for the nature of the dark matter.

What about observations of the local, present-day Universe? The simplest exercise one can perform is to count the number of galaxies predicted by each of the sterile-neutrino and CDM-model universes, and compare those numbers to the total number of satellite galaxies we observe around the Milky Way. Unfortunately, this procedure is not quite as well-defined as it seems. While numerical simulations are able to capture the physics of dark matter (*i.e.*, gravity) very accurately, the physics of galaxy formation is much more challenging. Indeed, there is enough uncertainty in the models we use to translate haloes of dark matter into observable galaxy populations that one could easily explain away differences between theory and observation by resorting to 'uncertainties in gastrophysics'. On the other hand, the number density of haloes formed in a given dark-matter theory is known to exquisite precision. So, is there a way to count the number of dark-matter haloes in the *real* Universe directly?

Incredibly, it turns out that there is! By exploiting a phenomenon known as 'strong gravitational lensing', it is possible to probe directly the underlying matter distribution — visible or dark — in the Universe. Lensing, a natural outcome of Einstein's theory of General Relativity, is the process through which the light from a distance source (*e.g.*, a galaxy) is distorted and magnified by the gravitational field encompassing large distributions of matter between the source and an observer. This provides a natural test for dark matter: if the Universe is very lumpy (*i.e.*, plentiful in dark-matter haloes, as predicted by CDM), images of distant galaxies will be distorted much more than a Universe that is smoother (as in the sterile-neutrino case). Excitingly, this technique has now been applied successfully to real images of galaxies, opening a window into the dark Universe in the process. Using the COCO simulations to perform 'mock' strong-lensing observations, we estimate that as few as 100 such strong-lens systems may be enough to determine definitively whether our Universe more closely resembles one composed of CDM or one of sterile neutrinos. The catalogue of strong lenses is expected to grow dramatically with the advent of upcoming observatories, such as the *Large Synoptic Survey Telescope* (*LSST*).

Understanding the nature of the dark matter remains one of the outstanding mysteries of cosmology. Despite the tremendous progress made by the astronomy community in understanding the role played by dark matter in the process of galaxy formation, several fundamental questions remain: how heavy is the dark-matter particle? Do these particles free-stream in the early Universe? Are there, in fact, more exotic interactions between these particles beyond simply gravity? What are the observable predictions of different theories that are least degenerate with uncertainties in modelling galaxies? And, finally, what are the experiments we need to build to detect eventually a dark-matter particle? The symbiosis between theory and data over the next decade will be crucial to addressing each of these issues.

The President. Thank you very much. Open for questions or comments?

Mr. H. Regnart. A fascinating presentation — thank you. Just a suggestion: if by any chance dark matter is a product of phase changes, is it possible that it is left cold if the other component (or components) carry away (or are wholly or partly constituted of) the latent energy of the phase change?

Dr. Bose. The particular example that I took here, which is about sterile neutrinos, is actually a relatively simple scenario where it is just a primordial thermal velocity we are talking about. If I were granted maybe ten minutes more, I would have gone into interacting dark matter, where the particles at the time of their creation actually have some non-negligible interaction with the baryon plasma. It actually collisionally interacts with it and ends up showing oscillations in the power spectrum on very small scales. These oscillations can in fact, as we have shown in simulations, be detected, not by galaxy clustering, but by the Lyman-alpha forest. These possibilities are perfectly viable because they occur on scales that the cosmic microwave background doesn't actually probe, so they can be eminently present without ruining any of the agreements on large scales that one requires. It is certainly possible, yes.

Professor R. S. Ellis. You said yourself that the cold dark matter has not been detected, and there is another way of going and that is fuzzy dark matter, where the particle is very low mass, has wave-like properties, and seems to be getting a lot of attention. Should we put our money on fuzzy cold dark matter?

Dr. Bose. I am not a betting person to begin with, but I certainly think that the fuzzy-dark-matter model in the past couple of years has accelerated in interest. There is still a lot to be done in terms of how these models are simulated. The actual interaction between fuzzy dark matter and baryonic physics and galaxy-formation physics is still in quite a nascent stage, and is, in fact, something I am working on with colleagues of mine in the US. But I certainly would say it is worth keeping an open mind for all of these as long as there is a justified motivation for doing so, which is that there should be some element of realism to these models from the realm of particle physics for doing it.

Reverend G. Barber. There also seem to be some very large objects very early on (supermassive quasars and so forth). Is this not a problem if it is warm dark matter actually to explain how such structures can form at high redshift?

Dr. Bose. I am not sure how to answer that because it is not obvious to me what the mechanism is for forming these structures. On the scale of individual stars, for example, you don't really expect there to be too much of a difference in what is actually happening. However, what may change is when the first stars start forming — which could then mean, if you want to form a very highly accreting quasar at redshift eight or whatever, you might find it a challenge to do so in the warm-dark-matter model, if the formation of the first stars is delayed for too long. Models that are viable at the moment are those that maybe evade that level of detail because the delay is only by half a giga-year or so, in terms of when the first stars are formed. But I certainly think in order to address that question in greater detail, the actual challenge lies, firstly, in our understanding of what the formation mechanism of the first stars is, regarding cooling gas and what allows direct-collapse black holes and so on, which, I think, is very poorly understood regardless of what your dark-matter model is.

The President. Let us thank Sownak again. [Applause.]

Our last talk this evening is from Dr. Ben Rozitis from the Open University, and he is a holder of one of our RAS Fellowships. The title of his talk is 'Probing Solar System processes using extreme asteroids'.

Dr. B. Rozitis. Asteroids are the left-over building blocks that formed the planets in the Solar System 4·5-billion years ago. They come in a large range of shapes and sizes but they also come in a large range of different structures. Most people think that asteroids are solid rocks, and indeed some are. Other asteroids have solid cores covered with asteroidal soil, and other asteroids are fractured bodies. Finally, there are 'rubble-pile' asteroids that are basically a bundle of rocks and dust held together by gravity. Gravity and collisions were thought to be the dominant forces driving the evolution of asteroids but the reflection and thermal re-emission of sunlight also drives their evolution too.

For instance, the 'Yarkovsky effect' applies a propulsive force to asteroids which causes their orbits to drift slowly over time. The related 'YORP effect' applies a propulsive torque to asteroids which cause them to spin faster or slower over time depending on the direction of the torque. If the YORP effect were to make a rubble-pile asteroid continually spin faster, then the asteroid would deform in shape and eventually lose material due to centrifugal forces. The shape deformation induced can make the asteroid look like a 'spinning top', and the ejected material can also gravitationally re-accumulate in orbit to form a satellite around the original asteroid. The asteroid rotation period at which this happens is around two to three hours because that is where centrifugal forces balance or exceed the asteroid's self-gravity. Observations of asteroid spin rates show a 'spin barrier' at two to three hours, which implies that most asteroids are rubble-piles. However, there are a few 'extreme asteroids' that do apparently spin faster than that barrier. Studying these extreme asteroids can provide additional insights into physical processes that operate throughout the Solar System. Two extreme objects that I've been studying in my work are the near-Earth asteroids 1950 DA and Cuyo.

1950 DA is about 1 km in size, has a spinning-top shape, and is spinning faster than the so-called spin barrier. Thermal-infrared observations of 1950 DA taken by the *WISE* satellite indicate that it has a dusty surface, which is surprising as you would think that its fast spin rate would cause it to shed its dust. Astronomical observations also show that the Yarkovsky effect is causing 1950 DA's orbit to shrink, and modelling the rate at which it is shrinking indicates that 1950 DA has a low bulk density of 1·7 g cm^{-3}. Such a low bulk density indicates that 1950 DA is a rubble-pile asteroid but its fast spin rate implies that half of its surface experiences 'negative effective gravity'. Negative effective gravity occurs when centrifugal forces exceed the asteroid's self-gravity. Therefore, another force, in addition to gravity, must be holding 1950 DA together. It turns out that cohesive forces, in the form of Van der Waals forces, are strong enough to hold 1950 DA together. Models of the rotationally-induced stress inside 1950 DA find that just 64 Pascals of cohesive strength is needed to prevent 1950 DA from breaking up and flying apart. That is equivalent to the weight of a penny in the palm of your hand. Such a small cohesive strength can easily be produced by fine dust particles, and this nicely explains why a dusty surface was seen in the thermal-infrared observations of 1950 DA. Furthermore, such cohesive forces are believed to have helped initiate planet formation in the very early Solar System.

Cuyo is about 3 km in size, also has a spinning-top shape, and is spinning close to the so-called spin barrier. Thermal-infrared observations of Cuyo taken with the *Very Large Telescope* in Chile indicate that it also has a dusty surface. To check if Cuyo was doing anything unusual in the past, a search through archival data was performed to identify any changes in the apparent brightness of Cuyo. A thermal-infrared spectrum of Cuyo taken by the *Spitzer Space Telescope* in 2005 December was found, and interestingly it showed Cuyo to be brighter than expected. The flux excess seen in the *Spitzer* spectrum has the shape of a Planck function with an effective temperature of 216 K. That happens to be equal to the equilibrium temperature of dust when illuminated by the Sun at the heliocentric distance Cuyo was at. Therefore, this indicates that a transient dust cloud was surrounding Cuyo in 2005 December, and is likely to be the result of centrifugal forces throwing dust off the surface of Cuyo due to its fast rotation. The total mass of the dust cloud is estimated to be between 500 and 10 000 tonnes when suitable dust-particle-size distributions are assumed. Furthermore, models of the YORP effect suggest that this amount of material can be 'lofted' from the surface of Cuyo every 12 to 233 days. This indicates that some asteroids are very much not solid bodies, and that they can be surprisingly active over short timescales.

Going forward from these studies on 1950 DA and Cuyo, the *Hayabusa 2* and *OSIRIS-REx* sample-return missions have just arrived at their target asteroids Ryugu and Bennu. Both of those asteroids have characteristic spinning-top shapes, and we are likely to learn a lot more about extreme asteroids from these two *in-situ* investigations.

The President. Open for questions or comments.

Mr. G. Roberts-Borsani. Thank you for your talk. I was wondering how many asteroids do you classify as extreme? These were two examples, but then on your plot, if I saw correctly, there was one point, maybe two at a maximum.

Dr. Rozitis. Yes. I would say at the moment we probably know about two dozen, say twenty-ish, at the moment. It is a bit hard. If you know an asteroid has a rotation period of two hours based on light-curves, it could also have had a period of four hours or one hour. So it is hard to confirm the periodicity in the rotation rate. At the moment we have measured the cohesive strength of around twenty asteroids.

Dr. P. Daniel. The Yarkovsky effect comes in two flavours. The diurnal, which is the one you showed, and the seasonal, and YORP also can be due to asymmetry in the albedo as well as shape. Did you take that into account in your modelling, and if you didn't, maybe that will account for the oddballs?

Dr. Rozitis. For the Yarkovsky, the seasonal effect happens when the asteroid's spin pole is in the plane of the orbit. For both of these two asteroids, the pole is perpendicular to orbit and so the diurnal effect is maximized and the seasonal effect is minimized. At the moment we haven't detected the seasonal effect for an asteroid yet, because there are not many that are in the plane of its orbit with the sufficient astrometric observations for us to measure an orbital drift. For the question about YORP, it is actually not the albedo asymmetry. There is another effect called the tangential YORP effect, which is basically if you have got rocks lying on the surface, there is temperature asymmetry from one side of the rock face to the other side of the rock face. That can also provide an additional torque, which may be an important process acting on these asteroids as well. You may end up with an equilibrium point between the shape-induced YORP effect and the tangential, and the two cancel each other out and you end up with a quasi-static regime.

Mr. M. Hope. I was wondering if anything about your research suggests anything unusual about the age of these asteroids? Can you work back from their losing mass to see where they would have had a complete mass which wasn't a peculiar shape.

Dr. Rozitis. That is a good question. Firstly, I have been looking at near-Earth asteroids. These come from the main belt, and tend to require a few million years to transfer from the main belt to near-Earth space. I showed the simulation of YORP spinning up and making a moon. That is predicted to take place over time-scales of maybe hundreds of thousands of years. Once it has made a satellite, it can actually potentially lose its satellite. If you supply angular momentum to it, you can eventually supply too much so the satellite becomes unbound. So, you can probably place constraints on the lifetime of a binary asteroid and look into the population statistics of spinning tops with a satellite and spinning tops without a satellite to estimate how long these smaller satellites hang around for. I imagine, again, that would be of the order of hundreds of thousands of years or so.

The President. Thank you very much [applause]. We have had four exceptional talks by four exceptional young scientists recognized by the RAS. Can I remind you of the drinks reception in the Library across the way. And, finally, I give notice that the next A& G Open Meeting of the Society will be on Friday the 8th of February.

CORRESPONDENCE

To the Editors of 'The Observatory'

A Working Model of the Hale Telescope

I enjoyed reading Leonard Matula's review[1], printed in the February issue, of Oscar Marshall's *Journeyman Machinist en route to the stars: Stellafane to Palomar*. Matula mentions in passing the $\frac{1}{10}$-scale model of the *Hale* 200-inch. Over forty years ago I got to know that instrument well: for decades, Caltech used it to instruct undergraduate astronomy students in the rudiments of observational technique. Built as an engineering model, it was an exact replica in miniature, down to the heaters for the oil that floated the horseshoe equatorial mount bearings: the first thing one did on entering the dome was to turn those heaters on. While, in terms of optical quality, it was not the best telescope I've ever used for observing, by a long ways it was the most fun. In the early 1980s it was replaced by a modern 14-inch instrument. Today it resides at Corning Community College in Corning, Steuben County, New York.

Yours faithfully,
JOHN MORGAN

5626 Stardust Rd
La Canada
California
CA 91011
USA

2019 February 20

Reference

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Einstein's Biggest Mistake?

What, if any, was Einstein's biggest mistake, the one most affecting our physics today? There is a perhaps apocryphal story, recounted by George Gamow, that he counted his cosmological constant as his biggest blunder. O'Raifeartaigh & Mitton have recently[1] summarized the available evidence and conclude that "We also find it quite plausible that Einstein made such a statement to Gamow in particular." In any case, recent observations suggest the need for a cosmological constant term in the field equations after all[2,3]. Virginia Trimble has argued that his lifelong rejection of quantum mechanics, an interesting side-story in the evolution of 20th-Century physics, is a candidate. None of these introduced difficulties in how our physics is done today.

It can thus be argued that his biggest actual mistake, one that affects many subfields in physics and chemistry and bewilders students today, occurred in his classic paper that first derived his A and B coefficients from considerations of the blackbody law and statistical equilibrium[4]. The Einstein A is the rate of spontaneous emission of photons as an electron moves from an upper to lower energy level and is universally called his transition probability. Energy is conserved during the transition, so the photon energy is equal to the difference in energies between the two levels. Although electronic transitions produce most of the optical/UV/X-ray line emission, other transitions are possible. They include changes in the rotation or vibration of a molecule or the nuclear spin of an atom. The Einstein A applies in all of these cases, so the idea has very broad applicability.

In statistics, a probability is a dimensionless number between 0 and 1. Einstein's A has dimensions s^{-1} and ranges between, for example, $\sim 3 \times 10^{-15}$ s^{-1} for the HI 21-cm line in the radio to $\sim 3 \times 10^{14}$ s^{-1} for the Fe XXVI Kα line in the X-ray. Einstein's A is clearly not a probability.

In his original 1917 paper, Einstein introduced his A as follows:

"*Die Wahrscheinlichkeit dW dafut, dass dies im Zeitelement dt wirklich stattfinde, sei* $dW = A_m^n\, dt$ *wobei* A_m^n *eine für die betrachtete Indexkombination charakteristische Konstante bedeutet*", which can be translated as "Let the probability dW for this to happen during the time interval dt, be $dW = A_m^n\, dt$ where A_m^n is a constant characterizing the index combination under consideration." The German word '*Wahrscheinlichkeit*' unambiguously translates to the English 'probability'. The source of the confusion is the definition of dW. If dW were really the probability over a time interval dt, then A would be the probability per unit time, what we now call the 'transition probability'. Actually, dW is the number of photons emitted over the time dt. The A is actually the rate photons are emitted, the Einstein transition *rate*.

The term transition "probability" creates considerable confusion for students of astrophysical spectroscopy. Consider the quantities that enter into the description of how matter emits (section 3·5 of ref. 5). Collisions can cause transitions within a two-level atom with upper and lower levels u and l. At the most basic level, collisions between u and l are described in terms of a quantum-mechanical cross section σ (cm^2) which depends on the velocity v ($cm\ s^{-1}$) of the colliding particle. This cross section is integrated over a velocity distribution, usually Maxwellian, to obtain a rate coefficient q_{ul} with the strange units $cm^3\ s^{-1}$. The rate of collisional transitions is $c_{ul} = q_{ul}\, n$ (s^{-1}) where n is the density of colliders (cm^{-3}). The total rate that electrons move from u to l is then $r_{ul} = q_{ul}\, n + A_{ul}$. Knowledgeable students who understand dimensional analysis are bewildered by the concept of adding a rate and a probability.

Although the term "transition probability" is an established part of the field[6], the only part of quantitative spectroscopy which employs something like a probability involves many-level systems. The *branching ratio* from a level u is defined as $R_{ul} = A_{ul}/\sum_{k<u} A_{uk}$. This is the probability that level u will decay by the route $u \rightarrow l$, is dimensionless, and ranges between 0 and 1.

A is Einstein's transition rate.

Comments by the referee, Virginia Trimble, are gratefully acknowledged, as is support from NSF, NASA, and STScI.

Yours faithfully,
GARY J. FERLAND

Physics & Astronomy
The University of Kentucky
Kentucky
USA, 40506

email: gary@uky.edu

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Improving Sunspot Records: Misreading of 'Rosa Ursina' by Scheiner

Sunspots have been documented before the telescopic era by different cultures[1,2]. However, the total number of records available is small[3]. It was not until the invention of the telescope at the beginning of the 17th Century when sunspot observations became more or less continuous[4].

The first great compilation of sunspot records was performed by Rudolf Wolf[5] in the mid-19th Century. For example, Wolf recovered sunspot records made by Schwabe, Flaugergues, and Staudach. He developed the relative sunspot number and applied that concept to his compilation of sunspot records. The next great collection of historical sunspot records was made by Hoyt & Schatten[6]. Unlike Wolf, who compiled both the number of individual sunspots and sunspot groups, they only recovered the number of sunspot groups. Instead, Hoyt & Schatten carried out a significant work retrieving thousands of sunspot records from the 17th Century. However, several works[4,7] have indicated some problems in the Hoyt & Schatten database. Thus, a new revised collection of the number of groups[8] (based on the previous Hoyt & Schatten database) was recently presented in order to avoid problematic data from dubious observations.

Christoph Scheiner recorded sunspots during the first half of the 17th Century. According to the current sunspot database[8], he was the most active sunspot observer before the Maunder Minimum[9]. His most important work was *Rosa Ursina*[10], a book where Scheiner studies sunspots that includes high-quality drawings and discussions about the nature of sunspots, *inter alia*. Thus, that work is considered a bench-mark in historical studies of sunspots. *Rosa Ursina* was previously analyzed by Hoyt & Schatten. That documentary source, together with sunspot observations made by Malapert[11], includes the vast majority of the sunspot records available in the group databases from 1618 to 1630. After analyzing sunspot drawings included in *Rosa Ursina*, several mistakes have been detected in the group databases related to that source. For example, on 1625 January 16, Scheiner recorded four sunspot groups while three groups were reported by Schönberger (see *Rosa Ursina*, p. 173). However, according to the current databases[6,8], seven groups were observed by Scheiner on 1625 January 16. Furthermore, other mistakes can be found. For example, three groups were reported by Schönberger on 1622 February 27 (see *Rosa Ursina*, p. 199). Instead, the current group databases[6,8] consider that, on that date, only one group was observed by Scheiner.

Certainly several cases of sunspot observations assigned to wrong observers and with inaccurate number of groups have been detected in sunspot databases due to a misreading of *Rosa Ursina*. In conclusion, a complete revision of sunspot observations registered in *Rosa Ursina* is necessary. However, this is an arduous and time-consuming work that requires the collaboration of Latin scholars and historians of science. We are working on this task. This revision could provide us with a better understanding of the solar activity *c*. 1620.

This work was partly funded by FEDER – Junta de Extremadura.

Yours faithfully,

VÍCTOR M. S. CARRASCO

Departamento de Física
Facultad de Ciencias
Universidad de Extremadura
Avda. Elvas, s/n
06071 Badajoz
Spain

2019 February 21

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REVIEWS

Sark in the Dark: Wellbeing and Community in the Dark-Sky Island of Sark, by Ada Blair (Sophia Centre Press, University of Wales Trinity Saint David), 2016. Pp. 190, 18 × 12·5 cm. Price £15 (paperback; ISBN 978 1 907767 42 5)

Although astronomers need no convincing of the necessity for darkness, not just so that they can carry out observations, but also because it is essential for the wellbeing or even survival of many (if not all) life-forms on Earth, the necessity for darkness at night seems to be becoming more acknowledged by the general public. There have been numerous scientific studies of the effects of light pollution on various species, but this is probably the first to study the result of the declaration of a particular area as a dark-sky site. (Sark is the first island in the world to achieve Dark Sky designation. Coll, in Scotland, subsequently obtained similar recognition.)

There is a tendency, certainly among astronomers, to feel that only certain societies, such as the Aboriginal people of Australia and the Native American tribes, had a close connection to the night sky. Ada Blair shows, however, that, although now largely unrecognized, many cultures (such as western-European ones) have been affected by the night sky, despite any direct connections having now been lost. In addition to the discussion of the implications of the award of Dark Sky status to Sark, Blair includes an extensive survey of the way in which the night sky has (or has had) an impact on various societies. An interesting example of how modern societies have become divorced from the night sky is the tale of how, following an extensive blackout over Los Angeles, concerned residents contacted the police about a 'silvery glow' in the sky, which turned out to be the Milky Way. This is somewhat reminiscent of the way in which recently the blue glow from an electrical sub-station failure in a New York suburb was thought by some to be evidence that aliens had landed. Unfortunately, an increasing number of amateur 'astronomers' seem to have become divorced from the sky, because they tend to turn to 'apps' on their GPS-enabled smartphones to identify even the brightest stars in the sky.

Another point that astronomers forget, and which Blair explores, is the somewhat atavistic feeling among a surprising number of individuals of the actual 'Fear of the Dark'. It is this that causes some to oppose any suggestion of the dimming or extinction of lights at night. She recounts how she herself felt disquiet on first encountering Sark at night, but how she gained complete confidence in moving around in the dark. She also discusses extensively how various forms of tourism, such as those associated with astronomy, heritage, and nostalgia also affect visits to Sark and similar sites.

But what of Sark itself? Blair conducted interviews with various Sarkese, and comes to the overall conclusion that conferring Dark Sky status has been generally beneficial and welcomed. She ends with a discussion of the various 'themes' that she found to be particularly relevant.

All in all, a useful work for anyone hoping to promote a Dark Sky site, whether under the auspices of the Intenational Dark Sky Association or as part of the Dark Sky Discovery Site scheme. A website devoted to the book is at: https://sophiacentrepress.com/2017/03/10/announcing-sark-in-the-dark/ — STORM DUNLOP.

Imaging the Messier Objects Remotely from Your Laptop, by Len Adam (Springer), 2018. Pp. 520, 23·5 × 15·5 cm. Price £39·99/$44·99 (paperback; ISBN 978 3 319 65384 6).

Springer are notorious for publishing unproofread vanity books in the *Patrick Moore Practical Astronomy* series. They also have a reputation for the poor reproduction of images and diagrams, an issue only too obvious in this book. Len Adam has basically written a guide to using the telescopes in the *iTelescope.net* network based around simple images of the Messier objects. The book starts with a guide to the sites and telescopes involved in the *iTelescope* network and then gives a very basic guide to astronomical co-ordinate systems. There is a brief guide about how to login to the *iTelescope* web interface. There is in addition a brief reference on how to calibrate astrometrically the images so you can identify other objects in the field (minor planets, other deep-sky objects, *etc.*).

The meat of the book is a catalogue of the Messier objects along with information on how each was imaged. Each object has some historical data, which I quite liked. A chart of the location of each object is also included. No information about what, if any, processing was done to each image was given. The images are reproduced in black and white even if they were taken with a colour camera. Most of the images are short single exposures. Although some discussion is given on framing images at the beginning of the book, the author obviously does not use this, as most of the images of, say, globular clusters, are so small as to make them difficult to see, the result of using too small a telescope to get the magnification required. The dynamic range of the printing of the images also makes most of those of elliptical galaxies show only the core. The book ends with an image gallery of all the objects.

It is not clear to me at whom this book is really aimed, as it is not like, say, the *Deep Sky Companions* book by O'Meara, which gives both historical and astrophysical information on each object, so it is not a guide to the Messier objects *per se*. If it was aimed as a guide to using the *iTelescope* network then it would be useful to have a lot more information on that, like the costs of using it and how really to use the information to select object framing. As noted above, in common with most Springer books, the images and charts are poorly reproduced, which is a bit of an issue with a book devoted to imaging. I think I would find it hard to recommend this book and I am sure there must be better guides to remote imaging out there. — Owen Brazell.

Turn Left at Orion, 5th Edition, by Guy Consolmagno & Dan M. Davis (Cambridge University Press), 2019. Pp. 256, 31 × 26 cm. Price £25/$34·95 (spiral-bound; ISBN 978 1 108 45765 9).

This book first appeared 30 years ago and it is not surprising that it is still in print, now in a new 5th edition. Its aim is to guide the novice amateur astronomer through from choosing a telescope to finding and identifying a wide range of objects in the night sky. It also acts as an excellent resource for the more experienced.

There is a clear introductory section written in a chatty informal style that covers the advantages of different telescope types — especially Dobsonians and SCTs — with a small amount of optical theory. This is followed by sections covering observations of the Moon and planets and then by observations of fixed objects grouped by season. The lunar section describes the appearance of key topographical features as they are revealed by the lunar terminator as the Moon waxes and is thus visible in the evening sky. The images used to illustrate this and all the other objects in the book are appropriate for telescopes with apertures of 3 to 8 inches. The planetary section deals with what the new astronomer can hope to see, and with planetary motion. Although it covers the whereabouts of the outer planets in outline from now until 2050, it sensibly refers readers to planetarium apps and programs for more detailed positional information.

The major part of the book relates to stellar and deep-sky objects. Uncluttered star charts featuring mainly first-magnitude stars are given and act as starting points for the details of how to find the objects of interest. Instructions are given for finding many stars and deep-sky objects with reference to the brightest constellations — hence the title of the publication. Finder charts are provided based on the likely field of view of a small SCT or slightly larger Dobsonian with left–right reflection and inversion as appropriate for those in the Northern Hemisphere. Except for the entries relating to objects near the South celestial pole, the appropriately orientated charts for Southern Hemisphere observers need to be downloaded from the publisher's website.

The choice of objects is heavily biassed towards double stars and star clusters. This is acknowledged by the authors who say that this reflects their personal interests. The format of the book is of large spiral-bound pages. The size makes it a little unwieldy but the ability to fold the pages back on themselves offsets this. The availability of all the finder charts on-line and thus downloadable means that it is not necessary to take the whole book to the telescope while benefitting from its data.

The book fills a gap between guides to the constellations for newcomers and detailed star atlases. I will have no hesitation in recommending it at outreach events to those who are interested enough in astronomy to buy a small telescope. — MIKE RUSHTON.

Astrophysics for People in a Hurry, by Neil deGrasse Tyson (W. W. Norton), 2017. Pp. 223, 19·3 × 12·2 cm. Price £13·99 (hardbound; ISBN 978 0 393 60939 4).

This is a book adapted from essays published in *Natural History* magazine. The late Stephen Jay Gould, who taught geology, biology, and history of science at Harvard and, like Tyson, was affiliated to the American Museum of Natural History, published several books based on his 300 essays written for that magazine. Tyson has written several popular books, and this is the second based on such essays. I learned more from Gould's books, both because I am not an expert in the topics which he covered (in fact, much of my knowledge of those topics comes from Gould's writing), and also because Gould often used detailed examples to illustrate general principles, included historical angles, and so on. (Gould was mainly a scientist who made a substantial contribution to the popularization of science; Tyson is (now) mainly a popularizer of science, though with a background in research and teaching.) This book, by contrast, is more a straight popular-science book. (As my history teacher used to say, just an observation, not a judgement.) As such, it competes with many others of the titular readership: those with an interest in astrophysics but without the time or inclination to pursue it in depth. For such readers, Tyson does a very good job: the book is well written; the chapters are self-contained; the material is up-to-date; the topics are those which interest the general public the most (cosmology, laws of Nature, the place of Earth and humanity in the Universe, *etc.*); even some of the jokes are funny.

Tyson hosted *Cosmos: A Spacetime Odyssey*, a documentary television series which was a follow up to *Cosmos: A Personal Voyage*, by Carl Sagan (like Gould, a very productive scientist who became even more well known as a popularizer). Sagan (like Tyson and Gould a native of New York City) was noted not only for his content (and for his — often parodied — over-the-top presentation) but also for his prose, which managed to be spiritual yet atheistic at the same time. The last chapter in Tyson's book, 'Reflections on the Cosmic Perspective', reminds me of and is a worthy successor to Sagan's sense of awe and wonder when contemplating humanity's place in the Universe.

I noticed neither factual mistakes nor misleading or inaccurate analogies (often a problem, not only with popular-science books), except in one case: the discussion of geometry and destiny, *i.e.*, how the matter content determines the spatial curvature of the Universe and whether it will expand forever or collapse, is correct if Ω refers to the matter density. However, a few pages later, after introducing inflation, Ω obviously refers to the total density (*i.e.*, $\Omega_M + \Omega_\Lambda$), in which the description of the geometry still holds but that of the (future) expansion history does not.

There are no figures, and apart from the main text the only substantial section is an 11-page index, but that is entirely sufficient for such a book. While not perfect, the editing is better than most, and I have only the usual quibbles about matters of style. The small size of the book is well suited to the intended readership — the book is convenient to read on a train or plane. Perhaps, if he were alive today, Lucretius would write a similar book, casting what we know about the Universe in an almost poetic form suitable for the proverbial man on the street, but without loss of accuracy. Recommended. — PHILLIP HELBIG.

The International Astronomical Union: Uniting the Community for 100 Years, by Johannes Andersen, David Baneke & Claus Madsen (Springer), 2019. Pp. 375, 23·5 × 15·5 cm. Price £34·99/$49·99 (paperback; ISBN 978 3 319 96964 0).

The International Astronomical Union is 100 years old, having been founded in Brussels in 1919 July as part of the reorganization of international science in the wake of World War I (not yet known to be I) undertaken entirely by the winners.

In 1994, Adriaan Blaauw (IAU President 1976–79) published *History of the IAU: The Birth and First Half-Century of the International Astronomical Union* (Kluwer). The cover shows (most of) the 203 participants at the 1932, Cambridge, Massachusetts, General Assembly, facing forward. Of the identified, only Harlow Shapley (1885–1972) lived long enough for any of us to have had a chance to know him. Blaauw himself (1914–2010), elected to IAU membership in 1948, necessarily relied heavily on archival materials for the earlier years. The volume has details of individual GAs, the political complexities of the founding, the Stalinist-purge period, post-world-war-II reconstruction, and much else.

The present volume covers the full century, but with an emphasis on the second half. Author Johannes Andersen (IAU General Secretary 1997–2000, elected to membership 1976, making him a whole GA, but I think only a year or two, younger than your present writer) is joined by David Baneke (History and Philosophy of Science, Utrecht University, The Netherlands) who made considerable use of the IAU archives, and Claus Madsen (Institute of Physics

& Astronomy, Aarhus University, Denmark, also one of Andersen's affiliations), who took many of the pictures.

They have provided a different sort of focus and viewpoint. For starters, the cover also shows a General Assembly, in Prague 2006, at the moment of the 'Pluto vote', but viewed from the back. Many yellow cards (how we used to vote) are held in the air, but there are lots of empty seats, no identifications, and, at least on my copy, the image is cut on the right side so that it just removes my left arm. Why am I facing forward? Because I skippered the team of tellers who ran up and down the aisles counting the yellow cards in favour of 'planet', 'dwarf planet', and various other choices during that disputatious hour or two. Andersen *et al.* have more of that story.

How else do I make the cut? Not as the first and, now probably forever, only person to serve as president of two different divisions (VIII Galaxies & the Universe 2000–03; XII Union-Wide Activities 2004–06). Not as the third woman president of the first commission to have three such (28 Galaxies, 1994–97), though my predecessors also don't fare very well either: E. Margaret Burbidge (elected 1955, C28 President 1970–73) makes a single appearance (as a participant in a photograph of the 1958 Moscow General Assembly), and Vera C. Rubin (elected 1964, C28 President 1982–85) is cited for dark matter in the 1970s "with her colleagues", mentioned for her invited discourse in 1985 in Delhi, where Alia Massevich also spoke (the first two women in that task); photographed in 1982 in Patras, talking with Bernie Burke and seated next to her husband Bob Rubin; and as part of a discussion group at Baltimore (1988) on 'Women in Astronomy', with future IAU president Silvia Torres-Peimbert and others. Me? Two captioned photographs, both from the spring, 1996, 68th meeting of the executive committee in Baltimore. Others in one of the photos include Presidents Franco Pacini (2000–03), Robert Kraft (1997–2000), and Robert Williams (2009–12). On top of everything else, I'm wearing the same dress in both, and it's the same one I wore on 2018 June 25 when my department, the AAS, AAVSO, and Lick Observatory organized a modest festivity in honour of my 75th birthday and 50th anniversary of PhD. Finally, on the 'whine' side, there are two of Andersen's own photos of IAU Colloquium 6, Elsinore, Denmark, 1969 (Mass Loss and Evolution in Close Binaries, though mass transfer was perhaps more to the point). I was there, but not in either picture, and probably not even covered by the caption "Several other senior astronomers are outside the photo".

Two more, at least, among the missing: Andersen *et al.* think that only two Russian/Soviet astronomers 'disappeared' in 1937 (Blaauw's text implies more), and even those are not named. The two clearest cases were Boris Petrovich Gerasimovich (1889–1937 November 30), director at Poulkova (1933–37) and dear friend of Cecilia Payne Gaposchkin; and Boris Vasil'evich Numerov (1891–1941 September 3; Noumerov in Blaauw) professor at Leningrad 1924–36, a key player in both theory (astrometry, celestial mechanics, *etc.*) and in the founding of Abastumani Astrophysical Observatory in Georgia. Gerasimovich had contributed to solar physics, variable-star astronomy, and other territories. Both have articles in *BEAII* and in the *Dictionary of Scientific Biography*.

Now, as for what is in the Andersen *et al.* book. Most notable are interview–memoires from 30 distinguished colleagues, including all the past presidents and general secretaries the authors were able to corral, and a few vice presidents, commission presidents, and such representing the education and public out-reach communities, plus Jocelyn Bell Burnell, who chaired the Pluto discussion in 2006. These are still, in some cases just, our contemporaries; I am aware of having encountered all except, perhaps, Lubas Perek, General Secretary 1964–67, and "President of the Milky Way" (a mild witticism from one of his successors) 1973–76. All are worth reading. The appendices include a list of the General Assemblies (years, locations, numbers of participants — typically about one-quarter of the number of members, though many participants now are not members — and the names of presidents and secretaries, but not the vice presidents, whom Blaauw included) and a list of the commissions, of which only C4 (Ephemerides) and C27 (Variable Stars) were stable for the entire 1922–2015 period, when they were abolished and replaced by others. The new Divisions and Commissions make a brief appearance along with a list of the national members, some of which also come and go (often for financial reasons — the IAU charges its national members, not its individual ones), and a list of the International Schools for Young Astronomers. If you care about the IAU, you might well want to read and keep this book. If not, possibly not. But do try to get hold of the first 50 years from Adriaan Blaauw as well. Be sure to check both indices for your name and those of your friends and mentors. Remember that the IAU is the only international scientific union with individual human members (13955 at last count) as well as nations (about 85). You will not, however, find the names of those who delivered the invited discourses in the more recent volume, nor the topics of the joint discussions. — VIRGINIA TRIMBLE.

The Royal Society and the Invention of Modern Science, by Adrian Tinniswood (Head of Zeus Ltd.), 2019. Pp. 208, 21 × 14 cm. Price £18·99 (hardbound; ISBN 978 1 78669189 7).

Most of today's professional astronomers belong to a scientific society; and they publish their research results as journal papers as opposed to books; and they attend scientific meetings to present and discuss their findings. But when did this all start? The year in question was 1660, and in that year a group of intellectuals, mainly from Gresham College and Oxford University, came together to form the Royal Society in London.

The emphasis was on general science, mainly because too little was known at that time about each specific topic for anyone to be a specialist. Meetings were held every Wednesday. Experiments were performed. The members concentrated on accurate observation and thorough interpretation, following in the footsteps of the 17th-Century natural philosopher Francis Bacon. The Society's motto *nullius in verba* stressed that when it came to scientific topics, you should try and find out for yourself and not accept established dogma. Results were written up promptly and published in *Philosophical Transactions*, the world's first and longest-running scientific journal. The Society had a museum, curiosities being donated by Fellows. Expeditions were supported, such as James Cooke's endeavour to observe the transit of Venus. Early presidents, secretaries, and fellows included such noteworthies as Sir Isaac Newton, Sir Christopher Wren, Edmund Halley, Seth Ward, and John Flamsteed.

The unique role of the Society was somewhat diminished at the beginning of the 19th Century by the founding of a series of specialist organizations such as the Linnaean Society (1788), Geological Society (1807), and the Royal Astronomical Society (1820). As the years passed it changed from being an organization open to all interested scientifically-minded folk to today's restricted powerhouse of the very great and very good.

Adrian Tinniswood is a well-established author who writes mainly about social, architectural, and cultural history. In the book under review he concentrates on the founding of the Royal Society, its historical role as a strong supporter of experimental enquiry, and as the bastion of an international approach to scientific endeavour. Little is said about what the Society is up to, or should be up to, at the present time. The book is an absolute joy, tastefully illustrated, informative, insightful, and concise. It paints a superb picture of the scientific life of an English gentleman of the 17th Century, and leads us to question why science, which can be a rather lonely and introspective occupation, also has a side to it where all scientists want to show off in public to their fellow scientists and stress what they have done, and why they think it is important. — DAVID W. HUGHES.

50 Years: Westerbork Radio Observatory — A Continuing Journey to Discoveries and Innovations, edited by Richard Strom, Arnold van Ardenne & Steve Torchinsky (Netherlands Institute for Radio Astronomy), 2018. Pp. 352, 24·5 × 17 cm. Available from ASTRON (hardbound; ISBN 978 90 805434 0 9).

Except for a summary in Dutch on pages 15 to 17, the entire book is in English. I believe the word 'summary' here actually means 'foreword'. The book is divided into 18 chapters and each chapter into several sections. Each section is written by a different author and is self-contained and may be read on its own in no special order, although they are arranged in roughly historical occurrence. There are more than a dozen authors including the three editors, and some have written multiple sections. The content of the sections is rich and varied. They run the gamut from personal nostalgic memoirs to historical narratives to technical descriptions of general procedures to detailed presentations of specific projects, all skillfully blended to present not only a history of Westerbork but an enlightening exposition of the last 50 years of radio astronomy in general. Although English is a second language to most of the authors, it is well written and comfortable to read, with very few, if any, typographical errors. The technical sections are written for the informed non-professional astronomer with very little maths, and easily understandable by anyone with the knowledge of a high-school physics course.

The book starts with a history of the beginnings of radio astronomy when in the 1930s a Bell Telephone Laboratories engineer, Karl Jansky, investigating various radio frequencies, discovered a source in the direction of the Milky Way with a repetitive period of approximately 24 hours, the rotation period of the Earth. Jansky was transferred to other projects and did no other work on this. In 1937, an amateur radio engineer, Grote Reber, built a 9-metre parabolic antenna that steered in elevation in his back yard in Wheaton, Illinois, that was the first viable radio telescope. He confirmed Jansky's discovery and made the first radio map. His first astronomical publication was a paper in 1940 June. Such were the modest beginnings of radio astronomy.

Westerbork radio observatory consisted initially of 12 25-metre parabolic dishes mounted on an east–west baseline extending over 1·5 kilometres. Construction was begun in 1966. It was upgraded in 1975–1980 with the addition of two movable dishes extending the array to 2·7 kilometres. The resolution of radio telescopes can be drastically enhanced by separating them from thousands of feet to thousands of miles and using an interferometric technique called aperture synthesis. Synthesis is a scientific term roughly meaning 'putting together in an orderly manner'. By combining the two radio signals in real time using this method an extremely high resolution can be obtained. The resulting radio map can then be overlaid on a photographic plate covering the same area and the radio sources identified optically. In the 1950s and later when much better radio maps were developed, the Palomar Photographic Sky Survey was used in early attempts.

That resulted in only a 20% success rate; this is described in Chapter 3, Section 4.2. Thanks to computers and modern electronics this has progressed to the point where virtually every radio source can be identified today. Radio astronomy has truly made much more progress in its first 80 years than optical astronomy had in an equal time after the invention of the telescope. The succeeding chapters go on to describe how through both mechanical and instrumental upgrades the Westerbork telescope array went on to perform much serious research: subjects such as the discovery of giant radio galaxies, supernova remnants, pulsar timing, and very-long-baseline interferometry (VLBI) of the *Hubble* deep field to name only a few — more projects than I can list here.

Each chapter is interesting in its own right — more than can be digested in a few evenings. The information gathered by Westerbork led to the construction of another radio telescope: the *Low Frequency Array* (called *LOFAR*). But that is another story for another time. The Westerbork book is well illustrated with a large number of very good photographs in colour and black and white of people, equipment, meetings, astronomical objects, and diagrams. There are many European Southern Observatory photographs with overlays of Westerbork radio maps.

Radio astronomy was a boon to the Dutch. In a sea-level country that is often cloudy, radio-astronomy research could be conducted day or night, cloudy or clear. From my extensive reading of astronomy history I've recognized some facts that have not been mentioned elsewhere. Although the Dutch people, including those of their former colonies, comprise one tenth of one percent of the Earth's population they fully account for 25 percent of the prominent astronomers of the last hundred years. My figures are an estimate but my instinct tells me that they are pretty accurate. Look at the names: Adriaan van Maanen, Maarten Schmidt, Jan Oort, Gerard Kuiper, and on and on. So prominent is the influence of astronomers of Dutch ancestry that two key parts of our Solar System are named after them — the Kuiper Belt and the Oort Cloud! Amazingly enough, although the Germans occupied much of Western Europe, the Dutch astronomers were able to conduct research during WW II! In 1940 with the occupation of The Netherlands, American publishers suspended all postal shipments to Europe. Bart Bok, a Dutch Astronomer working in the US intervened and arranged mailing them through neutral countries. It took six months but the journals were eventually received. Meanwhile, astronomical research in the US and its allied countries was subdued because many astronomers were involved in war activities. But, it was still going on. Actually the war in an indirect way contributed to its advancement. Walter Baade of Mount Wilson Observatory, who was not subject to military recruitment because he was classified as an enemy alien, was able through the graces of Edwin Hubble's influence with the FBI to use the 100-inch telescope, and aided by the wartime blackouts of Los Angeles to do invaluable research discovering the Population I and Population II stars. The 1940 June article by Reber finally reached the Netherlands and intense interest in the new science of radio astronomy intrigued the Dutch astronomers. Despite the fact that several Dutch astronomers were arrested for a short time and later released, and Jan Oort went into hiding, for the most part they were allowed to operate unhindered during the war. They even had two open meetings, in 1941 and 1944! This is detailed in Chapter 1.

Last but not least, beginning on page 323 is a blue-background section listing chronologically a discovery for every one of the first 50 years of Westerbork's operation, illustrated with top-notch photographs and diagrams. This is a fabulous book that has rekindled my interest in radio astronomy and should be in every amateur and professional reference library; it is worth re-reading a section at a time. — LEONARD MATULA.

Science with a Next Generation Very Large Array, edited by Eric J. Murphy *et al.* (Astronomical Society of the Pacific), 2018. Pp. 830, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 919 7).

For over 40 years the *VLA* has been a world leader in radio-telescope arrays. Radio has the advantage over other spectral regions through its ability to add coherently signals from large arrays, and this is now exploited over the whole wavelength range from 30 metres to 300 microns (10 MHz to 1000 GHz). The proposal for *ngVLA*, a next generation VLA, on the same site but greatly expanded so as to increase sensitivity and angular-resolving power by an order of magnitude, fits in well with recent world-wide developments in large synthesis arrays, which might be categorized by the centres of their wavelength ranges as *LOFAR* (decimetres), *GMRT* (metres), *SKA* (metres to centimetres), *ngVLA* (centimetres), and *ALMA* (millimetres). They all demand large resources in telescope engineering, wide-bandwidth digital electronics, computer capacity, money, and human resources. The case for such a large project has to be seen in a wide context of astronomy; this is the subject of this 800-page collection of 90 essays written by 285 authors, assembled by NRAO (the National Radio Astronomy Observatory) in preparation for the 2020 Decadal Review of astronomy in the USA.

The techniques of aperture synthesis have reached a level of maturity which naturally results in a design for the *ngVLA* which is similar to that of the centimetric part of the *SKA* (*Square Kilometre Array*), and the scientific case presented here is also similar, with a somewhat greater emphasis on planetary science and the Solar System. Mercifully the total volume and weight is only half of the corresponding volume covering the case made out for the *SKA*, and the compendium has become a useful set of references for current research in many branches of astrophysics. It also contains a useful summary of the *ngVLA* project itself. — FRANCIS GRAHAM-SMITH.

Heroes of the Space Age, by Rod Pyle (Prometheus), 2019. Pp. 320, 20·5 × 13·5 cm. Price $18 (about £14) (paperback; ISBN 978 1 63388 524 0).

About a week before this latest book from Rod Pyle arrived, the *London Review of Books* popped through my letter box containing a review of Roland Jackson's biography of the Victorian scientist John Tyndall, which included a definition of a 'Hero' by one of Tyndall's idols, Thomas Carlyle. In Carlyle's description heroism included acts of daring or bravery but done in the service of others — such as the heroic warrior protecting his people, or later, winners of military medals for valour, in which the heroic act saves lives by rescuing wounded colleagues or by taking out defences against overwhelming odds and thus preventing further bloodshed. Could Pyle's heroes of the space age be seen to be heroic in that service sense? There is no doubt that the early astronauts were brave, beyond comprehension, and their actions were selfless in that they served a higher ideal than simply surviving the latest rocket flight. As Pyle notes, each of his subjects "stood for something greater than themselves — in this case the exploration of space". We learn enough of their lives to know that all of the people described in this book were rather special, even exceptional in their chosen field — in fact the very opposite of the "spam in a can" insult that came to light in Tom Wolfe's book *The Right Stuff*.

But before I had completed my pondering on the nature of heroism I found I had raced through the almost 300 pages and finished the book. Like other books written by Pyle it is a fast-paced engaging read with enough technical detail for the astro-techno geek but also plenty of human interest for those with higher brain function as well.

I suppose that many readers of this *Magazine* will be familiar with the daring exploits of the ex-test-pilot cadre of astronauts — from stabilizing rocket planes tumbling in hypersonic spins at the edge of space, to Neil Armstrong ejecting from the 'flying bedstead' lunar-landing test vehicle seconds before it crashed into the high California desert one spring morning, only to carry on with routine office work after lunch. But from my brisk reading it is the humanity that proved to be the revelation in this book: the 4-year-old child who, playing with switches in the Apollo Command Module simulator while her mother busied herself with the control software, inadvertently led to the famous 1202 error code that we all remember as adding tension to the already fraught *Apollo 11* moon landing. (Pyle even gives us a photograph of the error display.) The little girl's mother inserted the error flag as a trap to prevent a fatal shut-down of the Lunar-Module computer if it found itself with computational overload — a need highlighted by the child's switch toggling. Without the overload trap the computer crash would have led to a pile of tangled wreckage and two corpses on the Moon. The mother was Margaret Hamilton, a name I had not heard before, a mathematician who had worked her way up from coding and debugging to become lead software engineer for the entire Apollo programme and indeed the very first 'software engineer', as it was she who coined the term. But in spite of this important job the lack of child care meant she had no other option but to take her daughter to work with her. More raw humanity is displayed as the second Lunar-Module crew of Conrad and Bean stripped completely down to their natural state to crawl back into the Command Module, in order to prevent the Moon dust, acquired on their space suits after several hours working on the Moon, from entering the Command Module and contaminating the delicate electronics responsible for bringing them home. Whether this became standard practice Pyle does not record.

One could argue with Pyle's choice of hero candidates — we could all come up with our own list and indeed Pyle admits as much, but given the constraints of book length, *etc.*, I think he has done a pretty good job. All the firsts are there — Gagarin, Tereshkova, Armstrong, and Aldrin but also some unusual names such as the already mentioned Margaret Hamilton. All are described in sufficient detail to see some of the person behind the legend. Gagarin's schooling, using as pencil and notebook, paper scraps and charcoal from a war-time ruined village, Tereshkova learning to enjoy skydiving, and Pete Conrad learning how to button his lip but retain a rebellious streak. Although a full life story is given for each of the subjects described we are not given much insight as to what made them special; what qualities enabled them to overcome the many obstacles. Maybe this is because that elusive characteristic is in fact undefinable, and so along with some salient biographical details about childhood and education we are given a sort of broad-brush character assessment. Armstrong — laconic; Conrad — wise cracker; Hamilton — diligent; we are left not too much wiser about the question that was on everybody's lips at the time: "for goodness sake why are they so fearless?"

No less an authority than the NASA History web site https://history.nasa.gov/ap11-35ann/legacy.html describes the Apollo programme as a triumph of management (amongst the other more obvious plaudits). The closest that management makes it to the heroic status of the people in this book, with the longest chapter, is the most famous of all flight directors, Gene Kranz, he of the buzz cut, flat-top hairstyle, and a taste for white waistcoats. The broad brush for Kranz tells us that he is patriotic. Like many of the astronauts he had also put his life at risk in the high-performance jet fighters of the 1950s before making a career as the guy who knew everything about all of the systems and subsystems involved in putting people into space.

We could ponder the nature of heroism and discuss whether a flight controller is really heroic or just very good at his admittedly difficult and challenging task. Or indeed whether being a full-time mother and childminder, whilst simultaneously holding down the job of devising software on which people's lives depend, is more demanding than leading a team of experts whose child care and domestic arrangements are contracted out *via* marriage. But that would be to miss the point. Published in this year of the 50th anniversary of the *Apollo 11* Moon landing, Pyle's book takes us vividly back to those times of high risk, high expectation, and fast-paced rate of technological progress — only three months after *Apollo 7*'s inaugural flight in Earth orbit, *Apollo 8* was launched on the first ever manned flight of a Saturn V rocket, to loop around the Moon, and barely seven months later the first people walked on its surface. For the grizzled old timer this excellent book is a chance to wallow in nostalgia and perhaps shed a tear for those past glories, for youngsters it is an adventure story in which real people, with real flaws but also very real strengths, achieved quite remarkable things, and enabled humans to walk on another world. Congratulations to Rod Pyle for bringing it all so vividly to life. — BARRY KENT.

Interplanetary Robots: True Stories of Space Exploration, by Rod Pyle (Prometheus), 2019. Pp. 320, 20·5 × 13·5 cm. Price $18 (about £14) (paperback; ISBN 978 1 63388 503 5).

During the past 60 years, hundreds of robotic spacecraft have been despatched to explore every corner of our Solar System. This great era of exploration has seen automated ambassadors from Earth conduct a detailed reconnaissance of the inner Solar System, first with fly-by missions, then with orbiters, landers, and roving vehicles. The remote gas giants and tiny Pluto have also been unveiled by twin *Pioneer* and *Voyager* spacecraft, and orbiters such as *Galileo*, *Cassini*, and *Juno*.

In a lively, easy-to-read style, author Rod Pyle describes the main missions and projects that have transformed our view of those distant worlds. Instead of fuzzy blobs in ground-based telescopes, we can now observe and study a remarkable menagerie of planets, dwarf planets, satellites, asteroids, and comets — each with its own unique characteristics. Not surprisingly, much of Pyle's story focuses on the pioneering work of scientists and engineers at NASA's Jet Propulsion Laboratory (JPL), the creative crucible where most of the robotic marvels have been transformed from imaginative proposals to robust pieces of hardware. However, it is refreshing to see that he also gives due credit to the endeavours of their Soviet counterparts, who, for a time, led the way in exploration of the Moon, Venus, and Mars.

The book is divided into 37 chapters, some of which are little more than short essays. The projects are described in roughly chronological order, although Pyle's interesting personal recollections of landmark events at JPL, such as the landing of the *Curiosity* rover on Mars, are inserted in a fairly random manner. Considerable prominence is given to keystone missions such as *Voyager*, *Galileo*, and *Cassini*. However, these momentous sagas are occasionally interrupted by chapters that touch upon promising future technologies, such as *Mars Sample Return*, or imaginative past projects, such as *Voyager Mars*.

I highly recommend this readable, informative overview of the age of interplanetary robots. — PETER BOND.

Extensions of f(R) Gravity: Curvature–Matter Couplings and Hybrid Metric–Palatini Theory, by Tiberiu Karko and Francisco S. N. Lobo (Cambridge University Press), 2018. Pp. 456, 25·5 × 18 cm. Price £130 (hardbound; ISBN 978 1 108 42874 3).

From the title, one might expect this to be a highly-specialized book that fills a particular niche in the modified-gravity literature, but in fact it covers both Einstein's General Relativity and f(R) gravity in some detail, with roughly equal space devoted, respectively, to GR plus f(R) theories, and the two extensions mentioned in the title. With this much discussion of GR, it acts as a very nice introduction to gravity theories and how one might extend them in progressively more complicated ways. It is a well-written book, which provides the motivation for modified-gravity theories, as well as a very clear formal development of the theories. — ALAN HEAVENS.

Stellar Populations and the Distance Scale (ASP Conference Series, Vol. 514), edited by Joseph B. Jensen, R. Michael Rich & Richard de Grijs (Astronomical Society of the Pacific), 2018. Pp. 214, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 912 8).

It is some years since I held a physical example of a conference book. In general they are expensive examples of vanity publishing, better relegated to websites. I happily picked up this one since it is a *festschrift* for, or at least the articles following a conference in honour of, Jeremy Mould. Jeremy Mould is a very special member of our astronomical community. He has a distinguished career, making innovative and substantial contributions to a series of topics which were at the time forefront science at the limits of forefront technology, from low-luminosity stars to precise determination of cosmological parameters. He complemented this with major contributions to scientific leadership in both the US and Australia.

Among the topical science reviews I note just a few *festschrift*-style articles of special note. The first, by Alvio Renzini, tells the story of how the scientific understanding of the AGB-evolution of 3–8-solar-mass stars developed during the 1970s/1980. This is a classic example of the positive interplay between theory and observation, driven by new technologies leading to much-improved understanding, with a great deal of hard work required. The second, by Paul Schechter, provides an up-to-date description of determinations of stellar mass in galaxies, with a focus on gravitational (micro)lensing results. This is a booming field, with clearly substantial progress still to come, building on these foundational studies. Jeremy Mould himself provides an update on the very important work trying to understand the intrinsic differences between the cosmological-distance-scale calibrator SN1a nearby and at high redshift. High-redshift supernovae are more metal-poor and in smaller galaxies with higher star-formation rates than are local SN1a. How important is that?

David Hanes completes the walk down memory lane with particular focus on the distance scale and determinations of the Hubble constant. This is a subject where differing deductions of the expansion rate from observations have progressed from large but not significant discordances to smaller but not yet significant discordances. — GERRY GILMORE.

The Physics of Gamma-Ray Bursts, by Bing Zhang (Cambridge University Press), 2019. Pp. 579, 25 × 19·5 cm. Price £57·99/$79·99 (hardbound; ISBN 978 1 107 02761 9).

The human race was nearly destroyed by astronomy on 1967 July 2. This marks the first detection of MeV photons by the *Vela* satellite, which was launched by the USA to detect Soviet H-bomb tests. But rather than triggering World War III, it was quickly appreciated that the signal was of astronomical origin — the first detection of a gamma-ray burst, or GRB. There followed three decades of accumulating statistics on an isotropic sky distribution (favouring an extragalactic nature of GRBs), before coincident optical transients were found in 1997, allowing redshifts to be measured for the first time. By that point, the currently accepted theoretical framework was in place through a series of papers by Rees and Mészáros in 1992–94 that outlined the role of shocks in a relativistic fireball. A key further step was to appreciate that these relativistic outflows were not isotropic, despite the 'ball' in 'fireball': the observed flux tends to break below the initial power-law decline with time, with an interpretation that the relativistic beaming angle of the decelerating shock, $\theta = 1/\Gamma$, has reached the cone angle of a relativistic jet. The inferred jet angles are a few degrees, implying that the flow has slowed to a Lorentz factor of $\Gamma \sim 10$, from initial values of several hundred. The association of GRBs with supernovae has suggested that the main progenitors are high-mass stars.

This general level of understanding of the GRB phenomenon has been in place for about 20 years, so the field now counts as mature and it is proper that GRB material should find a place in astronomy teaching. GRB research deploys an attractive palette of astrophysical concepts, making it interesting to study in its own right as well as introducing ideas and techniques that are of broader applicability in many areas of high-energy astrophysics. Bing Zhang of the University of Nevada has seized this opportunity to write a graduate-level textbook on the subject, focussing on the theoretical models of relativistic blasts and their radiation properties, but set nicely in the context of the observations that have driven the model developments.

After 100-odd pages summarizing the observational situation, the theory material starts with a relativity review, before a substantial chapter on relativistic shocks. This covers a lot of ground, including MHD complications and Fermi acceleration within the shock system. I found this a rather dry treatment, which could have benefited from more overview motivation: a diagram illustrating basics such as forward and reverse shocks and contact discontinuity is found only after 16 pages of detailed analysis. In general, many formulae seem to be presented without much discussion before moving on. For example, the Blandford–McKee jump conditions for a strong shock are presented as a problem for the reader, but without any further comment. I recall meeting these as a PhD student and attempting to derive them — it took me a week, following which I had a better understanding of the wry comment in the original paper: "these equations can be cast into the surprisingly simple form...". So I suspect there may be many hidden difficulties beneath the surface here. The shock chapter is followed by one on radiative processes, which has a similar character: it quotes exact results (such as formulae for synchrotron radiation from Rybicki & Lightman), but seems less concerned with providing much intuitive discussion of why these results look as they do.

After that foundation, the book moves into a number of chapters on detailed model building: general aspects of the fireball; late-time afterglow emission; early-time prompt emission; and then two chapters on the biggest open GRB issues, concerning the initiation of these explosions. Finally, the book returns to more observational issues: connection to cosmic rays, gravitational waves, and cosmological tests. In all these sections, there is a particularly strong connection to recent research literature, drawing on a colossal bibliography that contains roughly 1200 papers. That material reinforces the impression gained from the earlier chapters: that this is more the mother of all review articles, rather than a traditional textbook. For those of us who don't work full-time on GRBs, but who want to use them as a means of teaching relativistic astrophysics, this limits the value of the book: its focus is more on giving an encyclopaedic coverage of useful results, rather than a pedagogical exploration of relevant fundamentals. But for someone who is committed to working on GRBs at the professional research level, this book will make an ideal reference for the field. It is up to date with the most exciting recent developments, such as the *LIGO* detection of a kilonova, and it is an impressively complete survey of how far GRB research has come since the early days of total uncertainty over the nature of these events. — John Peacock.

From The Library

Silver Domes: Observatories of the World, by Claire Inch Moyer (Big Mountain Press, Denver), 1955. Pp. 174, 22 × 14·5 cm. Price not marked (hardbound; pre-ISBN).

The title alone dates the period of this book. From the early nineteen hundreds until the early fifties most observatory domes were painted silver because it was believed that this colour best reflected the heat of the day and kept the equipment inside cool. During the early fifties the United States Air Force developed a white paint that reflected the invisible infrared radiation as well as most of the visible light. This resulted in a much cooler interior. When the domes are opened for the night's observing, the equipment quickly reaches the ambient outside temperature. This paint in now used on all NASA and USAF Research Aircraft and radar and telescope domes. Its use soon followed in most of the observatories around the world.

This book is one of those little gems that might have escaped your attention as you browsed through the shelves of your local bookstore. And bookstore it would have been because the internet did not exist at the time of its publication. I owe my copy to my brother who has a computer and ordered it a few years ago on Amazon. It may have been reviewed when published because my copy contains a letter inserted from the author dated 1955 August 26 and addressed to Mr. Robert Fenwick, Empire Magazine Dept., Denver Post, Denver, Colorado, with a 3-cent stamp on the envelope! Considering that in the intervening years postage has only gone up to 50 cents for a first-class letter, it still one of the best bargains in the world for throwbacks like me who still use snail mail. I have been reading book reviews since I was in my pre-teens in the 1950s and I vaguely remember this book being reviewed in *Sky and Telescope* magazine, but it certainly deserves to be re-reviewed in the light of intervening history, and even re-published for historical purposes. I will never separate the letter from the book because I believe it is part of its historic provenance.

Silver Domes is unusual for several reasons. For the most part all of the books published at this time cataloguing the world's observatories deal over and over with the major ten or 15 facilities. This small volume lists 131 facilities around the world. Unfortunately there are only 13 photographs — I wish that there were more. But on the plus side many of the period photos of that time have never been seen by this writer (who has literally paged through thousands of astronomical publications over 60 or more years). The introduction consists of a brief but well-written description of observatories in history. There is no index and only nine references in the bibliography. I recommend that if the book is re-published an index is added. It would also be a good idea for readers to seek out and read all nine references which are readily obtainable. Another asset would be to seek out and include more period photographs.

The chapters following the introduction are divided by geographical areas starting with Africa and ending with the Philippine Islands. The author then wisely sets up a format for information about each entry that writers of today's books could well emulate. It begins with the address, geographical co-ordinates, director's name, publications, description of equipment, and sources of information. This allows a quick comparison of the various institutions. The only measurement missing is the surface area of the telescopes in square feet or centimetres to determine the light-gathering power. In the front, instead of a table of contents, the observatories are listed in alphabetical order with the corresponding page number making it easy to look up any individual observatory.

At this point I would like to point out some facts about the state of astronomy in general 64 years ago for the benefit of today's readers who did not grow up in that era. The way the general public perceived astronomy and astronomers was completely different from today. With the exception of Edwin Hubble, who was a gregarious person who loved pomp and circumstance, hobnobbed with the Hollywood elite, and had become famous in the newspapers for his discovery of the expanding Universe, most astronomers were thought to be highly educated individuals with their head in the clouds and uninterested in the mundane affairs of ordinary men. Most observatories did not have regular visiting hours and kept their gates locked. Only on special occasions such as a rare opposition of Mars or a prominent comet would pressure from the public and the press draw out astronomers from their sacrosanct havens to permit viewing and give interviews. When the public hysteria subsided the gates were locked and the astronomers would retreat into their splendid isolation. The living quarters on Mount Palomar that housed the astronomers while using the equipment was nicknamed 'the monastery' with good reason. They did not even have a ladies' bathroom! All this resulted in funds for new equipment being sparse and slow in coming. When Lick Observatory was building the 120 inch (at that time the second-largest telescope in the world) the last 100 000 dollars were hard to come by. This all changed when Russia, then a part of the artificially constructed Soviet Union, surprisingly launched the first man-made satellite. It was a tremendous psychological shock to the Western World and especially the United States — that a country like Russia, perceived in the west as a backwater nation run by peasants, could achieve such a technological achievement! You cannot imagine it unless you had lived through it as I did! Astronomers and space scientists were sought out for endless interviews and promoted to the rank of rock stars. There were endless discussion shows on television and radio. More than enough *mea culpa*s were passed round. That a nation like the US that built the atom bomb, broke the sound barrier, and built the finest aircraft in the world could be bested by a nation like Russia was astounding. The entire western world and especially the US went into action. Foundations, universities, and especially the US government made money available faster than ways to use it could be devised. All the sciences prospered, especially the space sciences and astronomy. While the UK spent £35000 on the *Isaac Newton* 98-inch telescope the US spent $115000 a mile to blast a road up to Kitt Peak to build the US National Optical Observatory. When Canada cancelled the CF-105 advanced-fighter project, most of the engineers came to the US to work on the Apollo Lunar Programme. The European countries formed a coalition and created the European Southern Observatory. Australia built several large radio telescopes. American science and industry steam-rollered the Soviet Union and did the Apollo Moon mission, six lunar landings, and *Skylab*. When the lunar programme had flagged the US went on to build the space-shuttle and became a major contributor to the *International Space Station*. Astronomy came out of hiding and with unprecedented public support built more telescopes than in all of history combined. Public and government support continues to this day with the building of ever larger instruments like the *Giant Magellan Telescope*, the *Thirty Meter Telescope*, the *European Extremely Large Telescope*, and the *James Webb Space Telescope*. The International Astronomical Union has started a world-wide outreach programme with the goal of interesting the whole world in astronomy and space research. The result is bringing up the educational level of every person in the world. Already the heavy investment in building observatories in Chile by several nations has raised them from a Third World country to rapidly becoming an industrialized nation. Who could predict what a large public interest in astronomy would do? Books like *Silver Domes* are very valuable because they represent a snapshot in time to help us see where we were and where we can go. I hope it is reprinted so that everyone can enjoy going back in time. — Leonard S. Matula.

CONGRATULATIONS

The Editors of *The Observatory*, and we are sure many others, wish to offer our special congratulations to Professor Margaret Burbidge on reaching the grand age of 100 years on the 12th of this month. She was the first lady Editor of this *Magazine* (1948–1951) and was evidently content with the tradition of the time where the *Correspondence* pages began with the word 'Gentlemen'.

OBITUARY

Peter David Read (1940–2019)

The death on 2019 April 20 of Pete Read has robbed astronomy of one of its most colourful characters. Although he was not a professional astronomer as such, he will be known to many, particularly in the British astronomical community, as the ebullient 'Mr Fix-It', since his technical skill and infectious enthusiasm got many apparently-doomed projects up and running.

Pete was born on 1940 January 22 in Devonport, close to a major Royal Navy base, during the first year of WW II. In 1941 their house was bombed and Pete and his mother had to be dug out of the cellar and evacuated to Truro where he started school. After the war they moved back to Plymouth and then on to the village of Bere Ferrers at the confluence of the rivers Tavy and Tamar; that watery setting gave Pete his enthusiasm for boating (and, evidently, salmon poaching!).

Pete started his technical training (in electronic engineering) at Plymouth Polytechnic in the late 1950s, where one of his projects was to design and build a sophisticated monitor for both gas and water flow in reservoirs. He later moved on to work at Decca Radar, before joining the Royal Greenwich Observatory at Herstmonceux in 1967 as an 'experimental scientist'. He found himself, with his wife Margaret whom he had married in 1965, in what he regarded as paradise — living in an idyllic environment with a fascinating job.

The start of 1976 saw Pete and his family on secondment to Cape Town to work on instrumentation there and at the Sutherland observatory. Perhaps the most important thing Pete learned to appreciate about his new environment was how to *braai*! South African barbecues are something rather special, especially when lubricated with a Castle Lager or glass of Pinotage.

Moving back to RGO in 1980, Pete was involved in the very successful development of the Reticon Photon Counting Detector System which was installed on the SAAO 1·9-m telescope. He continued his work on various sophisticated detector systems but also found time to play a major part in the social life of the RGO, as he was well placed to do living close to Herstmonceux Castle. He was prominent in the resurrection of the swimming pool in the gardens, a facility enjoyed by many of the staff; he built a crocodile for the RGO pantomime production of *Peter Pan*; and he helped build the raft for the RGO's participation of the Lewes Raft Race. He also played hockey for the RGO and stoolball, a fun game akin to cricket only found in Sussex and Kent.

But there were clouds appearing on the horizon in the early 1980s when money for science (among other things) in the UK began to dry up, and it was not long before the university-dominated committees of the Science Research Council saw the RGO as a target ripe for plunder. At first, in 1984, it was just a matter of trying to cut the staff numbers (DS was transferred out to Rutherford Appleton Laboratory (RAL) at that stage), but later the decision was made to transfer RGO to Cambridge. Pete was in the vanguard of efforts to resist this vandalism, presenting a well-costed case for retaining the RGO at Herstmonceux as the headquarters of a Northern Hemisphere Observatory, akin to ESO. Nevertheless, the move went ahead in 1989 despite Pete's well-founded misgivings about the cost; Pete and others (including IvB) were strongly reprimanded by 'the authorities' for their resistance to the move. Of course the process had not quite finished, and it took another nine years for the RGO at Cambridge, essentially England's oldest scientific establishment, to be extinguished.

With the closure of RGO, Pete took his valuable electronic skills to RAL where he contributed to several space projects including *ATSR*, *GERB*, *ROSAT*, and *SoHO*; the latter may have sparked his interest in the Sun, and he took the opportunity of going to Zambia to observe the total eclipse of the Sun in 2001. His expertise was also used outside the field of space research and he collaborated with Daresbury Laboratory on molecular biology.

Pete retired from RAL in 2006 and then enthusiastically launched himself into local affairs, becoming a school governor, supporting local charities, and becoming Mayor of Didcot in 2012.

Sadly, Pete suffered from melanoma for the last three years of his life, but even then he did not sink into the doldrums but took an active interest in the condition, taking part in vital clinical studies at the Churchill Hospital in Oxford. At a celebration of his life held in the Didcot Civic Hall, it was clear that he was an extremely popular figure in the town, and the many photos displayed showed the Pete that everyone knew — with a broad smile. Pete is survived by his wife, Margaret, son Simon, and daughter Claire, but he will be greatly missed by many more. — CLAIRE HAMPSON (NÉE READ), IAN VAN BREDA & DAVID STICKLAND.

Here and There

ANCIENT FARMERS TAKE THE LONG VIEW

Cave art could be a zodiac to map stars 40,000 years ago. And researchers … believe the positions of the paintings show their creators could even keep track of time and the changing seasons by observing stars move as the year progressed. The phenomenon, known as precession of the equinoxes, is caused by the gradual shift of Earth's rotational axis. — *The Telegraph*, 2018 November 28, p. 7.

ACCELERATION OF PLATE TECTONICS?

While ice melt is occurring in other places ... Greenland's location makes it a more significant contributor to polar motion. There is a geometrical effect that if you have a mass that is 45 degrees from the North Pole — which Greenland is — or from the South Pole (like Patagonian glaciers) it will have a bigger impact ... . — *Reflector*, **17**, 10, 2018.

ALIEN CONCEPTS

The comet appears red because it is ten times colder than the surrounding stars, such as the bright-blue one in the foreground. — *Meteorite: Nature & Culture*, by Maria Golia (Reaktion), 2015, p. 8.