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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2019 October 11 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

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

The President. Welcome to the first of our A&G open meetings for this academic session. We have an absolutely super programme this evening of great variety and interest, and it's my pleasure to introduce the first speaker, Dr. Rebekah Higgitt of the University of Kent, to give a diary talk entitled 'Expeditionary Astronomers; the 1769 Transit of Venus and British Voyages of Scientific Exploration'.

Dr. Rebekah Higgitt. A 1780s print from the third circumnavigation by Captain James Cook, portraying the ships *Resolution* and *Discovery* in the Society Islands, shows the expedition's land camp and observing tents that mark the location of the expedition's astronomers and high-precision equipment. Their presence was one of the legacies of the expeditions to observe the 1769 transit of Venus. The 250th anniversary of that voyage has been recently marked in New Zealand with the sailing of a replica of the *Endeavour*, which carried Cook and his expedition to Tahiti and then to the South Seas. This, not surprisingly, has provoked a complex reaction, especially from Māori who recall the deaths resulting from the immediate encounter, and the losses of lives, land, and rights that followed. It is an important reminder that such voyages were not just about astronomy.

Transits of Venus require prediction, travel, high-precision instruments, good observers, and international cooperation. They occur in pairs over a century apart and in the 18th and 19th Centuries were used to observe solar parallax and establish the distance between Earth and Sun. In 1716 Edmond Halley had published a method and, knowing he would not live to see the next transit of Venus, urged future astronomers to undertake the task. It was, in fact, the French who led the way before 1761, with other individuals and institutions playing catch up. The British hurriedly organized, got support for, and sent out two expeditions.

While knowing the Astronomical Unit is interesting for its own sake, it took more to convince governments and monarchs to support expeditions. They were persuaded of the personal and national glory of laying claim to such sublime knowledge, and of demonstrating the prowess of their astronomers and navies.

Even while the ultimate results depended on collaboration, efforts were driven by international competition and imperial contest. France and Britain were at war over imperial control and maritime influence. Showing that they could get to, stake a claim to, and be seen to be acting effectively in overseas territories was crucially important. Cook's instructions were to go on after the transit to locate new land, observe the potential of its natural resources, the "Genius, Temper, Disposition and Number of the Natives", and claim it for the king. Monarchs like George III were also persuaded of the importance of developing astronomy and the more accurate tables that such observations would feed into it because of its role in supporting navigation. Such voyages would also support surveying, develop navigational techniques, and, it was hoped, lead to new products, trade routes, and commercial opportunities.

As soon as the Royal Society heard that the French were planning expeditions for 1761, they began to consider what they would need. The immediate response of James Bradley, Astronomer Royal, identified the essential instrumentation of an astronomical expedition: a reflecting telescope for observing and measuring particular phenomena, plus an astronomical quadrant, refracting telescope, and clock to establish the exact longitude and latitude of the observing position. In 1761 George III gave £800 to each of two expeditions, though clouds foiled one and the other was disrupted by war. Five British expeditions were organized for 1769 by the Royal Society and the Board of Longitude. For the *Endeavour* expedition, George III provided £4000 and the Admiralty spent over £4500 to acquire, modify, and fit out the ship.

The observing location, Tahiti, was picked after the *Dolphin* returned from a 1766–68 circumnavigation. That expedition, a mark of Britain's renewed interest in maritime exploration, confirmed the ideal situation of the island. The suite of instruments was shipped out along with individuals with the skills to make and process the observations. The expedition's observer was Charles Green, a former teacher, assistant at Greenwich, and assistant to Nevil Maskelyne on a trial of three longitude methods in 1763–4. After the transit, Green reached New Zealand and Australia, making observations on land to fix positions and using the newly published *Nautical Almanac* to test the lunar-distance method. The Royal Society and Board of Longitude also supplied him with a range of instruments for carrying out surveys and observations of geomagnetism, meteorology, hydrography, and more. He sadly died at Batavia in 1771.

Cook was the voyage's commander, but also Green's observing assistant. While Green's story tells us about the mathematical and observational skills linked to the Royal Observatory and its production of the *Nautical Almanac*, typical of the observers on the other British transit expeditions, Cook's tells us that they could be a route to gaining recognition in the navy. Cook, as ship's master, gained navigational and surveying experience in North American waters during and after the Seven Years War. This gave him a practical training in mathematics and astronomy that he developed in his own time. On 1766 August 5 he observed a total solar eclipse and sent a short report to the Royal Society, which accounts for the Society's willingness to appoint him as observing assistant. He was capable of making the same range of observations as Green, including of lunar distances, and oversaw the expedition's surveys and high-precision charting.

The *Endeavour* voyage was a success and, a year after his return, Cook was to be sent out again. While this voyage included Cook and other skilled navigators and surveyors, plus civilian naturalists and artists, because there was no transit, it might have lacked specialist astronomical expertise had Maskelyne, by now

Astronomer Royal, not intervened. He wrote to Lord Sandwich, First Lord of the Admiralty, in 1771 October to suggest that the voyage "may be rendered more serviceable to the improvement of Geography & Navigation than it can otherwise be if the ship is furnished with Astronomical Instruments as this Board hath the disposal of or can obtain the use of from the Royal Society and also some of the Longitude Watches; and, above all, if a proper person could be sent out to make use of those Instruments & teach the Officers on board the ship the method of finding the Longitude".

The Board of Longitude agreed that Maskelyne should find two observers and "prepare a Draft of Instructions proper for the said Persons and also a List of the necessary Instruments". He selected William Bayly, a Royal Observatory assistant and 1761-transit observer, and William Wales, who had also observed the 1761 transit and was a computer of the *Nautical Almanac*. In terms of instruments, instructions, and personnel, this voyage followed the model of the earlier ones. In terms of inserting astronomers and expectations of high-precision onto a naval voyage of exploration that lacked a primary astronomical purpose or the initiative of the Royal Society, it set the pattern for the future.

The long list of instruments and tables for the second Cook voyage defined ambitions of instrumental precision and experimentation. It was the model for subsequent voyages and Maskelyne drew up similar lists for Constantine Phipps's voyage to the North Pole, Cook's third circumnavigation, the flagship of the First Fleet, and George Vancouver's voyage to the North West Pacific, among others. Another fixture was the portable observing tent. High-precision exploration required ships to transport large amounts of equipment and tents to allow sufficiently prolonged land observations to make an accurate fix of position. Each set of instruments was accompanied by an observer, appointed by the Board of Longitude and enjoined to teach the new techniques to officers and crew. We can trace lineages of navigating officers who were taught by people like Green and Wales, and some expeditionary astronomers, including Wales, Bayly, and James Inman, became teachers at naval colleges and schools.

By the end of the 18th Century, at least some naval officers could navigate effectively by timekeeper and lunars and carry out precise surveys. Increasingly, the Navy Board could supply the kind of instruments that had once only been available *via* the Royal Society and Board of Longitude. After the hiatus of the French Wars, the Board of Longitude again sponsored and supplied expeditionary observers, supporting a new project of Arctic exploration. When the Board was dissolved in 1828, its functions were absorbed into the Royal Navy, its Hydrographic Office, and naval colleges. Survey voyages of the 1830s, like those of the *Chanticleer* and *Beagle*, were a continuation of earlier efforts, marked by the use of high-precision instruments, observing tents, astronomical tables, and mathematical calculation. This time, however, the observers were all naval officers, without need for supernumerary astronomers.

The President. Rebekah, thank you very much indeed. This is open for questions.

Reverend G. Barber. I noticed in the picture of the tent, there seemed to be a grandfather clock. Now that would seem to be absolutely useless on-board ship, so how would you get an accurate time when you are transporting halfway round the world?

Dr. Higgitt. Yes, a pendulum regulator; and no, absolutely not for use on-board ship, hence the whole problem with longitude and trying to find a timekeeper that will work on-board ship. It has to be set up, under its tent, on land, and you have to be there long enough to make the astronomical observations to establish local time and to check that the clock is working properly. Whenever the ships did stop long enough, the observer leaps out, sets up his tent, and tries to make these observations in time and with sufficient precision.

Reverend Barber. But you have to convert local time to Greenwich Mean Time.

Dr. Higgitt. Well that's what the *Nautical Almanac* is for. So you need to know what time it is there and then your almanac will tell you, through your observations, what the time is at Greenwich and then you can work out your longitude.

The President. The clock I liked on your list was the Alarum clock. I think I could do with one of those. Anyway, other questions, please.

Mr. C. Taylor. With regard to the transit of Venus and the solar parallax, you know a great deal has been made, and to my mind actually overstated, about the difficulties of measuring the parallax itself as an angle because of the black-drop effect. But if you are going to measure the linear distance to the Sun, you need to know accurately the length of your baseline as well, and it seems to me an interesting question as to how much of the error in the resulting solar distance came from the geographical error in the baseline rather than the astronomical error in measuring the angle of parallax on the sky. Have you any thoughts on that?

Dr. Higgitt. No, in terms of doing the numbers and thinking what that was. I think the main problem with the black-drop effect is that they were all surprised and they weren't expecting it and they thought that was something they could control in a way that you couldn't necessarily control other things. So it did really mess them up. And they thought photography would solve it in the 19th Century and it didn't.

Mr. Taylor. I think both of the 18th- and the 19th-Century values for the solar parallax were within about 1% of the modern value.

Dr. Higgitt. I knew someone was going to ask me this. The figure that they came up with in the 19th Century, interestingly, lessened the importance of what they got from the photography but added in a weighted way to the data from the 18th Century. They came up with 92 702 000 ± 53 700 miles, so I will let someone else do the calculations as to how. In 1769, it was more out, it was 95 000 000 odd.

Mr. Taylor. But that could have been geographical error because I think Hornsby in Oxford calculated a value of 8·13 arcsecs or whatever, which I think is very close to the modern value of the parallax, not of the distance.

Dr. Higgitt. Yes, if someone wants to get into the figure, it would be interesting.

Reverend Barber. Which goes back to my original question. The error in the baseline is because you actually don't know your longitude unless you have an accurate Greenwich-mean-time clock. So, you can do astronomical observations, but you still need to know the time as to relative mean time.

Dr. Higgitt. But that's what the *Nautical Almanac* gives you. It's a very valid way of doing it and at the time, and long in to the 19th Century, lunar distances was considered, as long as you did them enough, a more accurate way of establishing longitudinal time at the local site and finding a comparative time than the time keepers. It's an interesting question: if they'd had the time keepers available in 1769 rather than 1771, would that have made a difference? But I should say that Cook's survey is still considered very good and that his data in some parts of the world are what we use.

Professor R. S. Ellis. A very enjoyable talk but with a very embarrassing outcome for me. Thirty years ago, I went to Tahiti and I went to the island of Maria where there is a bay called Cook Bay where I naïvely imagined that was where the measurements were made, but clearly I was wrong.

Dr. Higgitt. Point Venus is the geographical location. I am afraid I don't know how the two match up, if anyone else has been.

Professor Ellis. Did he not make measurements in more than one place, weren't two teams sent?

Dr. Higgitt. There was only one team sent but I think different observations were made on the day — they weren't right next to each other

The President. I think we have to thank Rebekah again. [Applause.]

Our next speaker is Dr. David Jones from the Instituto de Astrofísica de Canarias, and he is going to talk to us on 'Common Envelope Evolution; from Binary Star Chrysalis to Cosmic Butterfly'.

Dr. D. Jones. Once stars with masses similar to our own Sun have exhausted the hydrogen in their cores they become red giants, dramatically increasing in size — often by a factor of one hundred or more. These red giants then slowly expel their outer layers in the form of a dense stellar wind, exposing their degenerate cores which contract and heat up before joining the white-dwarf cooling track. With this standard evolutionary picture in mind, it is thus difficult to understand how evolved close binaries with a white-dwarf component could come to have orbital separations much smaller than the radius that the white-dwarf progenitor would have occupied while a red giant. A little over forty years ago, Bohdan Paczyński (although he credited Jeremiah Ostriker and Ronald Webbink for the idea) proposed that such binaries pass through a 'common-envelope phase', whereby the white-dwarf progenitor's outer envelope engulfed the companion, with drag forces then leading to a shrinking of the binary orbit and the ejection of the envelope — leaving behind a close binary with a white-dwarf component.

Intriguingly, in both common-envelope and single-star evolution, once the envelope of the star has been removed (*via* common envelope or stellar wind) it will be ionized by the exposed pre-white-dwarf core leading to the formation of a planetary nebula. This makes post-common-envelope planetary nebulae particularly important tools for understanding the common-envelope phase, as the central binaries of such systems are 'fresh-out-of-the-oven', having not had time to adjust following the envelope's ejection, while the planetary nebula itself comprises the ejected envelope, allowing one to study the morphological and kinematical properties of the ejection process. Indeed, Paczyński himself saw the discovery of a close-binary central star in a planetary nebula as a key confirmation of the common-envelope model — with the first being identified by Howard Bond in the same year as Paczyński outlined the model, 1976.

Nowadays, roughly sixty close-binary central stars of planetary nebulae have been discovered, and the study of their properties and those of their host nebulae has revealed much about the common-envelope phase. Broadly, planetary nebulae with binary central stars present with bipolar morphologies, the symmetry axes of which are always perpendicular to the binary orbital plane. This is seen as observational confirmation that the common envelope is ejected principally in the orbital plane (as a result of the conservation of angular momentum which is transferred from the binary orbit) and it is this equatorial density enhancement which goes on to form the waist of the bipolar nebula (restricting the subsequent fast but tenuous wind, which emanates from the emerging pre-white dwarf, in the orbital plane but allowing it to flow freely in the polar directions).

Returning to the morphologies of post-common-envelope planetary nebulae, a number display collimated polar ejections or jets which, when subjected to a detailed kinematical study, are found to pre-date the central regions of these nebulae by of order a thousand years (*i.e.*, they were formed around a thousand years before the common envelope was ejected). Given that current models suggest the time frame of the common envelope from formation to ejection is a year or less, this means that these jets must originate from a period of more stable mass transfer which a thousand or so years later led to the runaway engulfment of the companion and a common-envelope event. Probing this pre-common-envelope evolution is key in understanding the whole process, and, thus far, modelling attempts have generally begun by placing the companion already on the very edge of the primary star's envelope. Further evidence that the pre-common-envelope evolution must be taken into account comes from the observed properties of main-sequence companions in post-common-envelope planetary nebulae. In almost all cases, they are found to be highly inflated with respect to isolated field stars of the same mass — some of which could be due to the high levels of irradiation they experience from the nearby and much hotter pre-white-dwarf component, but most likely this inflation is a consequence of a significant episode of accretion to which the main-sequence companion has not yet thermally adjusted. This hypothesis is confirmed for the central star of the Necklace Nebula which presents with a pair of polar jets, launched prior to the common envelope, as well as a low-mass main-sequence companion which has been enriched in carbon by material accreted from the nebular progenitor while it was still a red giant (*i.e.*, during the same mass-transfer episode which led to the launching of the jets).

Studies have also shown that a significant number of post-common-envelope central stars of planetary nebulae are made up of two white dwarfs, rather than a white dwarf and main-sequence star as discussed earlier. One might naïvely expect such systems to be particularly difficult to form, given that they would likely have to pass through two common-envelope phases, the first of which would have already shrunk the binary orbit to such an extent that a second common envelope would be impossible to survive. However, their apparent abundance indicates that these systems most likely avoid the first common-envelope event, instead evolving *via* a phase of stable but non-conservative mass transfer, and only experience a common envelope when the second star becomes a giant. The seemingly large number of double-white-dwarf central stars could have important implications for other astrophysical phenomena such as the cosmologically-important supernovae type Ia, which could form from the merger of such double-white-dwarf binaries (if they are sufficiently massive). In fact, two of the strongest candidate supernova type Ia progenitors known are found to be central stars of planetary nebulae, and a significant fraction of supernovae type Ia explode in circumstellar environments consistent with a remnant planetary nebula. As such, future detailed studies of both individual double-white-dwarf systems in planetary nebulae, as well as the properties of the population as a whole, may hold the key finally to understanding the origins of supernovae type Ia and their suitability as a standard candle for measuring cosmological distances.

The President. Thank you very much — that was an excellent talk. Open for questions.

Reverend Barber. There seem to be three models for a type Ia supernova, that is the single-degenerate, double-degenerate, and the sub-degenerate. There is one paper where they say that if there were still hydrogen content, contamination of a very low percentage, nevertheless, it would actually reduce the Chandrasekhar mass which would go supernova. The question is, are we going to use them as standard candles at cosmological ranges, because we establish they are standards at local ranges? I just think if the three types form a mix, but evolve separately over cosmological time, then we could actually be misleading ourselves as far as dark energy and so forth are concerned.

Dr. Jones. I absolutely agree, which is one of the main reasons why I think this is very interesting work in that kind of context. If we want to prove that type Ia supernovae really are valid standard candles on cosmological distance scales then we really should understand their origins, and if there are multiple competing pathways which all contribute, are they still standard enough?

The President. Thank you, David, again. [Applause.]

Our next speaker is Dr. Ryan Zeigler, curator of Apollo samples at NASA Johnson Space Center, and he's going to talk on 'NASA and the Moon; From Apollo to Artemis'.

Dr. R. Zeigler. [The speaker explained that it was his job is to curate all NASA's space material. This consists of eight main collections, of which the Apollo samples are the first and best. There are also collections of cosmic dust, some of which is gathered from high-altitude reconnaissance plates (10% of the sample collected comes from cometary material drifting down through the atmosphere), from missions to comets such as *Hayabusa*, a JAXA mission to collect samples of material from an asteroid, a mission to Comet Wild 2 during which samples were taken from the coma and tail, material from the solar wind, and also a collection of meteorites. In future the collections will be expanded with material from *Hayabusa2* and *OSIRIS-REx* which will be coming back from asteroids in the next few years.

The Apollo material was housed in the Lunar Receiving Laboratory until 1972, but after it was found that the samples no longer needed to be kept in quarantine they were transferred to a new custom-built structure in 1978.

Why is Apollo so important? It was an immense technological achievement which required a huge commitment in money ($125 billion), people (250 000), and companies (10 000), but it also represents a huge scientific and cultural legacy. One of the most important things we have from the Apollo samples over the last 50 years is a lot of knowledge about the Moon but also about the terrestrial planets. Another important consideration is the human intervention. Robots can be built to make geological surveys, but astronauts can drive vehicles, pick up samples from the surface, set up networks of instruments, drill holes, and make real-time decisions, such as which samples to collect. They were also able to pack the samples, with difficulty, in vacuum containers on the Moon, and *Apollo 15* brought back three such lots, only two of which had kept the vacuum intact. One has been opened and another remains to be opened. The Apollo samples consist of 842 lb (382 kg) of rock and soil which were collected from six locations on the Moon, ranging from the heavily cratered highlands to the basaltic maria, and a few rare igneous examples were found which appeared to have formed deep within the Moon. The soil represents 30% of the whole collection and 10% of the material is more than 1 mm in diameter. Each small rock has a story and we have not looked at them all yet. The core samples yielded the vertical stratigraphy within the Moon.

The archive also has about 200 lunar meteorites which have fallen to Earth as a result of impacts. It is important to keep the lunar-surface samples in conditions as close as possible to those found on the Moon. They are stored in cabinets in an atmosphere of dry nitrogen. Over the last 50 years we have received 3200 requests for material and we have handed out about 50 000 samples. The request rate was high in 1984 at 1000 per year and requests have now returned to that level. There are currently 125 investigators in 16 countries looking at the samples, 12 of whom are based in seven institutions in the UK.

What did the samples tell us about the Moon and the Solar System as a whole? The isotopic evidence shows that the Moon and the Earth were originally part of one body and that the Moon was formed after a giant impact from a Mars-size body. The Moon had a magma ocean and was molten to a depth of 1000 km, and as it started to cool out the first minerals we see are olivine and pyroxene which are iron-rich and which have sunk to the core, and plagioclase and anorthosites which are iron-poor and remain near the surface. This also gives us some understanding as to how Venus and Mars might have formed. Does Mars have a magma ocean or not? Some work is being done on that topic now. The youngest impact feature on the Moon is the Orientale Basin which is 1000 km across; there are 40 other such features and the relative age of each is known. This can be done by examining how the ejecta lie on top of each other, and they can be graded young or old. *Apollo 11* looked at the basaltic flows and also carried out crater counting, and by noting the size, the age of each crater could be estimated. The ages found can differ by tens of millions of years. The technique works on Venus and Mars but not as reliably.

Results from the surface samples can also be combined with those from remote-sensing satellites. For instance, the gamma-ray detector on the orbiting *Lunar Prospector* has recorded gamma rays emitted by thorium on the Moon and found concentrations of between one and 12 parts per million. Two more examples might be mentioned. The use of lunar rocks to give an estimate of lunar albedo can be applied in exoplanet spectroscopy. The Moon's surface is a good place to sample the flux of Galactic cosmic rays over time since there is no atmosphere to degrade the incoming particles. The deep-core examples give the best results. We used to examine the insides of lunar breccia by cutting them open with a saw but we can now do this by using X-rays. The soils contain five or six different rock types and this evidence helped to contribute in 1969 towards a magma model of the Moon.

Are more samples needed? Certainly, planning is underway to go back to the Moon in 2024 on the Artemis mission. The plan is to land near the South Pole where the illumination conditions are favourable for constant solar power. The tops of some craters such as Shackleton can be in sunlight for 96–97% of the time. Also the bottoms of deep craters provide a cold sink for volatiles which includes water ice, but it is 7 kilometres from the crater edge to the bottom so some thought as to how to get down there will be needed. It is planned to collect samples of the lunar mantle from the South Pole – Aitken Basin which is the largest, oldest, and deepest region on the Moon.]

The President. Thank you very much for a really excellent talk. It's open now for questions.

Ms. Gail Campbell. Just a couple of quick questions. The first one is, looking forward, we've seen *Chang'e* go to the far side of the Moon. In terms of reciprocity, and I know there is a political aspect to this, how do you determine who to share your samples with and whether or not they'd be prepared, for example China, to share with you?

Dr. Zeigler. That's a couple of levels of government above me — the state departments. We traded samples with the Soviet Union in 1972 and 1978 but, although the scientific community would be very excited to do that, there are US laws about agreements between Chinese institutions and US institutions that we would like to go away, but no, that is a complication.

The President. This is being fed to the White House.

Dr. Zeigler. I understand. [Laughter.]

Ms. Campbell. There is still a potential opportunity. And my very quick second question: on *Apollo 17*, the last mission, Harrison Schmitt was the only geologist to go to the Moon and to walk on the Moon. Was it a tremendous boost in terms of the samples he selected?

Dr. Zeigler. It certainly was. A lot of the astronauts and certainly astronauts on every mission were avid geologists, even if they were amateur geologists. Jack (Schmitt) was obviously the only professional, and he is still involved with the samples. He'll be there when we open the sample in a few months. He's not going to be the one cracking it open, though I don't think we've broken the news to him, but hopefully he will be watching. [Laughter.] He has played an active part and his samples really were special, and Gene Cernan's too.

The President. One more question.

Mr. M. Wrigley. If my memory serves me right, I was about 16 when *Apollo 11* happened. In fact I went to Sheffield Museum to see a little vial of black substance. If I'm correct, quite a few were given away as diplomatic presents. So the question is, have any of them ever come back and how many were given away?

Dr. Zeigler. I don't have the exact number, but it's about 120. Every country that was a country in 1969 and 1972 was given a goodwill sample from *Apollo 11* and then again *Apollo 17*. And when I say everyone, I mean Cuba in 1972 got a goodwill sample, and we didn't have very good relations with them at the time. They were out and out gifts so we don't keep track of them. One or two have turned up and been recovered in various ways and returned to the country they came from, but we don't actively do that. We just help when they ask. Is that a diplomatic answer?

The President. That was a fantastic talk, Ryan, thank you very much. [Applause.]

The President. Our last talk this evening is from Dr. Robert Massey from the Royal Astronomical Society and Dr. Alexandra Loske who is the curator of the Royal Pavilion in Brighton; exactly how they're going to give this talk in parallel I don't know, but please come up and we look forward to your talk. The title is 'Moon: Art, Science and Culture'.

Dr. Alexandra Loske & Dr. R. Massey. Commemorating the 50th anniversary of *Apollo 11*, our book *Moon: Art, Science, Culture* explores the influence of the Moon on human thinking, from calendars and religion to contemporary science fiction, alongside science, and visions of our future in space.

There is some evidence that representations of the Moon date back to the Palaeolithic era, with symbols reminiscent of its phases in the Lascaux cave paintings. Less disputed are Neolithic monuments like Stonehenge aligned with the range of lunar (and solar) positions in the sky. The Nebra sky disc, created 3600 years ago, is the oldest known portable artefact, representing the Moon and stars in bronze and gold.

In the early Renaissance the Flemish painter Jan van Eyck appears to have been the first to create a realistic lunar representation in the mid-15th Century *Crucifixion and Last Judgement*, where a waning gibbous Moon shines above Christ on the cross, complete with darker maria features. Physician William Gilbert created a crude naked-eye Moon map too, just before the invention of the telescope and its transformative impact on science, art, and imagination.

Almost 170 years later (1609) Thomas Harriot from West London and Galileo Galilei made the first telescopic maps of the Moon within a year of the patent for the new invention. The first views of mountains and craters on the lunar surface transformed our understanding of the Moon as a world as never before, prompting speculation about life there, and science-fiction stories about visits. The same year saw artist Adam Elsheimer's *Flight into Egypt*, whose ownership of a telescope led to a painting with a realistic lunar image and night sky.

Astronomers created ever more detailed maps for the next three centuries, culminating in the drawings of Hugh Percy Wilkins that supported the Apollo programme. Scientific rigour did not, though, diminish the romantic appeal of the Moon in the sky, and moonlit landscapes and people. The German Lunar period, typified by Caspar David Friedrich's *Two Men Looking at the Moon* from 1819, captures this best. This iconic painting has travellers gazing at the setting (realistic) Earth-lit crescent Moon, and with their backs turned they invite the viewer to join them.

Scientists also drew on artistic techniques to share their work. An excellent example is James Nasmyth and James Carpenter's 1874 work *The Moon: Considered as a Planet, a World, and a Satellite*. Detailed photography of astronomical objects was still a challenge, so the authors photographed plaster models, and used physical metaphors, including a cracked glass sphere, a human hand, and a shrivelled apple to represent features on the lunar surface.

The public appetite for lunar science, and imagined exploration, grew with newspaper articles like the 1835 Great Moon Hoax that made up observations by John Herschel of aliens on the Moon, and the more lasting works of Jules Verne from 1861. The French author described a lunar voyage and return to Earth with remarkable prescience, setting aside the huge gun that launched his astronauts on their way. H. G. Wells's 1901 story resorted to anti-gravity, and explored themes of colonialism and war through the lens of intelligent lunar insects.

The 20th Century brought the Moon to the big screen. George Melies's short silent film *A Trip to the Moon* (1902) has a lunar face violated by a spaceship landing, and astronauts who look back to Earth, anticipating the Earthrise image 66 years later. At the end of the silent-cinema era, Fritz Lang and Thea von Harbou's 1929 masterpiece *Frau im Mond* not only places a woman on the Moon, still unrealized 90 years later, but also anticipates features of modern spacecraft like multi-stage rockets, a vehicle-assembly building, and introduces a countdown to launch. Rocket pioneer Hermann Oberth worked on the film, and though banned by the Third Reich, it was a favourite of Wernher von Braun, the leader of the Nazi V2 project in World War II, and later architect of NASA's Apollo programme.

Forty years later, driven by well-documented superpower rivalry, and pledges from assassinated US President John F. Kennedy, the *Apollo 11* landing and five more successful missions took 12 men to the lunar surface. The NASA programme switched off just as quickly, not least as a result of its huge cost, reaching 5% of the US federal budget at its peak. NASA commissioned artist Robert Rauschenberg, who in 1969 created *Stoned Moon*, an appropriate title for the time. The positive response to the landing was essential propaganda for a US administration mired in Vietnam. In the same year Mark Rothko's *Black and Grey* appears to reference the dearth of colour in lunar landscapes, where gold on the Apollo landers and the red, white, and blue of the American flag stand out against the (spectacular) tarmac hues of mountains, rocks, and craters.

Artistic interest in the Moon waned with the scientific effort and declining public and political appetite for large-scale exploration. Like the building of the Amundsen–Scott base forty years after the first voyages to the South Pole, it has taken several decades for a commitment to return to the Moon to become a reality.

In 1999 Aleksandra Mir's *First Woman in the Moon* marked the 30th anniversary of the first lunar landing with women on a Dutch beach, noting the paucity of female space explorers and making a jibe at modern-day Moon hoax protagonists. As memory of the landings fades, contemporary artwork grows, such as Leonid Tishkov's *Private Moon Project, 2003–17*, where the artist took a crescent Moon model around the world, and in the UK Luke Jerram's wildly successful *Museum of the Moon* that attracts crowds wherever it goes.

As the space agencies of the world make plans to send astronauts back to our neighbouring world in a few years' time, we look forward to new inspiration for artists as well as reinvigorated enthusiasm for space and astronomy. Perhaps in a few years we may even see the first paintings and sculptures on the lunar surface — celebrating a very human story.

We look forward to future exploration inspiring artists — might even see one travel on the *BFR* (*Big Falcon Rocket*)!

The President. We have time for just one question.

Mr. H. Regnart. First, thank you very much. May I, rather than a question, share with everyone, very briefly, two literary lunar fragments. One, from one of Ezra Pound's transliterations from Chinese poetry, a description of someone who got drunk and drowned trying to embrace the reflection of the Moon in water. The other one from an Irish poet, Frank S. Flint, wonderfully surrealistic, called Eau-forte, a very short verse: "On bare black trees, a stale cream moon. Hangs dead, and sours the unborn buds."

Dr. Loske. Ah, thank you very much and may I counter with the most famous line in German poetry, by Johann Wolfgang von Goethe who also bought himself telescopes and the latest Moon-maps, by the way, and he said famously that "the moon releases [his] soul in its entirety".

The President. We can't possibly follow any of that. Thank you both very much indeed, and in closing can I remind you of our drinks reception in the RAS library immediately following this meeting, and finally I give notice that the next monthly A&G Open Meeting of the Society will be on Friday the 8th of November.

CORRESPONDENCE

To the Editors of 'The Observatory'

Felix Tisserand and the Moons of Venus.

An unlikely-sounding title, for sure, but having only just read Allan Chapman's review of the recent biography of Tisserand in last February's *Observatory*[1], I couldn't resist passing on the following amusing item of trivia.

As a lifelong admirer-from-afar of all things Burgundian, and of the wine in particular, I have been visiting the Côte d'Or on a fairly regular basis for the last 25 years with my wife on our holiday jaunts. To a student of celestial mechanics, the name of Tisserand had already been long familiar* on the occasion of our first driving down the D974 from Dijon to Nuits-Saint-Georges in the summer of '94, but I had no idea that he had any association with that delightful little town. The reader can imagine my delight, therefore, on finding a very handsome monument of *la belle époque* picturesquely situated in the centre of a small square on the northern approach to Nuits, which, on a closer look, turned out to be Tisserand's — that, indeed, on the front cover of the book reviewed by Dr. Chapman (Plate 1). It is a superb piece of the stonemason's and bronze-founder's art of that typically French style of the end of the 19th/turn of the 20th Century, but my delight turned to amazement tinged with amusement when I saw the carved design on the southern face of the stone plinth, shown in the photograph here (Plate 2): a plan of the Solar System, complete with two rather dashing comets sweeping across the planetary orbs — perhaps a reference to the Tisserand Criterion? — and *Venus with two moons!* As an amateur stonemason and, as ever, having my trusty pocket-knife to hand, it would have been but the work of moments to have neatly pared off those astronomical *faux pas* from the relatively soft, fine-grained white limestone of the monument, but I resisted the temptation — they were still there last summer.

Tisserand is, in fact, not the only scientific savant hailing from that land of the vine. Just down the road in the geometric centre of Beaune is the Place Monge, dominated by an equally impressive monument to that great geometer and friend of Napoleon, Gaspard Monge. Like Tisserand, Monge seems to have been a genial sort, a passionate teacher greatly beloved of his students. So, should your holiday plans take you down that way, don't forget to pay your respects to two great erstwhile colleagues — and the local wine isn't bad either, even if the fondly remembered days when one could buy it for £3 a bottle (even in England) are now long gone!

Yours faithfully,
CHRISTOPHER TAYLOR

Hanwell Community Observatory
Banbury
OX17 1HN

2019 November 22

Reference

(1) A.Chapman, *The Observatory*, **139**, 11, 2019.

To the Editors of 'The Observatory'

A Further Historical Observation of STEVE?

A recent paper by Bailey *et al.*[1] drew attention to historical observations of the atmospheric auroral-like phenomenon commonly known as 'STEVE' (an acronym for Strong Thermal Emission Velocity Enhancement). STEVE typically takes the form of a short-lived arch, beam, or narrow band of light in the sky. To the naked eye it appears as a bright, very thin, east–west aligned band, typically positioned south of the zenith in the northern hemisphere rather than towards the north, as would usually be the case for aurorae.

* So much for Tisserand being a "Forgotten Genius".

I have recently researched the life of David Elijah Packer (1862–1936), an enthusiastic and accomplished amateur astronomer who observed from London and Birmingham[2], and came across an observation he made in 1905 which at least superficially resembles STEVE.

Packer first came to the attention of the astronomical community in 1890 when he discovered a variable star in the globular cluster M5, only the second periodic variable to be discovered in a globular cluster. He found a second variable in M5 shortly after. These early identifications of what later became known as Cluster Variables, or RR Lyrae stars, brought him to the attention of the astronomical world, including Williamina Fleming and E. C. Pickering at the Harvard College Observatory who followed up his work. It was probably those discoveries that established his credentials as a careful observer that led to his appointment in 1892 as an observing assistant on the 25-inch *Newall* telescope at the Cambridge Observatories. However, his Cambridge career was short lived and he left suddenly in 1892 September for reasons unknown. He later commented to family members: "professional jealousy soon drove me from Cambridge and I became an exile".[3]

He went on to become a librarian in Birmingham, taking on responsibility for managing several libraries across the city where he spent the rest of his life. He remained an enthusiastic observer of the night skies, reporting in the *English Mechanic* observations of meteors, variable stars, nebulae, and many other things. On one occasion, in 1890, he noticed a brightening in the nucleus of the galaxy M77, which Gerard de Vaucouleurs later speculated might have been a flare up of the nucleus of that Seyfert galaxy or, perhaps, a supernova.[4] However, it has to be admitted that not all Packer's observations were accepted by his peers at the time, and his enthusiastic reports of some meteor showers, sometimes accompanied by sound, were questioned by W. F. Denning of Bristol, one of the most respected meteor observers of the age. Furthermore, his announcements of brightness variability in some 'nebulae', including the Andromeda Galaxy, were almost certainly flawed.

Packer's intriguing observation of a luminous beam from south Birmingham in 1905 was described in his letter to the *English Mechanic*, published on September 1:[5]

"THE LUMINOUS BEAM OF AUGUST 18. — On the night of August 18, at 12.30 p.m.*, a luminous beam was seen traversing the eastern part of the sky. At the time when it was first seen, the sky everywhere was very clear, and the moon shining brightly. The beam resembled a nearly horizontal ray of pearly white light, about 80° in length, and ½° in breadth, stretching across the constellation Pisces Australis (above Fomalhaut), through Cetus to Eridanus, or from 330°–25° to 50°–10°. It moved slowly south by east, and at 12.45 transited Fomalhaut, which shone through it with undiminished brilliancy. As its altitude decreased, it became more parallel to the horizon. Its southern border was more defined than its northern, and its preceding termination in Eridanus was slightly broader and less defined than its following termination. It bore a great resemblance to the tail of a comet. No nucleus or decided condensation was seen at either end to justify a cometary origin, although it is well known that several large comets — notably, the great comets of 1880 and 1887 — have been seen without nuclei as mere rays similar to the appearance above-mentioned. Traces of the beam were visible at 13h. 20m. p.m. It could not have been a

* Greenwich Mean Astronomical Time (GMAT) was commonly used prior to 1925 January 1, so "August 18, at 12.30 p.m." is Aug 19 at 00.30 UT

cirrus cloud, as its appearance was too regular and defined, nor was it due to a searchlight, as it revealed distinct motion along its entire length. I hope it may have been observed elsewhere."

Could Packer's luminous beam have been an early observation of STEVE? Well, on the surface it is certainly reminiscent of STEVE and is consistent with most of the key characteristics of STEVE that are described by Bailey *et al.*[1], although it would be unusual to see the phenomenon quite so low in the sky in the south. Whilst solar activity was not particularly high at the time, there were reports of aurorae during 1905 August, although I could find no reference to an aurora within a few days of Packer's observation. STEVE is invariably associated with normal polar auroral activity[1], but Packer makes no reference to seeing an aurora. The main problem, of course, is that Packer notes that the Moon was bright (it would have been two days past full, located in Pisces), which raises the question as to whether the sky would have been too bright to detect a phenomenon like STEVE (at the same time, bright moonlight might also explain the absence of a visible aurora). Another possible explanation is that it could have been a cloud formation illuminated by the Moon, although as an experienced observer of the night sky, Packer must surely have considered such an obvious explanation and ruled it out in his mind.

We shall probably never be certain what it was that Packer saw that night, but his observation is at least intriguing.

Yours faithfully,
JEREMY H. SHEARS

British Astronomical Association
Burlington House
Piccadilly
London
W1J 0DU

2019 November 24

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(2) J. Shears, *J. Br. Astron. Assoc.*, **125**, 338, 2015.
(3) L. Smith, 'Biographical notes for David Elijah Packer' (1995). Unpublished manuscript containing biographies of D. E. Packer and his wife, including family reminiscences. It was written by Packer's granddaughter, Lynda Smith. Lynda was the daughter of Ruth Ida Smith (née Packer) and much of the information in the manuscript is attributed to Ruth.
(4) G. de Vaucouleurs, *The Observatory*, **111**, 122, 1991.
(5) D. E. Packer, *English Mechanic*, **2110**, 88, 1905.

REVIEWS

The Women of the Moon: Tales of Science, Love, Sorrow, and Courage, by Daniel R. Altschuler & Fernando J. Ballesteros (Oxford University Press), 2019. Pp. 299, 22·5 × 14·5 cm. Price £20/$26·95 (hardbound; ISBN 978 0 19 884441 9).

Of about 1600 named craters on the Moon, 29 bear the names of women, drawn from some thousands of female scientists to be found in other sorts of reference volumes. Authors Daniel R. Altschuler and Fernando J. Ballesteros have provided short biographies of 28 of these, all but Hildegard of Bingen, eponymized after the Spanish language original of their book was published. Only one is still living as we write, Valentina Tereshkova, the first (Russian) woman in space, the International Astronomical Union having adopted in 1973 a rule analogous to the one absolute requirement for being buried in the US national cemetery in Arlington — you have to be dead.

Of the women so honoured, you will almost certainly have heard of Marie Curie (crater Sklodowska, Curie being named for her husband and the smaller of the two). Also, I hope, of Lise Meitner (whose Nobel prize went to Otto Hahn), Caroline Herschel (who found many comets and nebulae, though never her own planet, unlike brother William), and quite possibly others, depending on your interest in astronomy, history, space exploration, mathematics (Emmy Noether and Sofia Kovalevskaya have made the cut, but not Sofie Germain), and, truthfully, popularizers (*e.g.*, Agnes Mary Clerke) and patronesses (*e.g.*, Anne Sheepshanks and Catherine Wolfe Bruce) of astronomy. A core of the Harvard computers are here (Williamina Fleming, Antonia Maury, and Annie J. Cannon, all of whom classified stellar spectra under William Pickering) but not Cecilia H. Payne-Gaposchkin, who interpreted some of those spectra to show that stars, in particular K giants, are made mostly of hydrogen and helium.

The authors urge that, if readers find a particular subject interesting, they should go read a whole book about her. They cite some such books, though not always the ones I would have chosen (for instance, not Michael Hoskin on the Herschels, and none of the three mentioned for Kovalevskaya is the one I own, which described her as a sparrow*). For some, *e.g.*, Louise Freeland Jenkins, there is probably not information out there for a proper biography, and her chapter has been padded with information about measuring the *Hubble Space Telescope* mirror and parallaxes from *HIPPARCOS*, measuring parallaxes having been one of the things she did during her years at Yale under Frank Schleschinger.

Giovanni Battista Riccioli's 1651 map of the Moon was the first to name large numbers of features, adding 147 new crater names, including a nice big one for himself, and two for women. Of his two, one, Hypatia of Alexandria (murdered for refusing to adopt Christianity) probably had the merit of existing. The other, Catherine of Alexandria (supposedly martyred for refusing to renounce Christianity) quite possibly did not. But a fireworks Catherine wheel was a feature of Fourth of July celebrations around Los Angeles in the days when we were allowed to have our own fireworks. Her original wheel consisted of knives, skin for the removal of.

* *Little Sparrow: a Portrait of Sophia Kovalevsky*, by Don H. Kennedy (Ohio University Press), 1983.

Other crater names were added informally by map makers through the 17 and 1800s, including a few women, like Maria Mitchell and Nicole-Reine de la Brière Lepaute (one of my 'hoo shee?'s along with Mary Adela Blagg). A few craters are shared, like Annie Maunder with her husband, and Fleming with the (unrelated) discoverer of penicillin; to make up for this, she is credited by the authors with the discovery of white dwarfs.

The IAU stepped up in 1935, endorsing many of the traditional names, adding some (including a few women), and from time to time, approving newer names. Exactly 14 of the 28 'female craters' are invisible from Earth, being on the far side. Many are small (all the good ones having been taken by guys in the past). And it is thus useful that the authors have provided 'finding charts' from *Lunar Reconnaissance Orbiter* images, and for most also map positions from the Lunar and Planetary Institute in Houston, Texas. Many of the women are described as firsts — firsts to be accepted into academic institutions as students or instructors, first society members, first prize winners, and so forth of their gender. A couple of these are possibly arguable (although Sofie Germain's degree was an honorary one and given at the insistence of her mentor, Gauss, leaving the distinction of the first maths PhD by a woman to Kovalevskaya).

This brings us inevitably to problems with the book. Obviously the authors are in no way responsible for the paucity of craters bearing women's names nor for the somewhat random choice of who has been honoured. But the Editor had to force me to exclude from the price of the book one whole pencil needed for marking the "No's", "Oopses", "Eh's", and so forth. In some cases the authors have not been well served by their translator. The RAS is mentioned on about 20 pages. Well and good. But there are a comparable number of mentions of the "royal astronomer". The IAU is described as having been founded in 1919 in Rome (no, it was Brussels; and the Rome meeting was 1922). Nor, next page, was the 1970 IAU in Cordoba, Argentina (rather Brighton, UK). And many others.

So, should you read this book? *Faute de mieux* probably, but, please, pencil in hand, and it might be worth starting with an article, 'The Women in the Moon' by William Sheehan and Kevin Schindler in *Discover* magazine, 2019 November, page 62. — VIRGINIA TRIMBLE.

The Lost Planets: Peter van de Kamp and the Vanishing Exoplanets around Barnard's Star, by John Wenz (MIT Press), 2019. Pp. 171, 21 × 14·5 cm. Price £20/$24·95 (hardbound; ISBN 978 0 262 04286 4).

When I was working in the Astrometry department of the RGO at Herstmonceux, I occasionally used a measuring machine to reduce some of the plates taken with the 26-inch *Thompson* and 13-inch astrographic refractors. Through this experience, I had an idea of what sort of positional accuracy we could get using an *x–y* measuring machine and an eyepiece fitted with a graticule. By using 20 or 30 astrometric standards the formal error on the position of the target star was of the order 0″·3 with the smaller telescope and 0″·1 with the larger one (about 30 microns on the plate). I remember reading with fascination about the work of Peter van de Kamp at Sproul Observatory, both through his textbook *Principles of Astrometry* and being impressed with the results of his long-term observational programme on a number of nearby stars, including Barnard's Star. Van de Kamp used the 24-inch refractor, which had a similar plate scale to the Herstmonceux 26-inch, and some of the perturbations which he was dealing with were of amplitude ±1 micron, and these points were the means of large numbers of plates taken over several decades, but he was convinced that what he was seeing represented the gravitational tug on Barnard's Star of two Jovian-mass planets. With the benefit of hindsight we now know that these perturbations are not real and that the apparent shifts in the position of Barnard's Star which he found were connected to maintenance of the Sproul refractor, including adjusting the main objective lens. Van de Kamp died in 1995, still believing that his result was correct.

Sproul Observatory was a department of Swarthmore College, Pennsylvania (the 24-inch has recently been moved to Arkansas), and the author covers in some detail the social and political climate existing in the College at the time. There was a disturbance connected with the policies of the College head, whose death in post was much publicized. There was also a significant amount of friction between members of the astronomy faculty, and this is covered meticulously. It makes for a fascinating insight into the workings of a research department, where the leading players have different axes to grind. Discussing the subtleties of very small movements of star images on photographic plates may not seem ripe material for a good dramatic narrative but the author does manage to inject some human interest into the story.

Although John Wenz appears to be a scientific journalist of some experience, it may be that astronomy is not one of his specialities. What are we to make of "..., and a new emulsion technique for installing the plates was put in place." or "The Voyager 1 craft is leaving our solar system.... at 11 miles per second. That's faster than the blink of an eye in human terms ..." or "guiding it more toward the study of double stars – whether visual or actual binaries", or "In 1987, the mirrors of the telescope had to be recoated ..."?

It is probably true that van de Kamp's work encouraged others to try their hand either to confirm his research or to find other nearby stars in which perturbations existed. In the end, it was Wulff Heintz at Sproul who helped put a nail in the coffin, and subsequent follow-up astrometry at another US observatory which confirmed the lack of a perturbation in the path of Barnard's Star. So it is with some irony that we now know there *is* a planetary body in the system, and that the exquisite precision that *Gaia* will bring to the position and proper-motion measurement of many millions of stars will reveal lots of new planetary bodies. The idea was right, but, in Peter van de Kamp's case, the available technology wasn't quite up to it. — ROBERT ARGYLE.

Creating the Molecules of Life, by Richard N. Boyd & Michael A. Famiano (Institute of Physics Publishing), 2018. Pp. 234, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1991 1).

Creating the Molecules of Life is primarily a platform for its authors to promote their SNAAP (Supernova Neutrino Amino Acid Processing) model, which attempts to explain the origin of chirality in the living world today. The story of left-handed chirality and life has a long history of scientists trying to understand it, dating from Louis Pasteur's early work in the mid-19th Century to the Miller–Urey experiment of the mid-20th Century and beyond. It remains one of the greatest mysteries in modern science. That history is not presented chronologically in this book and seems almost incidental to its main thrust.

The first four chapters provide a broad introduction to astrobiology, cosmology, stellar evolution, and aspects of astronomy, respectively, not to mention their own SNAAP model. The next four chapters describe the model itself in more detail and experimental tests which might, with unlimited resources, be able to prove or disprove it. The penultimate chapter is essentially a 'put-down' of previous models, aiming to convince the reader that their SNAAP model is the leading explanation for the chirality of life. The final chapter completes the introduction to astrobiology begun in the opening chapter and is the only one which talks about molecules of life beyond amino acids.

While I enjoyed reading the book, the ordering of topics was clearly designed to give the SNAAP model pride of place and did not feel natural. The level of the material is variable, as one moment you are informed that C and N in a chemical formula stand for carbon and nitrogen, while the next you are expected to know that 'ee's' refers to enantiomeric excesses. The book is written for a "diverse group of readers" with "discussions of each scientific discipline at a basic level", but nevertheless requires the reader to know about topics such as quantum-mechanical tunnelling.

The main text is mostly free of mathematics apart from some of the formulae used in the SNAAP model, making it generally easy to read. Mathematical details are confined to two appendices for those wishing to delve into the third-rank tensor for nuclear magnetic shielding polarizability and beyond. Each chapter has a full set of references, with plenty provided for the authors' own model. I'd have preferred to see more recommendations for further reading and fewer detailed scientific papers in there. Review papers, such as Barron (2007) on 'Chirality and Life' might have been more suitable.

Spoiler alert! The SNAAP model essentially goes like this: Molecules form on interstellar dust grains which coalesce into larger bodies. A meteoroid containing a racemic mixture of left- and right-handed amino acids is subject to a combination of strong magnetic and electric fields together with a flux of anti-neutrinos. A Type II supernova leading to the formation of a neutron star can give rise to these conditions, probably starting from a Wolf–Rayet star if destruction of the amino acids and meteoroid are to be avoided. The anti-neutrinos and magnetic field cause the mix of amino acids to become slightly more left-handed or enantiomeric by selective destruction of chirality in ^{14}N-based molecules. Subsequent autocatalytic chemical evolution amplifies the enantiomerism until the mix becomes homochiral, specifically 100% left-handed. The amino acids may have first led to the formation of peptides before making the proteins necessary for life. The SNAAP model requires an understanding of how the ^{14}N atoms are orientated differently in an external magnetic field according to the chirality of their molecule and of the nuclear reaction which leads to their destruction.

The book includes little on the subjects of interstellar chemistry or DNA/RNA and focusses very heavily on the amino-acid-chirality question. Another model, normally referred to as the Vester–Ulbricht hypothesis, also attempts to explain chirality *via* the weak interaction in cosmic rays, but is not named as such, is dismissed with minimal discussion, and is incorrectly referenced as "Ulbright". There is no mention of the first discovery of a chiral molecule in space (McGuire, 2016) and the potential of high-precision polarization measurements for distinguishing chirality in the future. The text also suffers from some repetition, *e.g.*, when each author, presumably writing their chapters independently, separately describe the *OSIRIS-Rex* and *Hayabusa2* asteroid missions.

Although the book has a glossary it has no index or nomenclature. With a wide range of variables appearing, especially in the SNAAP model, I had to refer back to find the meaning for some of them. I also struggled with some of the abbreviations, *e.g.*, CW, CCW, CPL, MCA, BBN, ee, and even SNAAP, and would have found a list of abbreviations helpful. Some archaic units are occasionally used, *e.g.*, ergs for a supernova energy output and Fahrenheit even gets a look in for the core temperature of the Sun!

Figures are of variable quality and in a few cases their lack of clarity makes details hard to distinguish. In one case the direction of arrows is hard to see and in another the colour scheme makes a complete arrow for an electric-dipole moment of an amino-acid molecule invisible. Some coloured plots seem to be included for their attractive appearance rather than as an aid to clearer understanding. There are some good figures which explain the essentials of the SNAAP model both simply and in more detail.

Overall the book is an enjoyable read covering a wide range of scientific disciplines and provides an interesting and, debatably, the best explanation of why left-handed chirality exists in life on Earth. — MICHAEL MCCABE.

Meteoroids: Sources of Meteors on Earth and Beyond, edited by Galina O. Ryabova, David J. Asher & Margaret D. Campbell-Brown (Cambridge University Press), 2019. Pp. 306, 28·5 × 22·5 cm. Price £110 (hardbound; ISBN 978 1 108 42671 8).

Meteoroid is the posh name for a cosmic dust particle, and the Solar System is full of them. They are produced when comets decay and when asteroids smash into each other. They are removed by either slowly spiralling into the Sun, by hitting planets, moons, and (unfortunately) spacecraft, and also by being ejected from the Solar System altogether.

In 2016 there was a conference on meteoroids in Noordwijk, The Netherlands, and IAU Commission F1 decided that meteor science had advanced sufficiently that a new book was required. Twelve review papers were generated by the great and the good in the shooting-star world, and this book is the result.

The first four papers discuss meteors and meteor showers. When a meteoroid hits a planetary atmosphere, it ablates, leaving behind a train of excited light-emitting atoms and a column of electrons. These can easily be seen, and also detected by radar. Spectra can be taken, velocity and deceleration measured, and orbits calculated. Then the fun starts. Desired quantities like meteoroid mass, density, and composition are the ultimate goal — and are difficult to obtain.

Papers 5 and 6 move away from Earth and discuss what happens when meteoroids hit other planets in the Solar System and also solid surfaces like that of our neighbour Moon. Papers 7 and 8 consider the cometary- and asteroidal-decay processes and the production of meteoroid dust streams. Much is made of the Geminids, Quadrantids, and the Taurid complex. Paper 9 investigates the minor showers and the so-called sporadic background. Planetary encounters can scatter orbits, as can inter-particle collisions, and these end up feeding the Sun's Zodiacal dust cloud.

Interstellar meteoroids are discussed in Paper 10. Our Solar System is throwing away meteoroids, and other planetary systems in the Galaxy are expected to do likewise. So here astronomers are searching for meteoroids on their way through our system with heliocentric velocities in excess of the parabolic limit. Unfortunately, the present-day results are still controversial.

Paper 11 overviews the impact damage that meteoroids cause spacecraft and ways in which this can be mitigated. The book ends with Paper 12 where the impact problem is brought closer to home and the impacting meteoroids are bigger. Here we find names like Tunguska, and Chelyabinsk, and we consider the threat that big meteoroids pose to human populations.

To summarize, this book is not only beautifully produced but is also comprehensive, authoritative, accessible, specialized, and up to date. It is an excellent introduction, at an advanced-student level, to a fascinating subject, and one that still holds many mysteries. — DAVID W. HUGHES.

The Atlas of Mars: Mapping Its Geography and Geology, by Kenneth S. Coles, Kenneth L. Tanaka & Philip R. Christensen (Cambridge University Press), 2019. Pp. 289, 36·5 × 28·5 cm. Price £39·99/$49·99 (hardbound; ISBN 978 1 107 03629 1).

This is a splendid coffee-table Mars atlas, beautifully printed and with full use of the large page size. Its intended readers, apart from the obvious specialist, are described by its authors as "scientists from other fields, interested non-scientists and persons who wonder what all the missions to Mars have told us."

In reading the explanatory text I noted with regret how change is often made for the sake of change. So in 2002 it was decided by the USGS to measure Martian longitude in degrees west from zero, instead of degrees east. This undid more than a century of tradition, and has already has led to confusion. The west system is used in this *Atlas*, together with areocentric latitude.

The introductory chapters usefully chronicle past exploration missions and offer whole-planet maps showing albedo, elevation, subsurface ice, crustal thickness, magnetization, dust cover, the occurrence of certain mineral types, *etc.* Geographical and geological survey chapters follow, and both the Hartmann and Neukum geologic time scales are illustrated. Martian meteorites and the issue of life upon Mars are not omitted.

The greater part of the book is a map section (some 180 pages), with an excellent accompanying text throughout. Each regional map is described in detail, and illustrated with images from orbit and from the Martian surface. Phobos and Deimos are not left out either, and receive three pages at the end. Appendices detail the geological units in the on-line map at the CUP *Atlas* website, and give Latin descriptions. There is a detailed glossary and a 26-page Gazetteer giving coordinates and the origins of feature names. The list of references is extensive and very useful. High-quality colour printing has been used throughout.

It is some years since we have had a really up-to-date and affordable Martian atlas on the market. Being a well-informed and comprehensive guide, this is far more than just a collection of maps, lists and pictures, and I warmly commend it to readers. — RICHARD MCKIM.

Cosmic Discovery: The Search, Scope, and Heritage of Astronomy, by Martin Harwit (Cambridge University Press), 2019. Pp. 348, 24·5 × 17·5 cm. Price £34·99/$44·99 (paperback; ISBN 978 1 108 72204 9).

Most astronomers tend to adopt a slightly blinkered approach to their research, pushing ahead with whatever ideas they are attempting to follow through, and pursuing to the furthest ends possible (or even beyond) where those efforts may lead. New instruments are always in high demand, and new techniques are seized upon with some glee if they herald a new era of observation and measurement. It hasn't always been quite thus; there used to be more space for discussion, for teasing out ideas, and for trying out new themes, and computers must bear a lot of blame for squeezing out those beneficial moments and replacing them with 'modelling', often derived through trial-and-error uses of black boxes. What Harwit does is to stand back for a moment, to analyse just who, how, and when breakthroughs were made, the respective parts played by new equipment, new techniques, and serendipity, and the extent to which they can be extrapolated into the future.

In some senses Harwit is right (especially as regards new instrumentation and techniques, a correlation that has long been apparent), but the picture he paints is a little too black-and-white, as if there has to be a name and a date to each new discovery. Rather, those researchers who are bearing down on furthering details with a hope of attaining the larger results constitute hidden workforces that ultimately enable that final breakthrough by someone or some group. The discovery of exoplanets is very much a case in point (though it seems to have escaped Harwit's attention altogether): one person invented a machine, others adopted, refined, and used it, and established a new sub-discipline. In his review of the first edition of this book in 1981, Hoskin has already argued[1] these same points quite forcefully and pointed out inconsistencies in the 'evidence' presented, but I did not see any attempt in this recent edition to modify them. That is a pity, because the novel approach which Harwit brings to this subject could benefit greatly the thinking of students who equate computer modelling with forward-looking progress.

Few have the leisure or the luxury of theorizing, as Harwit does, about the mechanisms and psychology of making discoveries, so it's helpful that Harwit does that for us, even though the application is rather strained. A science cannot proceed as if by rote or design because — like the weather — it evolves in mysterious ways and its progress harbours a strong element of chaos that may be impossible to forecast. That point was not made, nor was any recognition of the fact that much scientific progress, at least in a goodly part, results from the painstaking pursuance of a long-honed theme, and that not all 'discoveries' are in the realms of the fantastic or unforeseen.

It is not obvious that re-issuing a book written in 1981 has been altogether an advantage. Harwit's analyses show that many great leaps forward in astronomy have been made by individuals, although modern astronomy is seeing trends towards international cooperation and team-work. His list of discoveries does not mention gravitational waves, though clearly a massive breakthrough (and made two years before this book was re-issued); many of the announcement papers had tens, even hundreds, of co-authors, thus somewhat defying his argument that to each discovery there can be assigned 'a discoverer'. Even more startling, *HST* and *IRAS* are described only in the future tense, and *TMT* is passed over entirely. There is also contradiction: the requirement for stable, long-term funding to support investigations that need to continue for many years is argued strongly, but the practice of 5- or 10-year reviews later gets trounced for building unwanted stagnation into the system.

Astronomy as a discipline has evolved, and is still evolving. The era of individuals stretching to reach the skies has perforce given way to multinational collaborations; the nature and sources of funding have made sure of that. What could, prior to 1981, be shown to obey a simple ladder punctuated by advances in technology and materials has matured into projects of immense size, complexity, and partnership that any novel technology has become old-hat by the time the thing sees first light (in whatever waveband). Even harder to assimilate is the tendency for grant-funders to insist on results within what can be an unreasonably short space, thereby quelling altogether the chance for those essential long-term investigations that Harwit admits are essential.

The book is well written, though the target readership is not obvious. It mixes units with abandon, juxtaposing fractions, decimals, powers of ten and words like "thousands" in the same sentence. Some of the descriptions could only be phrased for non-astronomers, while discussions of funding sources and policies are advanced diets for administrators and planners. — ELIZABETH GRIFFIN.

Reference

(1) M. Hoskin, *JHA*, **14**, 64, 1983.

About Stars: Their Formation, Evolution, Composition, Locations and Companions, by Michael M. Woolfson (World Scientific), 2019. Pp. 368, 23 × 15·5 cm. Price £35/$38 (paperback; ISBN 978 1 78634 725 1).

Author Michael Woolfson begins by explaining that "about" means both "concerning" and "around", so that he is going to tell his readers both facts about stars and facts about planetary systems surrounding them. He also wishes to begin with "how we know" the properties of each before explaining how and why it all came to be. Reasonable goals both, but a book that includes quasars among "other stars and star-like objects" (with pulsars and Wolf–Rayet stars) and declares firmly that the quasar redshifts are gravitational is unlikely to lead us along the right paths to those goals .

Woolfson's real goal, however, seems to be to present and support his own theory for formation of planetary systems, in which a star and its planets form separately, in very high-density material, and the planets are later captured and interact, while a proto-cluster of proto-stars expands to become a cluster of stars. In this picture, isotopic anomalies in meteorites result from nuclear explosions triggered when planets collide, and the Earth and Venus are among the products of a collision of two previous gas giants (of about 800 and 600 Earth masses to start) called Bellona and Enyo — names not explained.

The list of other "no's" is very long (Doppler shifts for the expanding Universe as usual; 92 naturally-occurring elements on Earth; and so forth). Are there redeeming features? The discussions of barrier penetration for stellar nuclear reactions and of non-relativistic degeneracy for white dwarfs seem to be unexceptional. But the appendix on Eddington accretion (usually called Bondi–Hoyle) has a suggested problem that will leave the student with the impression that the Sun is sweeping up interstellar matter. Counter pressure by the solar wind is not mentioned. Indeed the solar wind is not mentioned, though the corona is, with its temperature unexplained. But the suggestion that appreciable dark matter might be low-luminosity baryonic entities suggests that the author has not been following recent developments very closely. The reference list and the name index have far more entries for Michael Woolfson than for anybody else, and he first put forward his capture theory in 1964 in *Proc. Roy. Soc.* back when your reviewer was writing about Cheops' pyramid. Some of the suggested homework problems require simple calculus, and the text in general is quite uneven about (sorry, concerning!) what a reader needs to know in advance. No standard volume on stellar structure and evolution is referenced, not even old ones, though a number of early Nobel lectures are. — VIRGINIA TRIMBLE.

An Anthology of Visual Double Stars, by Bob Argyle, Mike Swan & Andrew James (Cambridge University Press), 2019. Pp. 472, 27·5 × 22 cm. Price £34·99/$44·99 (paperback; ISBN 978 1 316 62925 3).

The authors' decades of experience in observing visual double stars and compiling catalogues has led to this wonderful selection of 175 visual binaries from both hemispheres that is a pleasure to thumb through and enjoy. For each system there is a table of astronomical data and catalogue designations, a finder chart, an ephemeris of future relative positions if an orbit is available, and selected early and recent measures. Concise summaries of their discovery circumstances and earliest observations supplemented with what we know about their astrophysical natures from 'the modern era' make for interesting reading, especially when there are problematic circumstances regarding the realities of reported companions. While this is an anthology of visual binaries, the relevant complementary results from techniques like spectroscopy and interferometry as they pertain to multiplicity degree are not overlooked.

But that's not all. The first 50 or so pages of this large-format book contain a very useful introduction, a description of instruments and techniques for measuring the relative positions of the components of visual binaries, and a succinct history of those techniques, ranging from the earliest use of a micrometer to the most modern ground-based interferometers and space-based survey satellites. Additionally, there is a list of organized groups around the world that foster double-star observations followed by an extensive compilation of resources — catalogues, software, and atlases — invaluable to the observer. A particularly appreciated and humanizing aspect of this book is a collection of biographies of classical as well as modern observers — both professionals and amateurs — who have contributed and still are contributing to this venerable subfield of astronomy. The appearance of many young faces in this group is heartening.

Of course, the first thing you will do when you get your hands on this self-contained and irresistible anthology is to jump in to find your favourite systems. In this reviewer's case, Capella (aptly considered by some as "God's gift to interferometrists" due to its brightness and the small Δm of its close components), W. S. Finsen's remarkable quadruple 'Tweedledum and Tweedledee', aka FIN 332, that for a time looked like a precision dance team, the possibly-quintuple and incredibly well-observed system ξ UMa, and the colourful triple (at least) system comprising Albireo (featured on the book's cover) were sought out without disappointment. This is a book that *aficionados* of double stars will return to again and again. — HAROLD A. MCALISTER.

Annual Review of Astronomy and Astrophysics, Volume 57, 2019, edited by S. M. Faber, E. van Dishoeck & Robert C. Kennicutt (Annual Reviews), 2019. Pp. 674, 24 × 19·5 cm. Price from $496 (print and on-line for institutions; about £385), $116 (print and on-line for individuals; about £90) (hardbound; ISBN 978 0 8243 0957 2).

Here we are in the 21st Century and women are still struggling to gain equality with men, even in science, including astronomy, where one might hope for a rational approach to such matters. In the last century it was far worse, and yet some women did manage to climb the greasy pole to positions of great responsibility. One such was Nancy Grace Roman, whose story illuminates the opening pages of the latest volume of the *Annual Review*. After a chequered career in astronomy, she eventually achieved a key role in NASA as Head of Observational Astronomy in 1959, at the start of a golden age culminating in the *Hubble Space Telescope*. (And if you want to see an equally inspiring story about that organization, visit your cinema to watch *Hidden Figures* and see the struggle of African-American women to gain recognition of their skills.)

And so on to the hard science. The Sun is addressed in two chapters, both concerned with those enigmatic outer layers, the chromosphere (Carlsson *et al.*), and the corona and solar wind (Cranmer & Winebarger) where the heating process is still a mystery.

Cosmic chemistry is a popular theme this year, where near at hand the icy bodies of the Solar System are examined with data from the *Rosetta* mission (Altwegg *et al.*), and then stars are subjected to 'industrial' methods (Jofré *et al.*) to produce abundances for huge numbers of objects (a far cry from my own endeavours of 50 years ago using glass plates, miles of paper, thousands of hand-measured equivalent widths, and curves of growth!).

The structure and evolution of stars is treated in papers on asteroseismological deductions (from *Kepler* data) concerning internal angular-momentum transport (Aerts *et al.*), and, for really massive stars with $M > 40\ M_{\odot}$, the final fling as super-luminous supernovae (Gal-Yam), which might prove useful as standard candles on the grand scale. Could such objects be the progenitors of objects emitting fast radio bursts? Read about them too (Cordes & Chatterjee). A wide-ranging study of star clusters and their evolution (Krumholz *et al.*) is, in a sense, also an 'industrial' process.

Then on to the bigger stage, first looking at the faintest dwarf galaxies (Simon) whose development seems to be hugely dependent on dark matter. Tracing the evolution of normal galaxies can be achieved through clever use of emission-line diagnostics (Kewley *et al.*) and, I imagine, valuable spectroscopic work at mm and sub-mm wavelengths in the laboratory (Widicus Weaver). If your galaxy is really active, then you'll want to think about its relativistic jets (Blandford *et al.*).

If you are concerned that global warming will do for us all in the not-too-distant future, you might think of decamping to another world, but you should first check out its atmosphere (Madhusudhan).

And finally, on the biggest scale of all, see what cosmological observations can tell us about the origin of gravity (Ferreira). Surely there's something here for everyone. — David Stickland.

Non-Inertial Frames and Dirac Observables in Relativity, by Luca Lusanna (Cambridge University Press), 2019. Pp. 322, 25 × 18 cm. Price £120 (hardbound; ISBN 978 1 108 48082 6).

Non-inertial frames are not often discussed in the context of Special Relativity, with many standard theories being defined in inertial frames. There are some circumstances where non-inertial frames are needed, such as the Sagnac effect, and there are issues of even how to define the geometry of a rotating disc. Inevitably, given that observers typically inhabit non-inertial frames, special relativistic inertial frames are something of a theoretical concept, and in practical applications, in the Solar System for example, the definition of suitable quasi-inertial frames has some subtleties. This book explores these issues from a special and general relativistic perspective, and discusses a solution to the problem of definition of the relativistic centre of mass with an associated consistent relativistic quantum mechanics of particles. In the General Relativity section, the book also covers Dirac observables and the challenges that remain in this context, and there is discussion on a cosmological scale of some open questions thrown up by the approach taken in the book. The book is very much a technical monograph, with very detailed mathematical descriptions that will need careful study to make best use of it. It is not always an easy read, but rather a formidable *tour-de-force* that will primarily be for experts in the field. — ALAN HEAVENS.

Dark Matter & Dark Energy: The Hidden 95% of the Universe, by Brian Clegg (Icon Books), 2019. Pp. 174, 19·5 × 13 cm. Price: $12·49 (about £10) (paperback, ISBN 978 178578 550 4).

As noted in a recent review[1] in these pages, Clegg is one of the few people (perhaps the only person) who has written for *Nature, The Times, Good Housekeeping*, and *Playboy*; having enjoyed the book[2] I reviewed then, I wanted to see whether he could provide a good introduction to the two topics in the title, so I bought this book, despite my qualms about supporting the term 'dark energy'*. Two introductory chapters describe the main topics (missing matter and the accelerated expansion of the Universe), and give a very brief introduction to the contents of the Universe and how our ideas of the structure of the cosmos have changed with time; subsequent chapters look at dark matter in more detail, the Big Bang model (starting with distance determination then discussing the expansion of the Universe and, very briefly, inflation and structure formation), accelerated expansion, and ideas about the future of research on those topics.

The chapter on dark matter is much longer than the others and looks at both evidence (flat rotation curves of galaxies, bound clusters with a velocity dispersion too high to be bound by the more-or-less directly inferred matter, the power spectrum of CMB anisotropies) and candidates (MACHOs, WIMPs) for dark matter as well as the lack of detection of the latter in laboratory experiments. A discussion of the expansion of the Universe is a necessary prelude to discussing accelerated expansion; the former chapter essentially explains Hubble's work before giving a capsule summary of the standard Big Bang model while the latter concentrates on the magnitude–redshift relation for type Ia supernovae, the work awarded the 2011 Nobel Prize in physics. The final chapter is more speculative, discussing some non-standard ideas in connection with both topics and also the question of funding expensive experiments which, many expect, will never find anything.

As in the case of another review in this issue[5], I would like to give the book a better recommendation, since it is generally well written and manages to give a good overview of two rather broad topics. However, numerous small mistakes, though not crucial for the main narrative, prevent me from doing so; here are the correct versions: it is generally the high velocity dispersion, not the speed of rotation, of galaxy clusters which indicates dark matter; primordial black holes are not ruled out[6] as dark-matter candidates; most helium was produced in the Big Bang; it is not clear that Bell Burnell and Rubin did not receive a Nobel Prize "because of their gender"; if the spin of a particle is not ½, then more (or fewer) states than 'up' and 'down' are possible; while the term 'spin' might be somewhat misleading, it is not just a label such as the 'colour' of quarks, as it is connected to angular momentum; annihilation of matter and antimatter is

*As noted here before[3], Sean Carroll has pointed out[4] that many things are dark and everything has energy; unfortunately, his much better term 'smooth tension' has not caught on.

not the most common way for matter to become energy; a theory of modified gravity involving tensor, vector, and scalar fields is commonly known as TeVeS, not STVG, and has now been ruled out*; while Slipher had measured redshifts in 1912, Humason did so only later; even the ancients knew that there were more than "a hundred or so stars"; the RGO is no longer at Herstmonceux (and what is left of it is now known as the ROG and is at Greenwich).

On the other hand, Clegg includes some things usually missed in books at this level (or higher): 'dark matter' would better be called 'transparent matter' since, while it does not give off light (one meaning of 'dark'), neither does it absorb it (another meaning); some dark-matter proponents before Zwicky are mentioned; MOND gets a rather extensive treatment; and other new ideas such as emergent gravity and superfluid dark matter are mentioned. (While MOND certainly should be mentioned when evidence for dark matter is discussed, Clegg does take the balanced treatment too far by mentioning the ideas that dark matter was somehow responsible for the extinction of dinosaurs (not a crank concept, but too speculative and more an answer in search of a problem), that evidence for dark matter is essentially a numerical misunderstanding since explicit *N*-body calculations would lead to other results than a continuum approximation (same remarks), and that negative mass could explain effects attributed to dark matter and dark energy.) A few other things are either confusingly worded or evidence that Clegg is confused about the concept, but discussing those would go beyond the bounds of this review.

There are a few black-and-white photographs and diagrams, two pages of suggestions for further reading, mostly of books at about the same level, including some by Clegg, and a good ten-page index. I like the fact that the few notes are footnotes rather than endnotes, but the editing, as in many recent books I've read, could have been better. The book is part of the Hot Science series, of which Clegg is the series editor, which covers various currently hot topics such as gravitational waves, big data, graphene, astrobiology, and artificial intelligence. Of the other books in the series, I've read only one[2]. There is certainly a need for new developments in science to be presented at this level with sufficient background and without the hype often found (not only) in popular accounts, but this book, and perhaps others in the series, could benefit from a bit of fact checking and editing. — PHILLIP HELBIG.

Reference

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(2) B. Clegg, *Gravitational Waves: How Einstein's Spacetime Ripples Reveal the Secrets of the Universe* (Icon Books, London), 2018.
(3) P. Helbig, *The Observatory*, **136**, 204, 2016.
(4) S. M. Carroll in S. C. Wolff & T. R. Lauer (eds.), *Observing Dark Energy* (ASP Conference Series, Vol. 339), 2005, p. 4.
(5) P. Helbig, *The Observatory*, **140**, 64, 2020.
(6) B. Carr, F. Kühnel & M. Sandstad, *Phys. Rev. D*, **94**, 083504, 2016.

A Student's Guide to General Relativity, by Norman Gray (Cambridge University Press), 2019. Pp. 151, 23 × 15 cm. Price £17·99/$24·99 (paperback; ISBN 978 1 316 63479 0).

General Relativity (GR) is the pinnacle of an undergraduate physics degree for many students. A subject shrouded in mystery, it seldom appears in the early

*Interestingly, it is mentioned in connection with the Train Wreck Cluster, recalling the German StVG, *Straßenverkehrsgesetz*, *i.e.*, street-traffic law.

years of study. While quantum mechanics usually makes an early appearance in physics courses, GR has a reputation for mathematical and conceptual difficulty which is seen as challenging. That view has not been helped over the years with a number of impressive tomes on the subject of such size and density they seem to distort space–time themselves. But the subject has moved significantly over the last few decades from a specialist niche area, interesting but limited in applications, to becoming much more mainstream. The detection of gravitational waves in particular has sparked a much wider interest in the subject, with many applications opening up in gravitational-wave astronomy, and the physics of merging neutron stars and black holes. Given this, it seems timely for a new generation of books on General Relativity aimed at an introductory level which tries to strip the subject of its complexity.

Norman Gray's *A Student's Guide to General Relativity* is clearly aimed at addressing this, and is part of a series of *Student's Guides* published by Cambridge University Press. The scope of the book, which is a slim 151 pages, is to explain and derive the fundamental equations of GR, the Geodesic Equation and the Einstein Equations, and is based on the first half of a course taught at Glasgow for many years. After a short introduction, the bulk of the book presents a mathematical framework which favours a more abstract coordinate-free representation, drawing on Bernard Schutz's *A First Course in General Relativity*, rather than the more traditional coordinate-transformation approach. There is a lot of very useful discussion of key concepts, including supplementary material which goes beyond the main scope of the book, and exercises at the end of each chapter provide a good opportunity to try things out and dig deeper. The text is illustrated with many figures which clarify the explanations. Perhaps due to the brevity of the book there are a few places where detailed derivations are replaced by references to other textbooks, such as the relationship between the Christoffel symbols and the metric. I also found it surprising that the discussion of Special Relativity and applications of the Einstein Equations were put in two Appendices at the end of the book, when they could have appeared in the main text.

In summary, this book marks a welcome move to shorter, more focussed introductions to General Relativity aimed at undergraduate students. As the mathematical half of a full GR course it works well, but perhaps a less abstract approach and greater emphasis on the geometrical nature of the theory might appeal more to some readers. — ANDREW TAYLOR.

Scalar Field Cosmology, by Sergei Chervon, Igor Fomin, Valerian Yurov & Artyom Yurov (World Scientific), 2019. Pp. 263, 23·5 × 15·5 cm. Price £85 (hardbound; ISBN 978 981 120 507 1).

This is a fascinating small volume that explores scalar fields in cosmology from an interesting perspective. It focusses on exact solutions to cosmological models and perturbations. I found that a surprisingly rich plethora of exact solutions exists in this field. A number of techniques for solutions are presented, including superpotentials, generating functions, *etc.* These solutions are compared with the more-common approximate methods based on, for example, the slow-roll condition.

In addition to this, other topics are covered, some slightly random but nevertheless interesting, such as multiverse models, phantom energy, and braneworlds, where the theme of exact solutions is once again taken up. A key step is the Abel equation, which features in a number of situations, including in a reformatting of the Friedmann equation. Exact solutions of this nonlinear first-order ordinary differential equation are then obtained for a number of scenarios.

The book is interesting and full of curiosities, and contains exact cosmological solutions that will be unfamiliar to many. It will be of interest to researchers in the field, and also perhaps to project supervisors wanting some interesting and unusual problems that lay a little outside what is generally taught in cosmology classes. — ALAN HEAVENS.

Gravity's Century: From Einstein's Eclipse to Images of Black Holes, by Ron Cowen (Harvard University Press), 2019. Pp. 191, 21·5 × 14 cm. Price \$26·95 (about £22) (hardbound, ISBN 978 0 674 97496 8).

The 100th anniversaries of Einstein's general theory of relativity and the eclipse observations which catapulted him to superstardom have spawned several recent books, some focussing on those formative years, some using them as a jumping-off point for a history of GR and its applications during the last century or so. This book is in the latter category, the two observational projects in the subtitle framing the period of interest. The author is a popular-science writer who has won many awards for his books with an emphasis on astronomy and physics and their history. The book covers the origin of GR, early tests of the theory, cosmology, black holes in general, quantum gravity, gravitational waves, and the recent imaging of black holes. Of course, in a book of this length, the chapters are only introductions to the corresponding topics. Most of the eight chapters have one or two "deeper dive" sections of a few pages which explore various topics in somewhat more detail.

The book is well written in the sense that it is easy and enjoyable to read as far as the style goes, but unfortunately not only contains an average number of stylistic mistakes (*i.e.*, too many) but also has several factual errors. In some cases, those are relatively benign; others are explanations which are not *quite* correct. Often, they are technically correct, but misleading; some leave out an essential aspect; some are confusingly worded. Someone who knows the topic can guess what is meant, but of course explanations should be clear and correct for those without such knowledge, presumably the target readership. Having said that, there are fewer goofs in the second half of the book, which deals with more-modern topics. Also, the "deeper dive" sections there provide introductions to topics not often found in books at this level, such as the black-hole information paradox, the history of ideas about gravitational waves, and early attempts at realistic illustrations of black holes.

A little more than a dozen black-and-white photographs (many familiar to me from elsewhere) and diagrams are scattered throughout the text. There are no footnotes or endnotes as such, but sources for direct quotations are listed by page and part of the quotation after the main text. The further-reading list (comprising books, articles, and web pages), at four-and-one-half pages of small print, is relatively thorough for a book such as this; most of the suggestions are more technical. The seven-and-one-half page small-print index is more than sufficient.

There are many illustrious people mentioned in the acknowledgements. I'm sure that they all provided something of value, but the book could have benefitted more from suggestions from one person with a reasonable knowledge of the field. As mentioned above, in general it is well written; it also strikes the right balance in compressing a century of the history of GR into a small book and is written at an appropriate level. I would thus like to recommend it more highly, but too many confusing, incomplete, misleading, or even wrong statements prevent me from doing so. — PHILLIP HELBIG.

Simulating Large-Scale Structure for Models of Cosmic Acceleration, by Baojiu Li (Institute of Physics Publishing), 2018. Pp. 198, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1585 2).

The last two decades have turned cosmology into a precise science and a laboratory for testing fundamental physics. In the coming decade, new surveys, of which many have understanding the origin of cosmic acceleration as one of their key scientific objectives, will further improve the quantity and quality of these data. The nature of the accelerated expansion of our cosmos remains poorly understood, prompting alternative explanations. To test effectively these non-standard cosmological models, the accuracy in the predictions must be on a par with the level of precision of the data. A comprehensive introduction to the elaborate numerical techniques that are indispensable to this endeavour has so far been lacking. Baojiu Li's book, published in the AAS–IOP Astronomy e-book programme, fills this gap. The author is a professor at the Institute of Computational Cosmology, Durham University, a leader and pioneer in numerical simulations of the formation of large-scale structure in non-standard theories of gravity.

The book provides only a very brief introduction to standard cosmology with a greater emphasis on alternative cosmic-acceleration models based on the presence of a scalar field with non-trivial interactions. It discusses in detail the complex non-linear screening mechanisms that render simulations an essential tool for the accurate study of the cosmological structure formed in these models. It does not give an exhaustive summary of the plethora of cosmic-acceleration models proposed, and readers interested in that are referred to a number of review articles. The book rather provides a compact overview and focusses on the subclasses in the framework of Horndeski theory for which numerical simulation techniques have been developed and applied. Various observational probes for alternative cosmic structure, the limitations of linear theory, and the role of simulations are discussed, giving concrete examples from Galileon gravity. The core of the book, and the part truly unique to current literature, is devoted to an introduction of the sophisticated simulation techniques in non-standard models. Elaborating on the multigrid relaxation algorithm for cosmological *N*-body simulations to solve numerically elliptical-type partial differential equations common to non-standard cosmic-acceleration models, it then devotes a detailed discussion on how the method is made numerically efficient and stable. The book then describes how to take advantage of adaptive mesh refinement in the relaxation method to render the simulations more efficient and its application to resolving screening mechanisms. A special treat is given in Chapter 5, where the author describes the application of these techniques to other problems such as in optimal transportation or in the reconstruction of the initial cosmological density field.

I highly recommend this book to anyone entering the field of numerical simulations of non-standard cosmologies, who will find here an apt introduction to the topic. The book, however, only provides a brief introduction to cosmology, and so prior knowledge of General Relativity and cosmology is advised. For the reader unfamiliar with cosmology but interested in the numerical techniques, the author has invested much effort to keep the discussion of that self-contained. Each chapter can also be used as stand-alone introduction, coming with a list of important references on the topic. The book does not provide an index for its use as reference work, but the clear presentation and organization of the chapters makes it easy to navigate, and the appendix gives a summary of frequently-used mathematical relations and manipulations for look-up. Finally, the reading material is nicely illustrated by many well-prepared colour figures, which makes for a joyful read. — LUCAS LOMBRISER.

Modeling and Analysis of Eclipsing Binary Stars: the Theory and Design Principles of PHOEBE, by Andrej Prša (Institute of Physics Publishing), 2018. Pp. 220, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1288 2).

Traditionally, double-lined eclipsing binary stars were the principal source of precise measurements of stellar radii and masses, and to a large degree that continues to be true to this day. Clever astronomers devised ingenious tools for modelling eclipses 'by hand' in the era before digital computers, but for the last half-century direct numerical integration of tidally-distorted, limb-darkened, mutually-irradiated systems has been the norm, more often than not using the pioneering 'Wilson–Devinney' code.

Around a decade ago, this venerable piece of software was given a facelift in the form of a fresh user interface, PHOEBE ('PHysics Of Eclipsing BinariEs'); and that project has subsequently evolved into a new code, of the same name, under continuing development (by Prša among others) but already in good shape for most standard cases.

However, don't let the (sub-)title of this book mislead you into thinking it's a user guide for a specific piece of software — it's much more than that. It is a comprehensive overview of the astronomy and astrophysics of eclipsing binary systems, covering the full range of observational inputs (not just spectroscopy and photometry, but also polarimetry, astrometry, and interferometry, all of which are of growing importance); the theoretical background (building up from the basic Roche model); and practical modelling considerations, including a thorough and pragmatic discussion of parameter-optimization methods.

The writing style is a pleasing combination of technical precision and easy readability; the book has all the authority of an author steeped in the details but conscious of the needs of a broader readership. Good use is made of colour in many figures (even if it seems gratuitous in some, and lacking in others), and overall production standards are high (although the illustrations of detached-to-contact systems in §3.2.4 have a very odd aspect ratio). Fifteen figures are separately available in animated (mp4) format as downloads from the associated IoP web site.

Although I was glad to have a hardback copy to browse, this volume, in common with others in the 'AAS–IoP Astronomy' series that I've seen, has all the hallmarks of being designed primarily as an e-book. The major disadvantage is that it's evidently not considered worthwhile going to the trouble of constructing an index for text that can be searched directly in electronic formats (and I was easily able to access a pdf through institutional-library arrangements). Notwithstanding that quibble, this book can be warmly recommended to anyone with a passing (or greater) interest in eclipsing binary stars. It will sit alongside Hilditch's *Introduction to Close Binary Stars* on the small section of my bookshelf that I can reach easily from a sitting position. — IAN D. HOWARTH.

Astrophysical Recipes: The Art of AMUSE, by Simon Portegies Zwart & Steve McMillan (Institute of Physics Publishing), 2018. Pp. 411, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1321 6).

This attractive and useful book is an introduction to the AMUSE software which provides a framework for linking together existing simulation codes in the astrophysical domains of gravitational dynamics, stellar evolution, hydrodynamics, and radiative transfer. For example, one might use AMUSE to model the evolution of a stellar cluster, simultaneously using both a stellar evolution code (*e.g.*, SSE) to model each star and an *n*-body code (*e.g.*, ph4) to model the gravitational interactions. AMUSE handles many of the practical difficulties arising in such a linkage: the differing spatial and temporal scales, the required communication between the two codes (how should the stellar-evolution code react to a collision; how should the *n*-body code react to a supernova?); and the (tedious but critical) need to convert between the different measurement units used by the two codes. The framework includes a 'bridge' algorithm to allow a symplectic (*i.e.*, generalized leapfrog) linkage between two codes.

The book is well written and pleasant to read (even amusing!). Initial chapters provide, for each of the four astrophysical domains handled, a concise overview of the physics, a description of the existing simulation codes available in AMUSE (*e.g.*, 18 different *n*-body codes), many examples (with source code) of calling these codes *via* AMUSE, a set of homework problems, a discussion of how to validate simulation output, and copious references. This pattern is then repeated in further chapters that describe how codes from two different domains may be linked. The many full-colour plots showing output-simulation results add to the attractiveness of the book.

Astronomical software is not always well documented and the authors are to be commended for investing the time required to create this book. The type of documentation given here (what the code is good for, how to do the simplest thing, an example of how to do something complicated, where to get more information, where the pitfalls are) is the type of documentation that the user really needs. My only quibble is that I missed having an index. And my only warning to the reader is that information about AMUSE is now available in three places (this book, on-line, and in files accompanying the installed software) and the book will diverge from the others over time. A website page 'here's where the book is now out of date' would therefore be helpful.

The authors suggest that the AMUSE framework might be applied in other disciplines; having useful documentation like this in support of their software will be a boost towards achieving that goal. — LORNE WHITEWAY.

Magnetohydrodynamics in Binary Stars, 2nd Edition, by C. G. Campbell (Springer), 2018. Pp. 474, 24 × 16 cm. Price £109·99/$159·99 (hardbound; ISBN 978 3 319 97645 7).

Magnetic fields and their effects on their environments are important in many astronomical objects, but close binaries are one of the few where they are also accessible to observations. Consequently, these systems make excellent testbeds for our understanding of magnetic fields and the ways in which they influence mass accretion and angular-momentum transport. This book addresses the role of magnetic fields in close-binary systems, and although it is aimed at the specialist reader, it has relevance to wider areas of astronomy than those addressed within it. The focus is strongly on theoretical treatments, and in particular analytic or semi-analytic approaches. While this might seem dated in this era of high-resolution numerical simulations, such models are still useful in providing both insights and test of numerical schemes in regimes where a computational approach is not possible.

Two classes of such binary systems are discussed in detail: the AM Herculis systems, where the primary star has a strong field that prevents the formation of an accretion disc, and those binaries (such as intermediate polars, X-ray binary pulsars, and millisecond pulsars) where the primary star's magnetic field is weaker and so partial accretion discs can form. Much of the theoretical development of channelled accretion flows, the application and evolution of torques, and spin evolution is explored within these two limiting classes. The remaining chapters cover briefly topics that are detailed more extensively elsewhere (winds and dynamos in stars and accretion discs) but viewed from the perspective of their relevance to binary-system physics. While these chapters may not be for the fainthearted, this book has as a great strength a couple of excellent introductory sections that treat the essential background physics in a way that is both clear and admirably concise. Not only the basics of magnetohydrodynamics (including wave modes), but also tides, viscous accretion discs, and spin dynamics are outlined in the introduction. Chapter 13 also covers magnetized winds, using an approach guided by the accumulated works of Leon Mestel. These background sections are extremely useful and bring the more specialized chapters that form the core of this book within the reach of a graduate student or young scientist.

Although close-binary systems have the advantage of being numerous and relatively easily observed, this book does not attempt to provide a comprehensive review of the current state of the observations in this field, or of its relevance to magnetic fields in single stars (with or without accretion discs). It is, nonetheless, a book that rewards patient and detailed reading, and which provides an excellent theoretical background to the role of magnetic fields in close-binary systems. — MOIRA JARDINE.

Digital SLR Astrophotography, 2nd Edition, by Michael A. Covington, (Cambridge University Press), 2018. Pp. 348, 24·5 × 19 cm. Price £27·99/$39·95 (paperback; ISBN 978 1 316 63993 1).

I was pleased to receive this book for review because, as the owner (for many years) of a high-end digital camera, I felt that I was not doing enough serious astronomical photography, particularly in the field of variable-star research, which has always been my main interest. As such, I was interested in the sections in Chapter 18 that deal with that work, the requirements for which differ considerably from those needed for imaging most other astronomical objects.

Overall, the coverage is impressive, with an initial discussion of basic concepts. Covington admits that he covers Canon and Nikon cameras in some detail, both because these manufacturers have paid special attention to the needs of astrophotographers, and also because he has most experience with these types. After the introductory section, there is a suggestion of five simple projects, including the always-popular nightscapes. This is followed by a detailed discussion of equipment and techniques, and then a comprehensive section on the all-important matter of image processing. The final main section is devoted to advanced topics, including sensor properties, spectral response, and even filter modification.

Covington does not discuss mirrorless bodies in detail, partly because they are the newest development in camera types. He does mention that the mirrorless Sony α7S (also known as the A7S), has earned praise, but condemnation as a 'star eater'. (A camera that tends to reject small, bright pixels as being 'noise', and thus tends to eliminate many faint stars.) However, on the latter point the review by Alan Dyer in *Sky & Telescope* (2019 April, pp. 60–65) discounts that criticism. (I strongly recommend that review and another, also by Alan Dyer (*S&T*, 2019 August, pp. 68–72) of the Nikon Z6, for their discussion of mirrorless bodies.) Pending a full review, Alan Dyer has posted a blog item (https://www.skyandtelescope.com/astronomy-equipment/first-look-canons-eos-ra-mirrorless-camera/) on the new, mirrorless Canon EOS Ra body, specifically designed for astronomical work. Canon EOS cameras are a little unusual in that they allow filters to be fitted into the body between the lens and the sensor. However, certain lenses may not be used with this option. Such Astronomik filters are discussed on pp. 316–317.

Oddly, the popular stacking programs REGISTAX and AUTOSTACKERT are not included in the initial listing of programs, although they are mentioned at times when the discussion is of specific images. Covington does not cover the removal of aircraft and satellite trails. The latter, in particular, has become a prominent issue since the launch by SpaceX of the first two batches of satellites in their major *Starlink* constellation, projected to include a total of nearly 12 000 satellites. Given that other organizations have announced similar constellations, this is likely to become a major problem for all astrophographers. This, of course, is one of the problems that may be tackled by most stacking programs. (Again, there is a useful *Sky & Telescope* blog post by Richard Wright, on 2019 June 10, on this issue.) — STORM DUNLOP.

Nightwatch: A Practical Guide to Viewing the Universe, by Terence Dickinson (Firefly), Pp. 192, 27 × 26·5 cm. Price £19·95 (hardbound (spiralbound); ISBN 978 1 55407 147 0).

This is an observational companion for those who are starting an interest or wish to advance their (maybe basic) understanding of astronomy. In its 15th printing, and first published in 1983, author Terence Dickinson has attempted to update this book to appeal to and help 'newbies' to take their first practical steps to become, hopefully, knowledgeable observational amateurs. The popularity of this book is impressive with estimated total sales three-quarters of a million sold over the years. The guide can be used in both northern and southern hemispheres (although the southern sky charts are at the back of the book, which will not be immediately obvious to a southern beginner), which is to be applauded and shows a commitment to global observers.

To begin with I shared this book with my family (my wife and two teenage girls) and they were impressed. This is a severe test as they have limited knowledge of the night sky and get bored of dad constantly getting them to explore the night sky! Comments included "this would be great for science at school", "are there two skies?" (alluding to the northern and southern hemispheres!), and "wow, space is really big!" were typical. The guide seemed to impart the warm enthusiasm of the author to my family in a far better way than I could, so I can thoroughly recommend this as an introduction to 'the family', at least if your family is anything like mine.

So to me this publication has several possible uses: (*i*) as a guide for planning a night's observations; (*ii*) as a night-time companion whilst observing — as long as you have a small red light to read by (to keep your night-vision); (*iii*) a coffee-table book that may prod the imagination and enthuse someone to go outside and 'look up'; and (*iv*) a basic reference work that can be used for quick guidance and verification. However, the latter is aimed at beginners and intermediate amateurs and is not an academic reference work for more advanced observers; if that is what you need then perhaps you need look for another book.

Each chapter stands out as being useful for a beginner. Chapter 2, 'The Universe in Eleven Steps', is a great way to put the scale of the Universe into context — although its true scale is beyond the ken of human experience it allows a beginner to begin to experience just how insignificant we all are. Chapter 3, 'Backyard Astronomy', is a useful way of finding your way around the sky with makeshift tools (including using your hands to measure the sky above your head), and even how to pronounce astronomical names and not risk derision from more seasoned observers! Chapter 4, 'Skies for All Seasons', has good charts (note that the southern skies are at the back) and instructions on how to use them. Chapter 5, 'Stargazing Equipment', is an excellent guide to selecting and buying binoculars and telescopes. Reading this is like having an old astronomer sitting down beside you with an astronomical equipment catalogue and hearing years of experience of old and new purchases — probably the best guide I have seen in such a book. Chapter 6, 'Probing the Depths', has excellent constellation charts with key astronomical objects of great interest. Chapter 7, 'The Planets', has useful guides on planetary location and tips on observation. The planetary guides are useable until 2025 although for some reason for a 2016 publication they start from 2013; it is a shame they didn't start from 2016/17 and conclude at 2028 to extend the practical use of this chapter.

Chapters 8 and 9, 'Moon and Sun' and 'Solar and Lunar Eclipses', respectively, are very good on lunar and solar observation, and especially on the safety aspects of solar observing! Chapter 10, 'Comets, Meteors and Auroras', is useful, if somewhat lacking in detail for observing or imaging, although some of that is covered in Chapter 11, 'Photographing the Night Sky'. This chapter is no more than an introductory one to the subject and one would probably need to research much further if one were to invest in equipment and start practising astrophotography. Chapter 12 is devoted to the southern hemisphere, which is to be applauded as it is right that southern-hemisphere observers should not be left out, and anyway some may be inspired enough to take this guide away with them on holiday to southern climes. Good charts allow those unfamiliar with the southern skies to get their bearings quickly and 'bag' great opportunities lacking in the north. Chapter 13, 'Resources' is a very useful collection of tips for the beginner to take their interests further, something a lot of guides seem to leave out or ignore.

In conclusion, the book title says it all, and it really does what it says 'on the side of the tin'! This is a very worthwhile and practical guide for those who wish to start looking up into the night sky or thinking of beginning amateur astronomy. It is also a very nice coffee-table book that may spark someone's interest and even get them out into the garden at night. It is simple to read and would make a great gift for adult or child. However, perhaps it would not be suitable for an intermediate or advanced amateur astronomer other than perhaps to flick through on that hypothetical coffee table — but it is a very nice, attractive, fit-for-use guide all the same.

If I were asked how it could be improved, I would say that parts need to be updated to give it a ten-year life-span, although this may face possible resistance by the publisher/author, as they may want a further updated reprint sooner rather than later (a cynical viewpoint, I know!). Also, as it is seemingly aimed at the beginner, I would also include a small red light to enable someone to take it outside and use it effectively. Some might say that is a bit 'gimmicky', but it's normally not something someone starting out would think of to protect night vision and really get to enjoy observational astronomy.

I would recommend this guide for someone starting out in astronomy. It would also make a great gift for young or old. Or it could be just worth buying for that very nice new coffee table. — GARY HUNT.

OTHER BOOKS RECEIVED

Physics of Magnetic Stars (ASP Conference Series, Vol. 518), edited by I. I. Romanyuk, I. A. Yakunin & D. O. Kudryavtsev (Astronomical Society of the Pacific), 2019. Pp. 270, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 923 4).

This conference, held at the Russian Special Astrophysical Observatory in 2018 October, ranged far and wide across magnetism in stars, not just those of the Ap classification, and brought new observations and theoretical studies to bear on the causes and outcomes of magnetic influence across the whole H–R diagram.

THESIS ABSTRACTS

A STUDY ON QUENCHING AND GALAXY GROWTH IN $z\sim1$ CLUSTERS USING *HST WFC3* GRISM OBSERVATIONS

By Jasleen K. Matharu

The work in this thesis uses 38 orbits' worth of *Hubble Space Telescope* (*HST*), *Wide Field Camera 3* (*WFC3*) infrared F140W imaging and G141 grism data on ten galaxy clusters at $z\sim1$ to study how the quenching of star formation in galaxies and galaxy-size growth operates in different environments at this redshift. The unique capabilities of space-based slitless spectroscopy with the G141 grism allows for the construction of spatially resolved Hα maps, providing the possibility to observe directly environmental quenching at $z \sim 1$ for the first time. This allows us to understand the detailed physics behind environmental quenching mechanisms and how they operate on galaxies at this high redshift.

The quenching of star formation leads to the build-up of quenched (or 'quiescent') galaxies in the Universe. Observations have also shown that quiescent galaxies grow disproportionately more in size than stellar mass from high to low redshifts. Many studies have argued that minor mergers are responsible for this size growth. To test this hypothesis, it is possible to use the cluster environment as a laboratory. Cluster galaxies have high peculiar velocities, making mergers between them rare. Since minor mergers are expected to increase galaxy size more than they do stellar mass, the most direct way to test this is to measure the stellar mass–size relations in both the cluster and field environments at fixed redshift and compare them to see if there is a significant offset in size. If the predictions of minor mergers driving galaxy-size growth are true, cluster galaxies should find themselves inhibited from size growth and will therefore be significantly smaller than field galaxies at fixed stellar mass. In Chapter 2 of this thesis, we do this experiment at $z \sim 1$, finding that quiescent cluster galaxies are smaller than quiescent field galaxies at fixed stellar mass. This supports the case for minor mergers driving size growth in quiescent field galaxies.

Nevertheless, the process whereby large star-forming galaxies quench and join the quiescent population at the large-size end has also been suggested as an explanation for the size growth of quiescent galaxies. Using ancillary spectroscopy of our ten clusters from the *Gemini* Cluster Astrophysics Spectroscopic Survey (GCLASS), we pick out 23 spectroscopically confirmed recently quenched galaxies in the clusters and study their position on the stellar mass–size relation in Chapter 3. We find that they follow a mass–size relation lying midway between the star-forming and quiescent relations. This result provides direct evidence showing that galaxies which quench later are on average larger than the bulk of the quiescent galaxy population at fixed stellar mass and redshift. This work showed that at least in the cluster environment, recently quenched galaxies will induce a rise in the average size of quiescent galaxies with decreasing redshift.

Finally, this thesis attempts to tackle one of the biggest unanswered questions in galaxy evolution: how does quenching operate in the high-redshift Universe? Surveys such as GASP and VESTIGE have already allowed us to build a comprehensive understanding of environmental quenching in the local Universe. Obtained using the *WFC3* G141 grism, spatially resolved Hα maps of cluster and field galaxies at $z \sim 1$ are used to observe directly where star formation is occurring in those galaxies and where it is not. In Chapter 4, we measure the stellar mass–size relations of $z \sim 1$ star-forming cluster and field galaxies in F140W and Hα. The lack of a clear environmental quenching signature in this work hints at the rapidity of environmental quenching in the high-redshift Universe, and/or a complete change in the physics of environmental quenching.
— *University of Cambridge; accepted 2019 October.*

Discovery and Characterization of Gravitationally Lensed Quasars in Wide-Field Surveys

By Cameron Lemon

The coincident alignment of two galaxies on the sky can create the rare cosmic phenomenon of strong gravitational lensing, in which light from the more distant galaxy is bent around the foreground galaxy to create multiple, distorted, and magnified images. When the background galaxy hosts a bright active galactic nucleus, a quasar, the system becomes a probe of accretion disc physics, quasar–host-galaxy relations, the Hubble constant, the stellar IMF, smooth-matter fractions, amongst many other applications. It has been 40 years since the discovery of the first gravitationally lensed quasar, and dedicated spectroscopic and imaging surveys have added over one hundred new systems to this list. In recent years, the amount of available data across the whole sky has grown exponentially. Full-sky data from X-ray to radio wavelengths exist, and predictions suggest there are many bright lensed quasars hidden in these datasets. This thesis presents several new techniques to mine these rare systems from whole-sky photometric datasets. We use the excellent resolving ability of *Gaia*, coupled with other wide-field surveys such as the Dark Energy Survey (DES), *Pan-STARRS*, and *WISE*, and present spectroscopic follow-up from the *WHT*, *NTT*, and *Keck*. By looking for multiple *Gaia* detections around photometric quasar candidates, and single *Gaia* detections near morphological galaxies, we have discovered 105 new lensed quasars. We also present a search based on significant offsets in astrometry and flux between *Gaia* and SDSS for spectroscopic quasars, suggesting several promising small-separation lens candidates. We characterize the confirmed systems based on ground-based imaging and the spatially resolved spectra, and comment on the purity, efficiency, and biasses in our selection. DES data provide multi-epoch photometry over the baseline of years at optical wavelengths, allowing a colour-independent selection of lensed quasars by looking for nearby variable pairs. We create a parametric modelling pipeline of the DES images to extract light-curves of system components, and show that it is a highly effective way to remove quasar and star projections before spectroscopic follow-up. We demonstrate that future searches based on detecting variability in multiple images will be biassed towards four-image lensed quasars. — *University of Cambridge; accepted 2019 May*.

X-ray Studies of the Innermost Regions of Black-Hole Accretion

By Jiachen Jiang

In this thesis, I present the results of my research on the X-ray spectra of accreting black holes. The content of this thesis can be broadly separated into two parts: the first half for stellar-mass black holes in X-ray binaries (XRBs) and the second half for supermassive black holes in active galactic nuclei (AGN).

This work mainly focusses on the X-ray spectral shape and the spectral variability of these accreting black-hole systems. By studying the broad-band spectra of XRBs and AGN, we are able to extract some information about the innermost regions of the discs from their X-ray observations. For example, we are able to (*i*) constrain the size of the coronal region that illuminates the disc; (*ii*) estimate some properties of the discs, such as the density in the disc surface; (*iii*) measure the spin parameters of the accreting black holes. In the meantime, I also study the variability of the innermost regions by comparing different observations or different flux states of individual sources. For example, Chapters 2–3 compare different accretion states of black-hole XRBs. Chapter 4 discusses the extreme and fast flux variability on a time-scale less than one kilo-second in the narrow-line Seyfert 1 galaxy IRAS 13224–3809. Chapter 5 studies the long-term spectral variability of the Seyfert 1 galaxy 1H0419577.

The main spirit of this thesis is to test for high-density discs. A disc-reflection model with a variable disc-density parameter is used for each source in this work. In the last chapter, I apply the same model to a large sample of Seyfert 1 galaxies in order to compare the disc densities at different black-hole mass scales and different accretion rates. — *University of Cambridge; accepted 2019 July*.

A full copy of this thesis can be requested from: jcjiang12@outlook.com

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OBITUARY

Lodewijk Woltjer (1930–2019)

Lodewijk Woltjer was Director General of the European Southern Observatory (1975–1987) at the time when the UK considered joining in the *Very Large Telescope* (*VLT*) project, but instead opted to be a junior partner with the United States in the *Gemini Telescopes* (from 1990 until they withdrew in 2012). The UK had also been involved in early discussions that led to the founding of the European Southern Observatory in 1962, but on that occasion preferred to be part of an Anglo-Australian Observatory and Telescope favoured by Sir Richard Woolley and Fred Hoyle. It was too late for British industry to benefit from the construction of the *VLT* when the UK finally joined ESO in 2002. Woltjer spent enough time at Hoyle's Institute of Theoretical Astronomy in Cambridge in the year following the 1970 General Assembly of the International Astronomical Union in Brighton to appear in one of the 'summer gang' photos, but was otherwise largely a continental European (and briefly American) astronomer.

Jan Woltjer, Sr. was professor of classical languages at Amsterdam. Jan Woltjer, Jr. (1891–1946) earned a PhD in 1918 from Leiden for work on the theory of motion of Saturn's satellite Hyperion (the first clear example of chaos in astronomy) and spent most of his career as a lector at Leiden (a position which did not permit formal PhD students). He and his wife, Hillegonda Hester de Vries, had four children, all scholars: Anna, later Halasz (sociology), Margo later Decker (classical languages), Jan Julian (history), and Lodewijk (astronomy).

The family sent son Lodewijk to Switzerland for part of the Second World War, from which he returned with fluent French (often preferred to his native Dutch) and a fondness for the country (later describing Geneva as "a very liveable city"), and in time to experience the grim choice between sugar beets (initially seeming almost pleasant, but soon cloyingly sweet) and the bitter tulip bulbs as comestibles. This must have contributed to his later strong preferences in food and drink and suitable company in which to consume them.

Other personal characteristics included a fondness for bananas, firm choice of baths over showers, and colour preferences ("I've always liked blue") reflected in the carpets leading to the ESO library in Garching, and the covers of the early volumes of the *Bulletin of the American Astronomical Society*, which spun off from the *Astronomical Journal* under his editorship in 1969. He expressed mild annoyance when later editors of *BAAS* adopted different cover colours to make each year look different. He generally wrote with green ink and carried a pocket watch, being exceedingly skilled at glancing at it during committee meetings and other public events.

His most famous one-liner, "The larger our ignorance, the stronger the magnetic field" (which appeared on the walls of 6th floor Campbell Hall, UC Berkeley, from at least 1998 to 2006), is the last line of concluding remarks at IAUS 31 in Noordwijk. You must read it yourself to get the context.

The surname Woltjer is not a common one, LW once saying that he had never encountered anyone with it who was not a traceable relative. This is possibly no longer true, not that there are fewer relatives, but because web-everything enables one to encounter many more people. Primarily on the model of his mother (whose English was, however, very fluent and somewhat less accented than his), Woltjer spoke what some of his fellow-countrymen have called 'Oxford Dutch'. In particular, the vowel sound 'ij' came closer to the English of 'weigh' than to the English vowel of 'white'. This sometimes presented a problem in buying white shirts or ordering white wine. The challenge of that vowel perhaps also contributed to his being almost universally called 'Lo', though he was not otherwise precisely an informal sort of person.

Woltjer received a Leiden PhD in 1957, working with Jan Oort on the magnetic-field structure of the Crab Nebula, followed by postdoctoral positions at Yerkes (1957–58) and at Princeton (1958–59). He returned to Leiden as a lecturer in 1959, becoming in 1961 Professor of Theoretical Astrophysics and Plasma Physics, with time out for brief visiting professorships in the department of mathematics of MIT and the department of physics and astronomy at the University of Maryland (where part of his chapter in the Kuiper compendium volume on galactic structure was written). The chapter emphasizes the coupling of gas, magnetic field, and cosmic rays, opting for a disc field of around 30 μG. This is large enough for him to have concluded that magnetic fields as well as gravitational processes (the solitons of Lin and Shu) would contribute to spiral structure, and he once described himself as having earned his living with magnetic fields for a while. Incidentally, that volume, edited by Adriaan Blaauw and Maarten Schmidt, and with chapters also by van Rhijn, Luyten, Oort, and Westerhout, was a rather Dutch affair.

In 1964, Woltjer moved to Columbia University as, variously, chairman of a small astronomy department, the Rutherfurd Professor, and director of a small observatory. He was elected to the Council of the American Astronomical Society for the term 1968–71 (the other two for that term were G. R. Burbidge and G. Wallerstein) and became editor of the *Astronomical Journal* in 1967 charged with somehow revitalizing it and broadening the range of astronomy research published therein. Norman Baker and Leon Lucy joined in that task and carried on when Woltjer returned to Europe, effective 1975 January 1, as Director General of the European Southern Observatory, in succession to, first, Otto Heckmann and then Adriaan Blaauw.

LW's early papers appeared in *BAN*. The first was on solar spicules and chromospheric dynamics (close to a topic his father had written on late in his career). Then came a few variable-star papers, and the thesis work on the Crab Nebula in 1957. He published an occasional supernova/SNR/Crab paper at least up to 2000, the later ones with colleagues. His most cited paper is the 1958 one on force-free magnetic fields, in *PNAS*, clocking in at 685 ADS citations in early 2019 September. Next, at 438, is Kahn & Woltjer 1959 on the mass of the Milky Way and M 31, from their approach speed. The number came out something like ten times the masses expected from the luminosities, and is now often cited in discussions of dark matter. They had presumed lots of gas (as did Zwicky for the Coma cluster), and LW described the resultant gas mass as "that was a number that crept into the literature and is now creeping out". The third most cited is his *ARA&A* article on supernova remnants, and fourth is Setti & Woltjer 1989 on the contribution of active galaxies to the X-ray background, the point being that the sum of the spectra of the contributors had better equal the spectrum of the sum.

Woltjer's term as director of ESO included the beginning of construction of the *New Technology Telescope* (partly funded by the 'initiation fee' Italy paid to join), and, at the last council meeting of his term, on 1987 December 8, Council approval for construction of the *Very Large Telescope* (*VLT*) on a site that had already been selected (Paranal, more desirable than the initial ESO site at La Silla) with him as an active participant in site visits and selection. As a result of those experiences, he opined that most people can function adequately at 4000m but 5000m is more challenging. La Silla and Paranal are at 2400 and 2600 m; Chajnantor, home of *ALMA*, is at 5200 m; and Cerro Peralta, which he visited, at at 4500m. (Be it here known that your writer cannot do integrals above about 5000 ft, but she can at sea level.)

LW provided a brief retrospective on his term as director (actually about 2½ of the standard 5-year terms, making him to date the longest-serving director) in the 1987 December issue of *ESO Messenger* (No. 50). It ends with a very long paragraph of acknowledgements and "last but not least, Ulla Demierre who has run my office with efficiency, optimism, and tact". And who became his second wife. At one point, he had planned to take up Swiss citizenship by virtue of long residence and marriage to a Swiss national. I am not sure that ever happened.

Lo had definite views about telescopes, past, present, and future. He wished very much that it might have been possible to bring the ESO 3.57-m (size chosen to permit a prime-focus cage large enough to admit a moderate-size observer) into operation sooner, when it would have been the first 'large' southern-hemisphere facility. Instead it was beaten by the US CTIO 4-m and the *AAT* 3·5-m. The delay was, as others had forecast, partly a result of having to harmonize the ideas and engineering products of multiple countries. The 4 × 8-m design of the *VLT* was one he strongly favoured over either a 16-m (whether monolith or segmented) or 16 one-metre mirrors. Advantages over the monolith were several — no one knew how to make one; with four telescopes you could build them one at a time, and start using the first almost immediately. On-going, there could be one, two, three, or four programmes executed simultaneously, saving the full aperture for when it was required for sensitivity, and allowing use of multiple mirrors for interferometry. Admittedly, at the start, no one quite knew how to produce an 8-metre mirror either, and he remarked on occasion that it had been wise to let the Americans go first and learn from their mistakes (examples probably censored). With the approach of the 20–30–40-metre era, he expressed reservations about aiming for a single mirror or even multiple mirrors with a single mount, wondering whether a set of, for instance, four telescopes might be wiser. The goal of letting the Americans go first this time will probably not be achieved. Incidentally, the Council that in 1987 December signed on for the *VLT*, consisted, according to the photo in the *ESO Messenger* No. 50 of 23 men! The 23 AAS officers and councillors who overlapped that year comprised 19 men and four women.

The Mathematics Genealogy Project credits LW with six PhD students completing their theses with him at Columbia. Of them John Landstreet (emeritus at the University of Western Ontario) has had at least 13 students of his own. John Trasco came to the University of Maryland soon after receiving his degree as a scientist–administrator, and kept the astronomy programme (later department) in good order, under circumstances of varying difficulty, for decades. He also appears as an AAS emeritus member. Mary Louise West (later Mary Lou West) spent many years at Montclair State College in New Jersey, but is no longer in the AAS directory.The other three, Edward Ng, Wai-Yin Chau, and Donald Dzamba disappear from the community earlier. Dzamba and Ng were not AAS members by 1973 (perhaps they never were); Chau was at Queens University, Kingston Ontario, Canada, in 1973 but had left the AAS by 1974. Perhaps he simply opted for a Canadian society! All wrote theoretical theses, two with strong magnetic fields, two on structures of disc galaxies, and one each on neutron stars and novae. At least two other students began work with LW, Anthony G. Sgro (on models of the Cas A supernova remnant) who finished with Kevin Prendergast and then spent many years at Los Alamos writing papers on plasma dynamics, probably of 'programmatic' significance; and Daniel P. Hayes, the only one to attempt an observational thesis at the 24-inch of the Harriman Observatory, on polarization of early-type stars. He finished up with Leon B. Lucy and never appears in AAS directories after leaving Columbia (with thanks to Prof. David Helfand for the connection; AGS I simply remembered as Lo having spoken of "Mr. Sgro".)

To the 'Columbia era' belong two remarkably prescient predictions. A Woltjer *ApJ* 'Note' from 1964 suggests at the very end that neutron stars, if they exist, might form with magnetic fields of 10^{14} G or more. That paper, submitted on 1964 June 5 from Columbia, already acknowledges AFOSR funding. Soon after, he suggested to Landstreet a thesis project that assumed a strong field for at least some white dwarfs. He then put together a team including also George Preston, James Kemp, and Roger Angel to look for such a field. Such was found and reported in 1974 from the star Grw +70° 8267, in the form of circular polarization of the photospheric light. But even Homer nods. A 1968 *AJ* paper on supernova remnants (what was the editor thinking of to accept this?) with Acadio Poveda, who had visited from Mexico, has an abstract that concludes by saying they find "there is no evidence that supernovae of Type II are catastrophic events related to ultimate stellar collapse". Instead they preferred some closer relation to novae and helium-shell flashes as a possible energy source (on the basis of spectral similarity). Indeed, accretion on white dwarfs gives rise to novae and their ilk, and accretion on neutron stars gives us various forms of X-ray bursts, but this is not apparently what they had in mind. Both AFOSR and NASA funding is acknowledged.

I have always privately held the opinion that the European Astronomical

Society and the Division structure of the International Astronomical Union came about because Lodewijk Woltjer (and to a lesser extent, Jacqueline Bergeron) didn't have enough to do. Anyhow, the EAS came into being in 1990, with LW as its first president (1990–93). The other main co-founders were Jean-Pierre Swings, and Martin Huber as treasurer. At any rate, it was Huber to whom I gave a check for $100 one morning at breakfast to become a charter member (regular dues being somewhat less). The UK is a major player in the EAS, having numbers of members comparable with France or Germany, and is the home of the current president, Roger Davies. Inevitably the EAS competes with national astronomical societies, of which there are significant ones in many European countries (I am a member of only the Royal Astronomical Society and the Astronomische Gesellschaft, but have also spoken at the Spanish and one of the Belgian). There are also national societies in (at least) Croatia, the Czech Republic, Denmark, Finland, France, Hungary, Ireland, Italy, Portugal, Russia (called Euro-Asian), Serbia & Montenegro, Sweden, Switzerland, and Ukraine. An effort is now being made to coordinate memberships, so that dues paid to a national society also buys you a free EAS membership. As a champion of European collaborations in astronomy, LW would surely have approved of this change. He was a foreign associate (honorary member) of the RAS, exempt from paying dues, unless you want to vote. The 2002 associate list held 150 names, of which eight belonged to women. The EAS in due course established a series of Lodewijk Woltjer lectures of which Lo gave the first one (2010) on 'The Changing Face of Astronomy'. His two worrying examples were both American ones, the *Superconducting Super Collider* and *JWST*.

The International Astronomical Union has always been a heavily Eurocentric organization. All of its General Secretaries, from Alfred Fowler to Teresa Lago have been at European (meaning west of the Oder–Neisse line) institutions. Of the Presidents, seven have been US-based, 18 European (same definition), and eight others (two from Japan, and one each from the Soviet Union, Russia, India, Mexico, Argentina, and Australia). The first woman President was Catherine Cesarsky, also a former director general of ESO. The Vice Presidents have been even more heavily concentrated in European countries, owing largely to a rule forbidding multiple executive-committee members from the same country at the same time. The governance process of the IAU is shrouded in both history and complexity but it must have been the Special Nominating Committee (another of those one-per-country affairs) appointed at the 1988 Baltimore General Assembly that selected Woltjer to become the President-elect from 1991 (Buenos Aires) to 1994 (The Hague) and therefore President from 1994 to 1997 (Kyoto). Jacqueline Bergeron was General Secretary 1991–94, and it was she who phoned me sometime in 1993 or 94 to ask if I were willing to become one of the Vice Presidents for the term 1994–2000. You bet I was!

The scientific tasks of the IAU have always been in the hands of 20–30 sub-disciplinary commissions, formed, re-purposed, merged, split, and dissolved when someone felt strongly enough to fight for the change. As far back as Jean-Claude Pecker's time as General Secretary (1964–67) there had been advocates of replacing the commissions with a much smaller group of divisions more rationally spread across the subject matter. The first stage happened in 1994, organized by Woltjer and Bergeron, in which existing commissions were divided into groups intended to have roughly equal numbers of members. Thus Comm. 28 (Galaxies) and Comm. 47 (Cosmology) became Division VIII (Galaxies and the Universe), both the new divisions and the old commissions having their own presidents, committees, and so forth. The divisions were slightly reorganized and renamed (VIII became J for instance) in 2012, and all the existing commissions (even 28 and 47) were abolished and IAU members invited to propose new commissions to belong to the lettered divisions in 2015. Neither LW or JB had any hand in that so far as I know. The shake-up left some major topics (like High-Energy Astrophysics and studies of the Milky Way) without any obvious commission homes, but I no longer care very much (despite being the default president of G-l, Binary and Multiple Star Systems until 2021). And Woltjer certainly doesn't care.

His Wikipedia entry and the drier obituaries posted by the IAU, the EAS, and the University of Leiden will tell you he received many honorary degrees (the one I remember was from the University of Bologna in 1988, when it was celebrating its 800th anniversary), prizes, and fellowships in foreign academies. He also chaired a countably infinite number of advisory bodies, and was involved in the joint effort with the European Space Agency and its then director general Roger-Maurice Bonnet to establish astronomical priorities for the 2000+ decade and beyond.

LW was widely recognized for his ability to bring wide ranges of people and views into harmony and agreement. He described his method as letting everybody talk as long as they wanted, then summarizing by saying "I think we agree that ... " followed by whatever main point he intended to carry. Then asking whether anyone wanted to disagree or say more. They hardly ever did. A number of successful outcomes of this method appear in his book *Europe's Quest for the Universe*, and a much more distant prospect in his volume with Bonnet, *Surviving 1000 Centuries*. They meant the survival of humanity, and in this LW really believed, though in late lectures he expressed some doubt about whether science could survive because of the enormous cost of frontier instrumentation, including CERN-successors and 42-metre telescopes.

Lodewijk's image of 'Europe' extended from the Atlantic to the Urals, giving us two more 'European' IAU Presidents and two fewer 'others'. He was undoubtedly always happiest within that rather small sector of the Earth's surface, though over the years I also attended various events with him in Australia, India, China, and South America as well as the US and Canada.

Woltjer and Johanna Eichhorn married in Leiden in 1955. The marriage ended during the Columbia years. Their daughter, Leonore W. Nelson was born in Noordwijk and married Robert Nelson in New Canaan, CT, in 1983. She occasionally went camping with her father, and Leonore and Bob enjoy sailing, kayaking, and cross-country skiing. Lo's second wife was the Ulla (Ursula her baggage tags said, so probably also her passport) Demierre you met some pages back. She eventually took the Woltjer surname (her e-mail address beginning ulladw) and during the ESO years and beyond was not only efficient and optimistic but also a skilled organizer of social events in Chile, Garching, S. Michel, and Geneva, where they finally settled.

Lodewijk was a bit stiff in the joints when we last dined together, in 2015 December in Geneva (where the Texas Symposium was meeting), but they were both ageing anyhow no faster than the calendar suggested (she was born in 1944) up to 2017, when he participated in the laying of the First Stone for the *E-ELT*. But in 2018 February in Leiden, Lo got caught in a revolving door and broke shoulder bones. Three surgeries did not repair things properly (remember those bones deprived of milk, cheese, and meat during the time of his adolescent growth spurt), and he was hospitalized almost continuously thereafter. I first realized there was a problem in 2018 November, when he did not phone on my birthday (a ritual since about 1986). I emailed Ulla after a few days. She explained about the accident, said he would surely phone when he was feeling a bit better, but that, meanwhile, she had developed cancer, and life was not very happy for them. Ulla died first, in 2019 March, and life was never the same for Lo. I visited him on July 13th, at a *Maison de repos* close to where they had been living in the Geneva suburbs (after having made a number of phone calls, written many letters, exchanged emails with his colleagues in Geneva who were visiting regularly, and having sent flowers for his birthday). I was in Valencia, Spain, the week of the 8th for a meeting on General Relativity and gravitation, and it seemed a sort of omen that there was precisely one flight a week non-stop from Valencia to Geneva, and it was on Fridays. There was a photo of a laughing Ulla on the wall over his bed; he was sadly diminished both physically and mentally, and only two things had not changed: his voice and the way his lips clung at the end of a kiss.

But the last words must be his (from *Quest*) … . "But is it too much to dream of the day when pan-European scientific organizations foster research on the continent on a basis of equality with others who have the same aim?" A European gentleman to the last. — VIRGINIA TRIMBLE.

Here and There

MYTHSTAKE

Like the myth, Perseus the constellation harbours a favourite object, the variable star Mira. — *An Astronomer's Tale*, by Gary Fildes (Century Books), 2016.

REMOTE PROSPECT

Some of the earliest findings of exoplanets appeared in our pages, including, in 1995, the first report of an exoplanet orbiting around a Sun-like star in another galaxy … — *Nature*, **575**, 7, 2019.