# THE OBSERVATORY

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## MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2019 May 10 at $17^h 00^m$
in the Geological Society Lecture Theatre, Burlington House

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

*The President.* Very well, ladies and gentlemen, let's start the Ordinary Meeting. First items on the agenda are the 2019 thesis prizes and I'm pleased to announce that the winner of the Michael Penston Prize is Dr. Alexandra Amon of the University of Edinburgh for her thesis entitled 'Cosmology with the Kilo-Degree Lensing Survey', so we should give her a round of applause [applause]. The runner up was Dr. Antonella Palmese of University College London. The Keith Runcorn Thesis Prize has been awarded to Dr. Ophelia Crawford of the University of Cambridge for her thesis entitled 'On the viscoelastic deformation of the Earth', so we give her a round of applause [applause]. The runner-up is Dr. Fred Richards of the University of Cambridge. We hope that the prize winners will be giving talks at future RAS Ordinary Meetings, so you may wish to look forward to that. Nominations are invited for RAS medals and prizes to be awarded in 2020 January. This will be a very special year due to reasons that I mentioned — it's our bicentennial year. I now call on Ian Crawford to take over the chair of the meeting.

*Professor I. Crawford.* Thank you, Mike. I thought my responsibilities as a Vice-President were over, but I have one last duty to perform. Before I introduce Mike and invite him to give his Presidential Address, Professor Steve Miller is going to give a short update on RAS 200.

*Professor S. Miller.* In the report, pages 16 and 17, there is a reasonably comprehensive summary of what's been happening in RAS 200 this year. I am very much indebted to Sue Bowler for having put that together, so I am not going to take too much of your time. I am going to point to one or two of the projects though.

I'd like to begin with the NSC Creative Planets 360 programme. I'm putting that up because it's been shown all around the country now, and if there is a planetarium near you that would like to show this then please get in touch with Paul Mowbray at the National Space Centre creative team. It's going to be shown in conjunction with the American Astronomical Society's meeting in Honolulu next year; I'm negotiating with the Bishop Museum there that has a planetarium to show it; and it will also be shown in Hilo at the Imiloa Center between Christmas and New Year, so it is getting international recognition and showings now.

One of our projects is with Girl Guiding. I can't remember what this group is called. It used to be called the Brownies; is it still called the Brownies? Yes. So they've got their space badge now that we've been involved through RAS 200, and there are lots of very exciting things going on. We have a project in Galway, Ireland, that is getting up and running now. This is an inter-generation astronomy-inspired art project but they are also going to be taking part in the Galway Festival in June and July; I just thought I'd highlight those three but do look at all the projects. Some of them I've already mentioned. We have the opening of the Bounce Back Centre in Brixton Prison that's coming up at the end of the month. That's a very exciting project, working with people who have taken time out at Her Majesty's pleasure. We're bringing all our projects together so we thought rather than have it at Burlington House, this time we'd go to Glasgow; the Glasgow Science Centre are being very accommodating, not charging us an arm and a leg like some places wanted to. And I would make the plea that I made last year which is that there are lots of projects around and we would like Fellows to get more involved. Thank you.

*Professor Crawford.* Thank you, Steve [applause]. It is a pleasure now to invite Professor Mike Cruise, our President, to give his Presidential Address on 'The gravitational-wave spectrum'.

*The President.* [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*.]

*Professor Crawford.* Thank you, Mike, for an outstanding Presidential Address [applause].

*Reverend G. Barber.* I have a question about inverse Gertenshtein conversion, in that, would it work? In the sense that, are not the Maxwell equations embedded in the space–time that is being stretched by the gravitational wave, so although they are passing through, they don't actually generate any electromagnetic radiation.

*The President.* Well, there have been at least five papers written using very different theoretical techniques, so it's been discussed by Mickelson and others using Feynman diagrams; the results come out the same as if you do a complete Einstein–Maxwell solution of the effect, so I think theoretically there is little doubt that the effect exists. Of course, until we have a really robust gravitational-wave generator in the lab, it is difficult to do an experiment and say that, but it's been examined by many authors, using very different theoretical techniques and they get exactly the same answer.

*Dr. P. Allen.* My question follows on from the last one really. Accepting that the mechanism works, you were talking about generating electromagnetic waves, but we're talking about the optical here, so how many photons can you generate — is it more than one?

*The President.* Well, if it is not, we won't be able to detect it, but that's the same problem with any such kind of proxy detector of gravitational waves because it clearly is half a step further away from the gravitational wave where test masses are moved. But, you know, the sensitivity calculations we're able to do are completely consistent with the kind of electromagnetic detectors we have available these days.

*Professor I. Roxburgh.* We may not have the gravitational waves, we may not be able to produce gravitational radiation in the laboratory, but we do have a Sun, and there are low-order oscillations of the Sun that fall within the *LISA* detection band, which you didn't mention. Either that's a gift to solar astronomy or it's a test bench for gravitation.

*The President.* That has been looked at by the *LISA* science team; I'm looking at Bernard Schutz now, and I think it was decided it was not quite detectable.

*Professor B. Schutz.* That's right. Unfortunately the Sun is not relativistic enough to generate the amplitudes of gravitational waves — we have to go to sources that are out at higher redshifts to get things that are strong enough for *LISA* to see. It's remarkable but the motions inside the Sun don't produce detectable amplitudes.

*Professor Roxburgh.* I just have to say that I disagree with you.

*Professor Crawford.* Can we thank Mike again for a really excellent talk [applause]. Just to remind everybody that we can now decamp to the library of the RAS, and the next Ordinary Meeting of the Society will be on Friday the 11th of October 2019.

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## THE ELECTRIC CHARGE OF BLACK HOLES: IS IT REALLY ALWAYS NEGLIGIBLE?

*By Michal Zajaček* & Arman Tursunov†*
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We discuss the problem of the third black-hole parameter — an electric charge. While the mass and the spin of black holes are frequently considered in the majority of publications, the charge is often neglected and implicitly set identically to zero. However, both classical and relativistic processes can lead to a small non-zero charge of black holes. When dealing with neutral particles and photons, zero charge is a good approximation. On the other hand, even a small charge can significantly influence the motion of charged particles, in particular cosmic rays, in the vicinity of black holes. Therefore, we stress that more attention should be paid to the problem of a black-hole charge; and hence it should not be neglected *a priori*, as is done in most astrophysical studies nowadays. We look at the problem of the black-hole charge mainly from the astrophysical point of view, which is complemented by a few historical as well as philosophical notes when relevant. In particular, we show that a cosmic ray or, more generally, elementary charged particles, passing a non-neutral black hole can experience an electromagnetic force at least sixteen times the gravitational force (calculated for a proton) for the mass of the Galactic Centre black hole and its charge being seventeen orders of magnitude less than the extremal value. Furthermore, a Kerr–Newman rotating black hole with the maximum likely charge of one Coulomb per solar mass can have the position of its innermost stable circular orbit (ISCO) moved by both rotation and charge in ways that can enhance or partly cancel each other, putting the ISCO not far from the gravitational radius or out at more than six gravitational radii. An interpretation of X-ray radiation from near the ISCO of a black hole in X-ray binaries is then no longer unique.

*Introduction*

Although initially believed to be out of the real Universe, like "unicorns and gargoyles"[1], black holes are not *corps obscurs* anymore. Instead, over the last decades, they have been fully accepted as real astrophysical entities. They form an integral part of stellar evolution and, even more importantly, 'feeding' massive black holes and the associated feedback appear to be crucial to account fully for galaxy evolution.

Experimental means to study black holes are now richer than ever. Since the end of the 1960s, their footprints have been successfully studied *via* multi-wavelength electromagnetic-based observations. At the centenary of the theory of General Relativity, a new channel was opened up thanks to the first detection of gravitational waves that resulted from the merger of two stellar black holes[2]. A recent detection of a high-energy neutrino in combination with the quasi-simultaneous $\gamma$-ray counterpart has enabled astrophysicists to pinpoint its origin to a supermassive black hole with the relativistic jet directed almost exactly towards us — BL Lac object TXS 0506+056[3]. This has opened a new era of so-called 'multi-messenger astronomy' — the term implying observations of four disparate cosmic 'messengers': electromagnetic radiation, gravitational waves, neutrinos, and cosmic rays.

According to General Relativity, any information about black-hole matter is hidden inside its event horizon, being inaccessible to external observers, which is referred to as the "no-hair" theorem, or rather, conjecture[4]. This makes it possible to describe any astrophysical black hole by just three classical, externally observable parameters: its mass, its spin (angular momentum), and electric charge (assuming we don't consider the speculative magnetic monopole at this point). One of the main motivations behind the exciting, and often time-demanding, multi-messenger experiments is to determine the black-hole mass and its spin. The third parameter, electric charge, is usually neglected and basically set equal to zero. This assumption is often backed up by arguing that the presence of plasmas around astrophysical black holes leads to prompt discharging. The neglect of charge has also affected the theoretical investigation of the particle motion in the vicinity of a Reissner–Nordström black hole[5,6]. Studies of the motion of charged test particles such as the paper by Pugliese *et al.*[7] could in principle have appeared decades earlier if the astrophysical motivation for charge had been bigger.

*The charge of a black hole*

However, is the black-hole charge always exactly zero? Hasn't it been neglected too often just to simplify calculations? And if there is any charge, can it lead to some observable effects?

First of all, how could black holes get charged? It was already pointed out by Arthur S. Eddington[8] that stars should bear a small positive charge to prevent electrons and protons from further separation in the stellar atmosphere due to the mass difference by a factor of nearly 2 000. To get an estimate of this charge, we consider the combined conservative gravitational and electric field around a black hole, $\phi(\mathbf{r})=\phi_G(\mathbf{r})+\phi_E(\mathbf{r})$, where the corresponding force is $\mathbf{F}=-\nabla\phi(\mathbf{r})$.

The distribution function $f(\mathbf{r},\mathbf{w})$ for the Maxwell–Boltzmann equilibrium distribution (MW) in the external conservative field can be expressed as,

$$f(\mathbf{r},\mathbf{w}) = n_0(\mathbf{r})\exp\left[-\frac{\phi(\mathbf{r})}{k_\mathrm{B}\mathrm{T}}\right]f(\mathbf{w}), \tag{1}$$

where $n_0(\mathbf{r})$ is the density distribution in the absence of the external field and $f(\mathbf{w})$ is the velocity-dependent part of the MW distribution. The density distribution of a particle species is simply given by,

$$n_\mathrm{par}(\mathbf{r}) = n_0(\mathbf{r})\exp\left[-\frac{\phi(\mathbf{r})}{k_\mathrm{B}T}\right]. \tag{2}$$

Since we expect that the density distribution of electrons and protons is comparable at any distance to ensure quasi-neutrality around astrophysical bodies including black holes, $n_\mathrm{p} \approx n_\mathrm{e}$, it follows from Eq. 2 that the potential value for protons and electrons should also be approximately the same, $\phi_\mathrm{p} \approx \phi_\mathrm{e}$. From the potential equality, we obtain a value of the equilibrium charge $Q_\mathrm{eq}$ and the charge-to-mass ratio can be expressed in terms of fundamental constants,

$$\frac{Q_\mathrm{eq}}{M_\bullet} = \frac{2\pi\varepsilon G(m_\mathrm{p} - m_\mathrm{e})}{e} \approx 76{\cdot}9\,C M_\odot^{-1}. \tag{3}$$

This was generalized by John Bally and 'Ted' Harrison[9] at the end of the 1970s, who derived that any macroscopic body in the Universe — stars, galaxies, and therefore also black holes — are positively charged, with the charge-to-mass ratio of approximately 100 Coulombs per solar mass. In this 'electrically polarized Universe', the positive charge of galaxies is compensated by a negatively charged, freely expanding intergalactic medium.

Another mechanism that supports the existence of charged black holes is purely relativistic. In the same way that space and time are fundamentally the same, being just the different components of the four-dimensional space–time coordinates, electric and magnetic fields are also just the different components of the antisymmetric, rank-2 tensor of an electromagnetic field, $F_{\mu\nu} \equiv \partial_\mu A_\nu - \partial_\nu A_\mu$, where $A_\nu$ is the electromagnetic potential. It appears that a rotating black hole immersed within the external magnetic field (produced by, *e.g.*, a dynamo of plasma around a black hole) in fact induces an electric field due to the twisting of magnetic-field lines. This was shown in 1974 by Robert M. Wald[10]. A convincing amount of evidence that magnetic fields are indeed present in the vicinity of astrophysical black holes, alongside the fact that any black hole is generally rotating, therefore implies that a non-zero charge of a black hole is quite plausible. A value of such an induced charge is proportional to both the strength of the magnetic field and the spin of the black hole, which is also recovered and applied in the recent studies focussed on the Wald mechanism[11,12]. The rotation of a black hole in the ordered external magnetic field leads to the Faraday induction, where the time component of the electromagnetic potential represents the induced electric field. The potential difference between the black-hole horizon and infinity is the following,

$$\Delta\phi = \phi_\mathrm{H} - \phi_\infty = \frac{Q_\bullet - 2a_\bullet M_\bullet B_\mathrm{ext}}{2M_\bullet}, \tag{4}$$

where $Q_\bullet$, $a_\bullet$, and $M_\bullet$ are the charge, dimensionless spin, and the mass of the black hole, respectively, and $B_\mathrm{ext}$ is a magnitude of the external homogeneous magnetic field. The potential difference expressed by Eq. 4 leads to the selective accretion of charges or, in other words, the charging of the black hole. The charging stops when the potential difference is zero, which occurs for the maximum net charge of $Q_\bullet = 2a_\bullet M_\bullet B_{\rm ext}$. Considering the supermassive black hole at the Galactic Centre with the mass of $M_\bullet = 4{\cdot}14 \times 10^6\, M_\odot$ immersed in the poloidal magnetic field of 10 G (ref. 13), the induced charge is limited by the maximum spin of $a_\bullet \leq M_\bullet$,

$$Q_{\bullet\rm ind}^{\rm max} \leq 2{\cdot}5 \times 10^{15} \quad \left(\frac{M_\bullet}{4{\cdot}14 \times 10^6\, M_\odot}\right)^2 \left(\frac{B_{\rm ext}}{10\,{\rm G}}\right) {\rm C}. \tag{5}$$

The sign of the Wald charge depends on the orientation of magnetic-field lines with respect to the black-hole spin. If the magnetic field is directed alongside the rotation vector of a black hole, then the charge is positive. This implies that, as for stars and galaxies as a whole, the charge of astrophysical black holes tends to be positive since a certain degree of an alignment between the accretion-flow angular momentum and the black-hole spin is expected on a sufficiently long time-scale.

Even if black holes are charged with the charge-to-mass ratio of about 100 Coulombs per solar mass, the motion of neutral bodies as well as photons in their vicinity is not significantly affected. Therefore the usual assumption of zero charge appears to be fair enough. Just to get some specific estimates, for the Galactic Centre black hole of 4 million solar masses[14], we would expect a charge of about $10^8$ coulombs based on the electron–proton separation[11] — see Eq. 3. The limiting, extremal charge of such a massive black hole, which would noticeably affect the space–time metric, is 19 orders of magnitude larger, which follows from the general Kerr–Newman black-hole solution,

$$Q_{\rm max}^{\rm rot} = 2M_\bullet\sqrt{\pi\varepsilon_0 G(1 - a_\bullet^2)}, \tag{6}$$

which for the non-rotating, Reissner–Nordström case ($a_\bullet = 0$) may simply be evaluated as

$$Q_{\rm max}^{\rm norot} = 2M_\bullet\sqrt{\pi\varepsilon_0 G} = 6{\cdot}86 \times 10^{26}\left(\frac{M_\bullet}{4 \times 10^6\, M_\odot}\right) C. \tag{7}$$

The value of an induced charge due to the black-hole rotation in the surrounding magnetic-field of about 10 Gauss, as inferred from the flaring activity of the Galactic Centre black hole[14], has an upper limit of about $10^{15}$ coulombs (see Eq. 5) which is still not large enough to have a noticeable impact on the space–time geometry[11]. Hence, so far the assumption of a zero charge seems to be on the safe side.

However, this assumption is only valid when one considers the motion of neutral matter including photons. The dynamics of charged particles, such as electrons and protons, can be profoundly affected when the black hole possesses even very small charge, as, *e.g.*, the probable value of $10^8$ coulombs for the Galactic Centre black hole. So what is then the consequence of this charge? In contrast to a magnetic field, an electric field can do work, and consequently it can support the acceleration of charged particles to very large, relativistic velocities. In particular, the charge of a rotating black hole generates the electromotive force between the pole of the black hole and its equator. A subsequent discharge of the black hole due to the accretion of oppositely charged matter slows down the black-hole rotation. This process became known as the Blandford–Znajek mechanism[15] and is generally considered to be one of the main processes for the generation of relativistic jets. This is how the rotational energy of black holes can be extracted out, and the charge is the driving engine in this case.

Three out of the four available cosmic 'messengers' — photons, gravitational waves, and neutrinos — are neutral particles that are naturally not affected by electromagnetic fields. This makes it possible to trace their origin even if the source is located very far from the Earth. Hence, the assumption of zero charge seems reasonable in the construction of theories of their formation. This remains true until the fourth messenger, the cosmic rays, comes into play. These are charged particles that are detected with energies unreachable by current particle accelerators. Recent discoveries[3] have traced their origin to supermassive black holes. However, the question as to why the energies are so high still remains mysterious. So not only are ultra-high-energy cosmic rays the most energetic particles, they are also the most baffling ones. The non-zero charge of a black hole would lead to an inevitable electromagnetic interaction of the black hole with cosmic-ray particles in their source region. This interaction can be much stronger than the standard gravitational one, since the ratio of the electrostatic and gravitational forces acting on a charged particle of charge $q_{\rm par}$ and mass $m_{\rm par}$ is larger than unity for even small charges of the massive black hole $Q_\bullet << Q_{\rm max}^{\rm rot}$,

$$\frac{F_{\rm elstat}}{F_{\rm grav}} = \frac{1}{4\pi\varepsilon_0 G}\left(\frac{Q_\bullet}{M_\bullet}\right)\left(\frac{q_{\rm par}}{m_{\rm par}}\right) \simeq 16\left(\frac{Q_\bullet}{10^{10}C}\right)\left(\frac{M_\bullet}{4\times 10^6 M_\odot}\right)^{-1}, \tag{8}$$

where the last equality was evaluated for a proton in the vicinity of a black hole of $4\times10^6$ solar masses. For the discussion of a potential effect of the black hole charge on energy-extraction mechanisms, see a review article by Zajaček *et al.*[16]. So, maybe the key for the demystification of ultra-high-energy cosmic rays lies in the neglected charge.

One of the crucial parameters in the accretion theory is the location of the innermost stable circular orbit (ISCO) of orbiting matter. For neutral non-rotating black holes, the ISCO is located at the distance of six gravitational radii from the singularity, $r_{\rm ISCO}=6GM_\bullet/c^2$. For rotating black holes, the ISCO shifts closer, up to the event horizon at $r_{\rm ISCO}=GM_\bullet/c^2$, for prograde rotation, *i.e.*, for a black hole rotating in the same sense as the orbiting matter. In contrast, for black holes that rotate in a retrograde sense, the ISCO shifts further away up to nine gravitational radii, $r_{\rm ISCO}=9GM_\bullet/c^2$. In a similar way as the spin, electric charge can also shift the ISCO, most profoundly for charged particles[7], both closer and away from the black hole for like and opposite charges, respectively. This is demonstrated for a non-rotating black hole with a small electric charge in Fig. 1. For like charges of the black hole and a charged particle, the ISCO shifts closer to the black hole; for opposite charges the ISCO moves away. As a consequence, it leads to a certain degree of *under-determination* of what can cause the actual shift of the ISCO. In other words, even a small charge can mimic the black-hole spin and it can become quite intricate for observers to decide what the real 'culprit' shifting the ISCO is. An interpretation of electromagnetic radiation from close to the ISCO of black holes, for instance X-ray light-curves in X-ray binaries or the Galactic Centre black hole, is thus no longer unique.

In conclusion, the black-hole charge may not be just a purely 'academic' parameter, with no relevance to observations. More attention should be paid to its potential effect on the dynamics of charged particles in the direct grasp of black holes, and thus it should not be neglected *a priori*, as it is routinely done in most astrophysical studies.

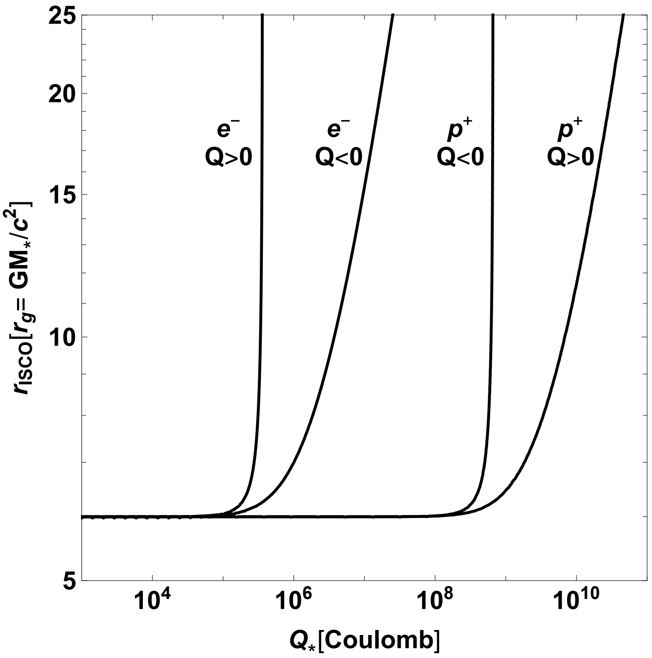


FIG. 1

The ISCO location (expressed in gravitational radii, $r_g = GM_\bullet/c^2$) for a non-rotating black hole as a function of the logarithm of a small electric charge (expressed in coulombs) for the black hole at the Galactic Centre with a mass of $10^6\ M_\odot$. The ISCO location for a non-rotating, uncharged case is at $r_g = 6GM_\bullet/c^2$.

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## CORRESPONDENCE

*To the Editors of 'The Observatory'*

*Some Common Misconceptions about the US Space Programme*

In this year of the 50th anniversary of the arrival of the first man on the Moon, a lot has been written about the American space programme that achieved such a remarkable feat. Much of the information, however, is not correct, and the book I review elsewhere in this issue (see p. 251) is not alone in making some loose assertions.

The first piece of information I noticed open to misinterpretation concerned Max Faget, the spacecraft designer, who was born in Belize, which might imply that he was not originally a US citizen. This could not be further from the truth. He was as American as apple pie, and Belize had not received independence in 1921 when Faget was born; it was known as British Honduras. His family was Cajun French, a much respected sub-culture in the fabric of the American melting pot. His ancestors came to Louisiana in the 1700s and after the Louisiana Purchase automatically became American Citizens. His grandfather was a well-educated doctor and his father a research doctor. Max was born in Honduras while his parents were working there. His father, with the help of a research team, developed a drug that was similar to quinine and effective in the treatment of both malaria and leprosy. Max graduated from Louisiana State University in 1943 and served as an engineering officer in the US Navy Submarine Service for three years. He then joined the Langley Research Center in Hampton, Virginia, as a research scientist. Langley was operated by the National Advisory Committee for Aeronautics which later became the foundation, with several other organizations, of the National Aeronautics and Space Agency (NASA). While working in that capacity he developed one of the most significant designs in the history of aeronautics: the blunt re-entry capsule. Putting the astronaut into orbit was one problem. Having him safely re-enter was another. Ballistic missiles faced a similar problem. If the warhead did not re-enter intact it would pose no threat. Common sense dictated the use of a pointed or streamlined missile to penetrate the atmosphere. In physics, common-sense solutions are often incorrect. As a prime example look at Einstein's discoveries *versus* classical physics. Many agencies and the Soviets were trying to develop the proper shape. Max, however, had a brilliant idea: enter the atmosphere with a blunt flat nose cone and disperse the heat buildup at a right angle to the direction of re-entry around the entire circumference of the heat shield. To further disperse the heat, coat the surface with an ablative coating that slowly burns away, taking much more of the heat with it. All further US spacecraft used this technique. Ballistic-missile warheads were modified and the later space shuttles used the entire flat bottom to disperse the re-entry heat. Although the Russians were first in achieving manned spaceflight they were slow developing both more efficient re-entry techniques and parachute-landing systems. Gagarin's capsule was a sphere and, although by spinning it dispersed a sufficient amount of the re-entry heat, there was no way to soft-land it. When it reached a safe altitude he was expelled from the capsule in a conventional ejection seat and landed safely by conventional parachute.

It is often claimed that von Braun was the father of the space programme, and while von Braun and his team of scientists and technicians from Germany greatly assisted the US and built the Saturn IB, the Saturn V, the Redstone, and the Juno rockets they were in no way the complete space programme. The six launches of the Mercury capsule atop the Redstone missile were all *sub-orbital*; there were two test launches of empty capsules, the launch of the chimpanzee, Ham, the launch of a boilerplate model, and the launches of Alan Shepard and Gus Grissom. The orbital missions all used the Convair Atlas missile built without the help of the German team. Those flights consisted of one with a simulated crewman (*i.e.*, a dummy), one with the chimpanzee Enos, and four more with live astronauts. The entire series of 12 Gemini flights used the Douglas Thor, another home-grown US rocket.

The true father of US rocket and missile technology was Robert H. Goddard (1882–1945). His monograph, *A Method of Reaching Extreme Altitudes*, written in 1919, is a classic text of 20th-Century rocketry. Goddard flew the first liquid-fuelled rocket on 1926 March 16. The Germans were not able to duplicate this until the early 1930s. Among many other devices Goddard patented were the multi-stage rocket, gyroscopic guidance, the gimballed engine, and control fins in the exhaust stream. The Germans obtained copies of those patents and used the ideas in their rockets. Perhaps (tongue in cheek) we can call Dr. Goddard the father of German rocketry! Goddard was a prophet unrecognized in his homeland. He got some support from the millionaire Harry Guggenheim and the aviator Charles Lindbergh, but he was scoffed at by many including the prestigious *New York Times*. Amazingly enough they published an apology 49 years later! This is not to diminish von Braun's contribution to the American space programme. He came here with slightly over 100 scientists and engineers, campaigned for a space programme, and built the Saturn that put us on the Moon and the Redstone that put our first satellite into orbit. As WW II faded into the past and Germany moved from being a conquered nation to an ally, several hundred more technicians and scientists migrated to the US. A small number of German engineers surrendered to the Soviet Union and helped the Russians build their first ballistic missile, which was essentially an improved V-2 with an extended range (400 miles *vs.* 200 miles). When the Soviets felt they had exhausted their talents they were deported to East Germany. The Germans who came to America were given good jobs, bought homes, were welcomed to become citizens, and had generous retirements. When we reached the Moon the cynics said "our Germans were better than their Germans". Nothing could be further from the truth. The US had many missile programmes going. There were tens of thousands of engineers and scientists working on the Apollo programme. Rocketdyne alone, the builder of the F-1 engine, had over 60 000 employees. I believe that the US could have built a Moon rocket on its own but it would have taken several years more.

Another forgotten US project was the Corporal and later much larger WAC Corporal (not to be confused with the much later US Army Corporal short-range ballistic missile developed at Redstone Arsenal and deployed in Europe). This rocket was designed in the US during and after WW II. After WW II, parts of approximately 100 V-2s were shipped to the US to be assembled and launched straight up as sounding rockets for research. Over 60 were actually launched under projects Blossom and Bumper from White Sands Missile Range in New Mexico and Cape Canaveral, Florida. Project Bumper was the brainstorm of US Army Colonel Holger N. Toftoy who personally escorted von Braun and his team to the United States and nursed them along for several years until they became accustomed to American ways. A WAC Corporal rocket was mounted on a V-2 and reached a record altitude of 244 miles on 1949 February 24. This was the first merging of German and American rocket technology.

Once von Braun became comfortable in his new American lifestyle and achieved greater fluency in the English language he became the world's most outspoken promoter of going to the Moon, a dream he had since childhood. He wrote endless articles for popular magazines and gave countless talks at everything from high-school graduations and science fairs to national space conventions. With the space artist Chesley Bonestell he produced a lavishly illustrated series of eight articles for *Collier's* magazine that depicted in detail how it would be possible to build an artificial space station, land on the Moon, and travel to Mars and return. This was picked by up Walt Disney — another great fan of space flight. Von Braun together with fellow German rocketeers Heinz Haber and Willy Ley, a pre-Hitler migrant to the US and a prolific author, produced three shows that were watched by an estimated audience of over 40 million viewers. If 'Uncle Walt' said we could fly to the Moon then it must be possible! Many popular movies of the era also added to this belief, most notably *Destination Moon*. This semi-documentary, which also featured realistic backgrounds by Chesley Bonestell, was well received. When President Kennedy made his speech setting the goal of landing on the Moon and returning before the end of the decade the American public was on his side. What had been a pipe dream of a few dreamers in the 1950s had become a mainstream belief of being possible in the 1960s. And the United States did it using the Rocketdyne F-l engine, the Grumman-built lunar lander, and Wernher von Braun's Saturn V rocket, and well-trained Canadian and British engineers.

On the question of what were the first man-made objects launched into space, many missiles — the V-2, WAC Corporal, and X-17 among others — achieved altitudes of over 62 miles which has been defined as the beginning of space. Several X-15 pilots were awarded astronaut wings for attaining altitudes above that defining line. *Sputnik 1* may not even have been the first man-made object to orbit the earth. The ubiquitous Fritz Zwicky, the world's most forgotten astrophysicist, a member of Carnegie Observatories, staff astronomer at the California Institute of Technology, a major player in the organization of the Jet Propulsion Laboratory, and holder of several aerospace patents, designed an experiment in which an explosive charge was surrounded with ball bearings. The charge was detonated when the V-2 reached maximum altitude (over 60 miles). The object of the experiment was to create artificial meteors. The ball bearings were blown in all directions with enough force that those that were propelled at the right angle in the right direction may have achieved a highly elliptical orbit around the Earth. Fritz Zwicky was sure that this had occurred. He was sure about many things and was usually right; this should be known for historical accuracy.

And here are a few more items I believe that space enthusiasts — including readers of *Mission Moon 3-D* — should know. The United States could have easily launched the first artificial satellite more than a year before the Russians. On 1956 September 20, von Braun and his team, which included hundreds of home-grown American engineers, launched a four-stage Jupiter-C. President Eisenhower called von Braun directly before the launch and told him to inspect the fourth stage personally and confirm that it was a dummy. He did not want the military to upstage the forthcoming Vanguard launch and destroy the perception that the US was dedicated to the peaceful uses of spaceflight. The missile reached an altitude of 682 miles and Mach-18 velocity. If the fourth stage was a live round it would easily have gone orbital. On 1961 April 12 the Russians launched the first man into space. Several weeks before this the Redstone-Mercury was ready to fly but NASA insisted on one more unmanned mission before it would man-rate the vehicle. It worked perfectly. The delay, however, denied the US the opportunity of putting the first man into space. It was suborbital of course but the world would not have noticed. It seems that sometimes we are our own worst enemy. Rocketdyne, after many teething problems, built the F-1 engine that produced one-and-a-half-million pounds of thrust. A cluster of five of these performed flawlessly during every lunar mission. The Russians did not have the metallurgy or other technical abilities to build engines that large. The smaller engines they were able to manufacture forced them to cluster together 30 of them to achieve the required thrust. Igniting them all at once became a nightmare. They had several launch-pad accidents, one of which killed over 100 technicians and engineers! In the end *Sputnik* was probably good for America. It created a hyper-shock that propelled the whole nation into action. After the great victory of WW II and the exploding post-war economy we had grown fat and lazy, taking our success for granted. *Sputnik* lit a fire under the American public, the universities, private foundations, and the US Congress. It resulted in virtually unlimited funds being made available for any project that could 'beat the Russians'. There was much soul-searching resulting in books being released like *Why Johnny Can't Read,* which sold in the millions. Congress especially released large funds.

Another boost to Apollo came from a source totally unexpected. In the military build-up of the Cold War it was perceived that the Russians possessed over 300 strategic bombers that could attack the US over the vast Canadian Arctic. The United States and Canada were building large numbers of Mach 2 or better long-range interceptors to counter that threat. When extensive aerial reconnaissance by the Discoverer satellites and the U-2 aircraft (amazingly using 3-D aerial photography) revealed that the Soviets only had about 30 aircraft and kept changing the tail numbers and shifting them around various bases to create the illusion of many more, it turned out to be very beneficial to the Apollo programme. It was felt that the existing McDonnell F-101 and long-range Convair F-106 aircraft were adequate to deal with this threat, so the Canadian Government decided to cancel the very high-tech Avro CF-105 Mach-2-plus interceptor; the Avro-Canada Company went out of business. The government was severely criticized but could not defend itself because reasons for the move were highly classified. The benefit was that over 30 of Avro's highly-trained engineers and scientists migrated to the Apollo programme. Many of them made significant contributions and several rose to high management positions in the Apollo programme. When the Eisenhower administration attempted to promote the so-called 'peaceful exploration of space' it was perpetrating a myth. The Vanguard was actually an upgraded version of the US Navy Viking rocket. This decision deprived the US from putting into orbit the first viable satellite (save Fritz Zwicky's ball-bearing objects).

It is very easy to assume that all information gleaned from the Web is accurate, but a source like that has to be used with extreme caution.

Yours faithfully,
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REVIEWS

**Archaeoastronomy in the Roman World**, edited by Giulio Magli, Antonio Cesar González-Garcia, Juan Belmonte Aviles & Elio Antonello (Springer), 2019. Pp. 205, 23 × 15 cm. Price £89·99/$119·99 (hardbound; ISBN 978 3 319 97006 6).

Archaeoastronomy wears two hats. Under the first, ancient data (some written, some not) can clarify parts of modern astronomy. Chinese (*etc.*) observations of the 1054 supernova, which gave rise to the Crab Nebula, is a well-known example. Under the second hat, astronomical information can clarify aspects of ancient cultures, often of the form "someone there, then had the skills to observe that and the interest to record it". Many of those items are alignments of ancient tombs, temples, and tumuli in directions corresponding to locations on the local horizon of Sun, Moon, planet, and star risings and settings on significant dates. Stonehenge is probably the best-known of those, but Magli *et al.* have collected numerous Roman examples as well. Chapters in the present volume extend 'Rome' to other Italian towns and the provinces (Egypt, Petra, Baalbek), and the time frame forward into the middle ages.

I grabbed my copy of *Archaeoastronomy* off a Springer display table, however, for the sake of two chapters on Etruscan temples and cosmology. There were apparently readers of Etruscan as late as the time of Augustus, but it has nevertheless been lost, despite being written with letters recognizably related to those of Greek and Latin. In childhood, I aspired to decode Cretan linear B; when that was done by others, I transferred my allegiance to Etruscan; but ended up with spectra of white dwarfs. The chapters here indicate that some progress has been made.

Antonio Paolo Pernigotti discusses the orientations of Etruscan temples. All 28 of the ones he has (re)measured face some direction, with, he says, a clear preference for directions in which the Sun never rises or sets, but such that the Sun will illuminate the front for some hours every day. The reasons might be 'cultural and ritual' or, I suppose, a desire to keep warm. My Irvine apartment is aligned like an Etruscan temple, with rent historically somewhat higher than the north-facing ones in the same complex. Giovanna Bagnasco Gianni addresses Etruscan cosmology as revealed by a ramped structure about 100 km north of Rome, dated to 600 (±30 or so) BC, in comparison with later Roman texts from Martiannus and Pliny and inscriptions on a bronze stylized sheep's liver used for haruspication. The bronze version was considerably easier to use than a real sheep's liver, especially if the sheep was not through with it. Its surface is inscribed in 40 cells (16 around the edge corresponding to directions on Earth and in the sky associated with various deities and such) each containing one or a few words. Various authorities have differed about which way is north among the margin cells. Some of the words can be read; *ati*, for instance, is 'mother'. (Etruscan was not an Indo-European language.)

Late Roman forts in the Egyptian Western Desert, on the other hand, seem to have been aligned in directions determined by prevailing winds, as read from Google images of nearby sand dunes (chapter by Corinna Rossi and Giulio Magli). Egyptian houses were often arranged the same way, so that prevailing winds from the north could provide some summer cooling.

Watching the sky was important for many groups of humans as far back as interpretable records exist, often to regulate calendars, the timing of festivals, and the dates for sowing and harvesting of crops. The calendars of the Nabataeans and the Roman province of Arabia (chapter by Juan Belmonte Aviles *et al.*)

were of this sort, with time markers for the full moon at the beginning of the year (month of Nisan), the summer solstice, the heliacal rising of Sirius, and the winter solstice. For the benefit of any reader for whom a year beginning with a month of Nisan rings a bell, let me assure you that the Nabataeans also had months of Iyar, Tammuz, Elul, Tishri, Kislev, Thebet (Teves), and Adar, and their language was a form of Aramaic, which can be read, and even written.

But let us end on an astronomical note, by quoting a chapter by Magli, who says that the Temple of Jupiter at Baalbek faced the heliacal rising of the Pleiades, around May 5 at the time of its construction. — VIRGINIA TRIMBLE.

**Simon Marius and His Research**, edited by Hans Gaab & Pierre Leich (Springer), 2018. Pp. 479, 24 × 16 cm. Price £109·99/$149·99 (hardbound; ISBN 978 3 319 92620 9).

It is no fun being accused of plagiarism, and even less fun when the accusation is unjustified and the accuser is the pompous Italian loud-mouth and know-it-all Galileo Galilei. This slur left the German margravial court observational astronomer, mathematician, and astrologer Simon Marius (1573–1625) under somewhat of a cloud until very recently. Four hundred years after Marius published his major work *The World of Jupiter* (*Mundus Iovialis*) a conference was held in Nuremberg and the twenty papers presented there make up this book.

Marius spent most of his life in southern Germany and worked under the patronage of the Ansbach margraves. He was a careful and accurate observer of celestial phenomena and was lent a Belgian telescope at about the same time as Galileo was making his own instruments. Marius wrote annual calendars/almanacs, a tract on the comet of 1596, discussed the nova of 1604, worried about the differences between the Copernican and Tychonian cosmos, recorded details of sunspot activity at a time just before the Maunder Grand Minimum (he was the first to observe sunspots telescopically), and naturally looked through his telescope at Jupiter. Not only did he discover the Jovian satellites independently of Galileo, he also gave them their names. Unfortunately, he published his results in 1614, four year after Galileo. Marius is also credited with 'discovering' the Andromeda Nebula, which he again observed telescopically. Unfortunately he overlooked the fact that it had been seen before, having been described in the *Book of Fixed Stars* by Abd al-Rahman al-Sufi in 964 AD.

The book under review will establish Marius as an illustrious pioneer of German astronomy. And it should erase Robert Grant's *History of Physical Astronomy* (1852) slur that described him as 'an impudent pretender'. The book abounds with references and foot-notes. Marius' major works are reproduced in full. It is rewarding, thorough, academic, comprehensive, and well-illustrated. It is just the sort of major work that will grace the shelves of an astronomy library for many decades to come. — DAVID W. HUGHES.

**Magnificent Principia: Exploring Isaac Newton's Masterpiece**, by Colin Pask (Prometheus), 2019. Pp. 526, 23 × 15·5 cm. Price $18 (about £14) (paperback; ISBN 978 1 63388 568 4).

The average scientist (than whom, of course, our readers are much more knowledgeable) can be expected to know (*i*) that *Principia Mathematica* is the *magnum opus* of a great, perhaps the greatest, physicist of all time, Isaac Newton, (*ii*) that it was written in Latin, and (*iii*) that even in translation, it is fairly heavy going for most of us, because the author used mathematical language, more geometrical than algebraic, that is not generally used today for talking about gravitation and related topics. Colin Pask is not the first to try to do something about item (*iii*), though he is surely the first whose title page proclaims "With a New Preface by the Author". The mind boggles at what (in a world where a single letter by Stephen Hawking was recently auctioned for more than $250 000) a previously-unpublished preface by Newton would bring in. That would, perhaps, not have been the case in his own time, for Pask passes on the rumour that some of Newton's lectures, required of him as Lucasian Professor of Mathematics, were given to empty rooms.

Knowing that Chandrasekhar had published a "modern-language" treatment of *Principia* in 1995, the first place I looked in *Magnificent* was the index, for Chandra's name, intending to compare the treatments. Not there, though the volume is footnoted in several chapters, with the warning that "for the common reader" may understate the challenges of reading Chandra with comprehension.

Portions of *Magnificent* are a pleasure to read, for instance the recounting of Newton's derivations of the shape of the Earth, the cause of ocean tides, and precession of the equinoxes. Pask, however, draws attention also to Newton's cherry-picking of data to have his calculations agree with the astronomical observations. One item I (and perhaps you) had been wrong about concerns the fundamental topic of inverse-square laws and orbit shapes. Newton, it seems, did prove that a conic-section orbit requires an inverse-square-law force; but the inverse, that an inverse-square-law force can produce only conic-section orbits is not so secure, with Bernoulli first to recognize the problem.

*Quid pro quo*, I do not like his dismissal of General Relativity: Pask claims that the "rotation" of the orbit of Mercury can be dealt with in Newtonian terms by adding a $1/r^4$ term. Unfortunately, his version of this term has a mystery parameter, $h$, which is clearly not the Planck constant, nor is it explained nearby in the book. Pask also avers that "in virtually all day-to-day situations, Newton's theory is completely adequate", and I hope his GPS dumps him off the coast at Ulladulla (his back-cover address is in Canberra). We can all, however, agree with Newton that the motion of the Moon is *very* difficult, owing to the multiplicity of the masses involved (three is 'many' in this context) and their not being point masses. — VIRGINIA TRIMBLE.

**The Scientific Legacy of William Herschel**, edited by Clifford J. Cunningham (Springer), 2018. Pp. 373, 24 × 16 cm. Price £131·50/$189 (hardbound; ISBN 978 3 319 32825 6).

I found this book disappointing. Finely produced, clearly and amply illustrated throughout, fully supported with scientific and other scholarly references, and brightened with occasional anecdotes, it nevertheless did not adequately live up to its title. Comprised of seven chapters by six different authors, it has a long central contribution that analyses the optical properties of Herschel's telescopes and which was — by the Editor's own admission — the principal reason for the book. The supporting chapters include an essay on Herschel's switch from musician to astronomer and the strong motivation displayed, accounts of his observations of comets, of 'sky sweeps' and star counts, assembled evidence of his firm belief in ETI, an analysis of Caroline Herschel's role in amateur science, and an anthology of poetry that may reflect Herschel in some way but contributes nothing to the title and purpose of the book. We also catch glimpses of his son John — collaborator, successor, and superior. The front cover portrays a historical figure romantically searching through a catalogue by candlelight, but its origin is not stated.

Having built a telescope (his regular workhorse, the '20-ft') that was recognized as among the best in the world, Herschel made observations that were almost guaranteed to turn up new objects — as indeed they did; his meridian-fixed 'sky sweeps' uncovered star clusters and nebulæ in large numbers, as well as comets. He undertook a scheme of star counts (probably his most valuable contribution to early astronomy as it attempted to depict the form of the Milky Way in 3-D), though frequently oscillating between star-counting and object-hunting.

The back cover hails William Herschel as "England's most famous astronomer", though where Stephen Hawking, Isaac Newton, Bernard Lovell, Jocelyn Burnell, or Patrick Moore rank depends on the context. Without doubt Herschel was determined, painstaking, persistent (and at times extremely lucky), but those are not the only attributes to make one great. He did indeed discover Uranus, but only by chance and not through any methodical calculations as was the case for Neptune, and he did learn telescope building and mirror figuring with results that seemed remarkably good given the tools and materials of the time; but fortune again was on his side, and family members assisted with complementary skills that he had not acquired.

The book is in fact its own downfall. The central chapter is a major discourse on the optics (as examined by ray-tracing with original or replicated materials) of Herschel's many telescopes, including his largest, the '40-ft' (which was curiously unproductive), and its major conclusion is that Herschel's optics could not actually have supported the resolution of all the observations that he claimed, even with the 20-ft. Optical aberrations were rife, though (again through luck) seem to have been minimized by fluke cancellations or overpowered by contrast when observing bright stars. Herschel had decided on a cometary theory that required comets to be spherical, and he claimed that his observations showed that comet images were indeed circular, yet the unavoidable presence of severe coma which that central chapter demonstrates undermines the credibility of his claims. In a Preface the same author remarks boldly that Herschel, "much as he was a great genius, had a strong propensity to cover up anything he considered 'smelling of scandal', that is, not conducive to the betterment of his reputation ...", and there — in a nutshell — is the impression that I too formed. Herschel was convinced of the existence of extra-terrestrial intelligent life, but not content to leave arguments of the plurality of worlds as something for speculation: he was unwise enough to claim that he had observed trees and other vegetation on the Moon, and even 'cities', though no-one else was allowed to borrow his instrument in order to try to replicate the observations. Living under royal patronage, and with a grant from the King to build that 40-ft telescope in order to reveal all kinds of new objects, he dared not admit the instrument's weaknesses, so some of his scientific life was a kind of lie.

Herschel comes across in this book as a gifted craftsman who allowed his personal ideas about the Universe to sway the scientific integrity of his actions. His sky sweeps yielded material that was of indisputable value as starting-ground for the future, but he would not allow others to inspect or share his equipment, did not give references in his papers to published works, and was anything but explicit in reporting the outcome of a major equipment grant. I saw rather little there to herald as 'scientific legacy', particularly not for our own younger generation to emulate.

Contrarily enough, it is the chapter on Herschel's sister Caroline that provides the most interesting and informative backdrop to 18th-Century science and society in Britain and the expected deportment of women even among its educated ranks. Describing the plethora of limitations that could be a minefield for any woman, however capable, the author (Emily Winterburn) reveals her subject not as the usual dutiful or doting amanuensis but as a strong yet well-controlled woman of consequence, trained to perfection in family support yet excelling in independence. But maybe this chapter too offers no role model for modern scientists. — ELIZABETH GRIFFIN.

**No Shadow of a Doubt: The 1919 Eclipse that Confirmed Einstein's Theory of Relativity**, by Daniel Kennefick (Princeton University Press), 2019. Pp. 403, 24·5 × 16·5 cm. Price £24 (hardbound; ISBN 978 0 691 18386 2).

When it comes to observational astronomy there are few more memorable occasions than that of solar eclipse totality. I have managed to go to six, five of which were successful. But when it comes to the advance of astronomical science, solar eclipses have decreased in value. Gone are the days when they led to significant breakthroughs like the discovery of helium, and that the solar corona had a temperature about 350 times that of the photosphere, and that prominences were solar plasma emissions and not gaseous ejections from supposed lunar volcanoes.

The last scientifically significant solar eclipse was that of 1919 May 29. The First World War had just ended. The German scientist Albert Einstein had put forward his general theory of relativity in 1915. This explained the anomalous perihelion advance of Mercury. It also suggested that light had weight and that space was curved. A light beam that passed close to the solar surface would be bent. In 1919 May the eclipsed Sun was in front of the Hyades cluster in Taurus. This highly populated star field meant that the general theory of relativity could be easily tested. So British astronomers decided to do just that. Arthur Eddington (Cambridge's Plumian Professor) set off to the island of Príncipe in the Gulf of Guinea south of Nigeria. Frank Dyson the Astronomer Royal went west to Sobral in northern Brazil. Both places were unfortunately near sea level and in the tropics, neither noted for good astronomical seeing.

Daniel Kennefick, associate professor of physics at the University of Arkansas, USA, celebrates the 100th anniversary of that eclipse by providing us with a detailed, engagingly written, and extremely well-referenced account of the results and their purported confirmation of General Relativity. Starlight was bent by the amount that Einstein had indicated; Newton was overthrown and Einstein was catapulted to world-wide and lasting fame. Kennefick investigates in depth the suggestions that Eddington was biassed. As one of the most significant theory tests in the history of science, Kennefick wonders why the accuracy of this light-bending experiment did not improve at subsequent eclipses in the following years. He overviews the scientific resistance to the acceptance of the results, and the importance of Andrew Murray's reanalysis of some of the original photographic plates at the Royal Greenwich Observatory in the 1970s.

Many astronomers at the time were reluctant to replace the simplicity of Newtonian gravity with the complexities of Einstein's relativity. Kennefick reports how the gravitational redshift in light from the huge gravitational fields at the surface of white-dwarf stars like Sirius B, radio-wave observation of solar occultations of quasars, orbital analysis of binary pulsars, gravitational lensing, and the acceptance of the existence of black holes led to Einstein being vindicated.

What I liked especially about this book was Kennefick's deep appreciation of how science works. He revelled in the interactions between widely different personalities, and the influences of sociological, political, and philosophical nuances. It was a great experiment, that teetered on the edge of the 'just do-able'. Few theory tests in the history of science can match the 1919 eclipse for drama, adventure, publicity, and consequence. Kennefick does it justice and has produced a book that deserves to be read widely and for many years to come. — DAVID W. HUGHES.

**Oor Big Braw Cosmos: A Cocktail of Cosmic Science, Imagery & Poetry**, by John C. Brown & Rab Wilson (Luath Press), 2019. Pp. 255, 21 × 17·5 cm. Price £25 (hardbound; ISBN 978 1 913025 05 2).

This book is refreshingly different. Written with a distinctive Scottish flavour by Astronomer Royal for Scotland, John C. Brown, and Scottish poet, Rab Wilson, it combines a lucid scientific account of our contemporary understanding of the Universe with a collection of cosmically themed poems and verses which have been integrated skilfully into the subject matter of each chapter. Copiously illustrated with images and artworks, the book emphasises the sheer beauty of the cosmos and the creative inspiration it provides for artists and poets.

While the science text is written (by John Brown) in English, the poems and verses, composed by Rab Wilson, are written in Lowland Scots, the language of Scotland's iconic National Poet, Robert Burns. As the authors indicate, Scots is a highly expressive language, well suited to conveying passion about the grandness of the cosmos, and (for those unfamiliar with it) relatively easy to grasp after a few readings. It is well worth making that effort in order fully to appreciate the many poetic gems that this book contains.

The science of the Universe, and the historical perspective on how we have arrived at our current state of knowledge, are explained with clarity, critical evaluation, and touches of humour. The substantial contributions made by Scottish scientists and astronomers over the centuries are celebrated throughout, most notably in a chapter entitled 'Some Early Great Scots Astronomers'. John Brown also includes some delightful personal recollections, including a short history of the origin and evolution of the post of Astronomer Royal for Scotland, and of his (successful) efforts to create an official Coat of Arms for the post. The book includes numerous images obtained by ground-based instruments, orbiting observatories, and spacecraft, and also showcases many fine images produced by amateur astrophotographers, many of whom are Scots (imaging from Scottish locations — despite the climate!). A few, perhaps, suffer from being reproduced at too small a scale, but overall this is a beautifully illustrated book, greatly enhanced by the inclusion of some outstanding artists' impressions and creative artworks (including some created by John Brown himself; who could resist, for example, his 'Planet Suite' on page 38?).

A couple of errors were noted in passing: the mass of the supermassive black hole at the centre of the Milky Way galaxy is quoted as '100 million Suns' at one point (the current figure is in the region of 4 million solar masses), and 'Ralph Shapley' is mentioned on page 149, instead of Harlow Shapley. The bottom line, though, is that this is an altogether splendid book which delivers a delightful, informative, stimulating, and intoxicating "cocktail of cosmic science, imagery and poetry". Visually attractive, a pleasure to read and subsequently dip back into, it should appeal to a wide range of readers from right across the broad spectrum of science, literature, and the arts. — Iain Nicolson.

**Cosmos: The Art and Science of the Universe**, by Roberta J. M. Olson & Jay M. Pasachoff (Reaktion), 2019. Pp. 303, 28·8 × 23 cm. Price £35 (hardbound; ISBN 978 1 78914 054 5).

Astronomy and art are often strange bedfellows. On the one hand you have the scientific boffin, wedded to ever larger telescopes, more-detailed data, faster computers, and extravagant space missions; on the other you have the smocked artist, brush in hand, paint-loaded pallet at the ready, standing before the canvas and easel eager to combine observation and imagination. Artists are allowed to make things up and exaggerate, astronomers are not. The artist's mind is encouraged to wander, the scientist is restricted to sordid reality. But both can stand in awe and wonder at the beauty of our Universe.

Roberta Olson is a New York art historian, and Jay Pasachoff is professor of astronomy and Director of the Hopkins Observatory, Williams College, Massachusetts. They have taken the cosmos and divided it into ten sections — astronomers; star-maps; the Sun and eclipses; our Moon; comets; meteors; novae, nebulae and galaxies; planets; aurorae; and space photography. Each chapter is ordered chronologically. They have then restricted themselves to 306 illustrations, 284 of which are in colour.

The pictures in this book are both absolutely stunning and superbly reproduced, and it must have been a daunting task deciding what to include and what to omit. In fact, two of my favourites, ones I stress when I lecture on the subject, did not make the cut. Claude Monet's *Impression, Sunrise* is mentioned in the text but is not illustrated. And Vincent van Gogh's *Starry Night over the Rhône* (a view only two minutes' walk from the Yellow House in Arles where he was then living) is not there at all, even though Vincent underlined the naughtiness of some artists by painting a south-western sky and including in the sky the constellation of Ursa Major which in reality was behind him.

The text is pacey, erudite, and informative and underlines the detailed, comprehensive, and impressive knowledge the authors have of the subject. I especially appreciated the extensive list of references and the suggestions for further reading. In total the book is a great joy. I loved the way that the authors related the astronomical art to the culture, literature, and politics of the times. One sentence, however, brought me up short. Half way through the book (page 150 to be precise) they state "drawing was a discipline that many astronomers overlooked". Surely that cannot be right. In pre-photographic days the only way that an astronomer had of recording what was seen was by drawing. And here accuracy and skill were paramount.

Interestingly one group of artists has been omitted entirely. They are the people who try to combine both scientific and artistic competence by painting the cosmically inaccessible as accurately as possible. Here we are taken, for example, out to the surfaces of planetary satellites, or into the rings of Saturn, or down to the surface of Venus, or back in time to when the Moon was formed. Names like Chesley Bonestell (1888–1986) spring to mind. That talented space-artist almost single-handedly convinced the USA public to support planetary exploration with their tax dollars. Maybe Roberta and Jay are saving this aspect of the subject for their next volume — David W. Hughes.

**Why Trust a Theory? Epistemology of Fundamental Physics**, edited by Radin Dardashti, Richard Dawid & Karim Thébault (Cambridge University Press), 2018. Pp. 438, 25 × 18 cm. Price £69·99/$89·99 (hardbound; ISBN 978 1 108 47095 7).

This volume has its basis in the landmark conference 'Why Trust a Theory?' held in 2015 December in Munich and organized by the book's editors, and with Dieter Lüst, George Ellis, and Joe Silk. The latter two physicists gave the conference its proximate cause, by authoring a 2014 letter to *Nature* entitled 'Scientific method: Defend the integrity of physics', in which they criticize a weakening in long-held principles of scientific methodology that they claim has arisen in speculative areas of theoretical physics, especially string theory, inflationary cosmology, and wherever the multiverse and anthropic reasoning are invoked. They conclude by issuing a call for a conference to be held where issues surrounding methods in theoretical physics could be discussed by philosophers and physicists from all sides of the debate. This call was answered by philosopher Richard Dawid, then at the Munich Center for Mathematical Philosophy, whose work is explicitly mentioned in the letter for its defence of a novel methodological perspective on theory confirmation (for example, in his recent book *String Theory and the Scientific Method*).

This collection of essays encapsulates the many points of view available on the epistemology of fundamental physics, and it includes papers presented at the conference and some invited afterwards to complement them. There are 22 papers by historians, philosophers of science, string physicists, string phenomenologists, cosmologists, and theoretical physicists working in several other paradigms. By no means does a common consensus emerge from the chapters (except perhaps the acknowledgement by all parties that empirical testing is definitive of substantial theoretical confirmation); the interest of the book lies rather in the diverse perspectives brought to bear on a common set of methodological concerns. Anyone interested in current speculations about fundamental physics, in particular debates about its methodology and justification, will find much fascinating reading here. — CASEY McCOY.

**Under One Sky: The IAU Centenary Symposium (IAU Symposium 349)**, edited by Christiaan Sterken, John Hearnshaw & David Valls-Gabaud (Cambridge University Press), 2019. Pp. 542, 25 × 16·5 cm. Price £96/$130 (hardbound; ISBN 978 1 108 47159 6).

The IAU decided to celebrate its centenary a year early, in keeping with its triennial pattern established from 1922 to 1925. Its own history occupied one plenary session (a talk, by Malcolm Longair, a written version of which begins the present volume) and one symposium, though scraps of history wormed their way into a supernova session and elsewhere. There is some overlap here with the comprehensive history of the IAU by Johannes Andersen *et al.*, recently published and reviewed in these pages (**139**, 158, 2019), particularly in giving a good many pages to the thoughts of past Union presidents and secretaries general.

Here are some of my favourite 'a ha!' items: (*i*) the first, 1922 Rome, General Assembly was held jointly with that of the International Geophysical Union; (*ii*) the Mexican delegation to 'the Star and Variable Star' commissions in 1922 tried hard to arrange an invitation for Einstein (even offering to pay the travel expenses). This was, however, impossible under the 'exclusion of the Central

Powers' rubric of early constitution and by-laws. The 'Astronomy in Mexico' chapter, incidentally, is wrong about Ludvik Silberstein being President of the Commission on Relativity when it voted itself out of existence. Recent perusal of Volume 2 of the IAU Transactions confirms my impression that Tullio Levi-Civita was in charge, and only the Italian delegation had suggested trying to look for bending of light by Jupiter; (*iii*) Anne Underhill was President of Commission 36 (Stellar Atmospheres) for 1967–70, beating E. Margaret Burbidge (President of 28, Galaxies) by a term, though I am still not sure who was the first woman Commission President; (*iv*) the first German IAU President, Otto Heckmann, had actually been a member of the National Socialist party in the years before World War II. This appears in a very interesting chapter by Jean-Claude Pecker, entitling me to two micro-anecdotes: first that J-CP is the only General Secretary with whom I danced at more than one General Assembly banquet, and second, that my suspicion that the first paper coming out of my PhD dissertation had been refereed by a Nazi was true; (*v*) according to former *ApJ* editor Helmut Abt (who broke a leg and was unable to give his talk), colour in printed journals no longer costs significantly more than black and white (and won't somebody please tell the publisher who recently asked me for about $1500 for colour graphics in a scientometrics paper); (*vi*) there is some study of indigenous astronomy in South Africa (and we hope many other places, including a pre-Hispanic solar observatory in Peru); (*vii*) some fascinating photographs taken by the American contingent in Belgium in 1919 July were included, for mysterious reasons, in the 'astronomical publishing' section.

You would undoubtedly have picked out different highlights from others of the 62 contributions, perhaps even my own, on international cooperation in astronomy before the IAU — that is a conflict-of-interest statement! — VIRGINIA TRIMBLE.

**Universal Life: An Inside Look Behind the Race to Discover Life Beyond Earth**, by Alan Boss (Oxford University Press), 2019. Pp. 206, 24·5 × 16 cm. Price £16·99 (hardbound; ISBN 978 0 19 086405 7).

Beware what you are buying with this book. It is almost entirely about discovering exoplanets and particularly establishing the fraction of stars that have potentially habitable Earth-sized planets. The latter is a term usually abbreviated $\eta_E$, and referred to as eta-Earth, which appears in the Drake equation. Despite the book's title there is so little about life in it that 'life' does not appear in the index. There is some discussion about planetary protection and the value of the regulations prohibiting Mars rovers from visiting the sites most likely to host extant life, and, in the finale, an opinion that characterization of an exoplanet's atmosphere (perhaps by the *James Webb Space Telescope*, *JWST*) will find evidence of life beyond Earth before any mission to Mars.

What it delivers instead is an insider's account of exoplanet-hunting satellites and ground-based telescopes, describing (very much from a US–NASA perspective) the rival techniques and the at-times-brutal rounds of competition for funding, battles to limit de-scoping, and the spinning of press releases. Its canvas is the spectacular decades or so leading up to today, during which exoplanets have gone from not-yet discovered to characterized in their thousands, and the confident knowledge that most stars have planets and that there might be more habitable planets around red dwarfs than for Sun-like stars.

Given that there could be more than one habitable planet in some systems, it now seems likely that $\eta_E$ is considerably closer to 1 than it is to 0·1. All this in an era overcast by the huge shadow of delays and massive cost over-runs to *JWST*.

Alan Boss does not shy away from wry asides, nor from frankness in his assessment of the motives and abilities of some of the more politically-motivated players when it comes to supporting (or otherwise) large projects. Towards the end he muses on whether "imaginary" might be a better term to describe a particular congressman's ideas rather than "visionary", going on to comment wryly that imaginary numbers would be needed to apply valuations of a Technology Readiness Level to some of the proposals he favours.

The book has a few minor stylistic errors, perhaps symptomatic of the haste in which this version, replacing the previous *The Crowded Universe* (2009) and *Looking for Earths* (1998), was overhauled to include events as recent as 2018 April. For example, I think it unlikely that readers of this book need to be told the value of π to twelve significant figures (on p.110), but any who do will not be helped by the fact that the 4 in the second decimal place appears erroneously as a 5.

This will be a great account for historians. It was an exhausting, but insightful read for me. I suspect few will easily keep track of all the missions, telescopes, and committees — thank goodness for the six-page list of acronyms. — DAVID A. ROTHERY.

**Apollo to the Moon: A History in 50 Objects**, by Teasel E. Muir-Harmony, (National Geographic, Washington, D.C.), 2018. Pp. 303, 23·9 × 19 cm. Price $35 (about £28) (hardbound; ISBN 978 1 4262 1993 1).

One of the fascinations of astronomy is the remoteness of the subject matter. Unlike many other sciences, you can look but you cannot touch. But in one instance this changed on 1969 July 20. Two men travelled to, and then walked on, our satellite Moon. By 1972 December that number had increased to twelve. That number has not changed since. Humans have not been back. We return to sitting on Earth and peering up.

The USA's Apollo mission is now history and there are few better ways of celebrating the fiftieth anniversary of this momentous adventure than by going to a museum and looking at artefacts. The book under review promotes the importance of museums in stimulating the support of the general public for science in general and planetary and astronomical science in particular. The specific museum is the Smithsonian National Air and Space Museum, Washington, D. C. (admission is free). The author, Dr. Muir-Harmony, is a curator there and an expert on the history of space exploration.

She has chosen fifty objects to commemorate the Apollo mission, each one being colourfully illustrated, catalogued, and explained. Muir-Harmony spreads the net wide. We read of the Airfix model kit of one-inch tall plastic Apollo astronauts; the urine collection and transfer assembly, which in the case of Buzz Aldrin broke when he leapt from the Eagle's ladder leaving him with a liquid-filled left boot; and of one of *Apollo 11*'s F1 rocket engines that has been retrieved from an Atlantic depth of 14000 ft. Then there is the Moon's first astronomical telescope, set up in the shadow of the *Apollo 16* lander. This imaged and took spectra in the far ultra-violet. The film was returned to Earth and the engineering model is in the museum. What I liked especially were the human things. The Gillette razor used by Michael Collins, the *Apollo 11* Command Module pilot; the chair that John F. Kennedy sat in when debating with Richard

Nixon at the start of the Space Race; the $45 drug-store camera that John Glenn bought to record views from the window of *Friendship 7*; the huge heap of software printout nearly dwarfing Margaret Hamilton, Apollo's lead software designer; and the, to me, rather unappetising-looking food produced by Rita M. Rapp, head of the Apollo Food System team. I also loved the charity collecting tin, rattled by members of the Southern Christian Leadership Conference — many of the USA's poor disagreed with the lavish space budget.

Muir-Harmony has got the balance right. I might have included some of the 'orange soil' found by Harrison Schmitt, a serendipitous discovery that underlined the usefulness of having a scientist on board, and maybe slightly more could have been made of the world-wide reception of this magnificent endeavour. But the end-product is a beautiful non-technical book that is inspiring, entrancing, and informative — one that surreptitiously underlines the role of museums in civilization, culture, and education. It made me wonder if today's astronomers are doing enough to support, encourage, and endow our museum system. — DAVID W. HUGHES.

**Mission Moon 3-D: Reliving the Great Space Race**, by David J. Eicher & Brian May (MIT Press & The London Stereoscopic Company Ltd.), 2018. Pp. 192, 31·5 × 24 cm. Price £30 (hardbound; ISBN 978 1 9996674 0 5).

I have been collecting 3-D books, photographs, viewers, and other devices relating to the subjects of astronomy, aviation, spaceflight, and aerial reconnaissance since the 1960s. I have acquired many great books but this volume contains some of the finest 3-D photographs I have ever seen. They are a joy to view when the viewer is properly held. (More about this later!) Published to honour the 50th anniversary of the first manned lunar landing in the summer of 1969, the uniqueness and quality of this publication may result in many future editions and wide sales.

At first glance the artistically designed cover gives it the appearance of a coffee-table book. Far from it: sandwiched between a foreword by *Apollo 16* moonwalker Charlie Duke and an afterword by *Apollo 13* astronaut Jim Lovell, who was denied the opportunity to walk on the Moon by the near-fatal accident that resulted in a harrowing trip back home, are a preface by author David J. Eicher, an introduction by co-author Brian May, and 14 chapters comprising a reasonably accurate history of the space age culminating in a celebration of the 50th anniversary of the first lunar landing. Throughout there are dozens of photographs magnificently reproduced in both two dimensions and 3-D, many of which this writer, despite spending 60 or more years reading a huge number of books and reports on the space age, has not seen. Overall I think it is a well-written account of the early space age.

I do, however, have issues with three statements that I hope will be corrected in future editions. But since they are rather more-widely-held misconceptions I will treat them in a letter elsewhere (p. 237) in this issue. First, on page 29, paragraph 2, line 4 it is stated that Max Faget was born in Belize. Second, the caption under the photograph of Wernher von Braun at the bottom of page 30 states "Dr. Wernher von Braun, the father of rocket technology in the United States" is completely in error. Third, the caption under the photograph on page 20 states "Sputnik 1, the first man-made object to enter space" is erroneous.

However, the writing style is fluent and easy to read. And it's nice to have it endorsed by Charlie Duke, one of the few remaining folk who's 'been there, done that'. Information on the cameras is also appreciated. On page 14 it mentions Viewmaster viewers and discs released in the 60s and 70s. Few people know that earlier versions go back to the 30s and were used by the military in WW II to train personnel in aircraft and ship recognition; I have some of these. I also have a vast number of astronomy, aviation, and spaceflight books and reports I've collected over 60 years. Not everything is on-line! I have been collecting books, documents, and other literature on astronomy, spaceflight, aviation, and optics since I was very young. In my pre-teen years I would send away order forms to the National Advisory Committee for Aeronautics, the predecessor of NASA, and receive large packages in the mail. Since then I have received or bought out several libraries of thousands of documents. I hope someday to leave them in a hardcopy library so people can enjoy them for generations after I am gone.

Unfortunately, one of the items missed in the brief history of 3-D photography are the contributions of two little-known societies. The American Photogrammetric Society and its British counterpart the International Photogrammetric Society. Those two organizations did much development work before, during, and after WW II to bring into existence techniques and methods of three-dimensional photography as applied to geology, agriculture, and aerial reconnaissance that gave unprecedented capabilities to the allies. These developments were also used extensively in forestry, agriculture, and many other areas after the war.

And finally, as mentioned at the beginning of this review, I would like to make some comments about the 3-D viewer included with the book. There are many comments on the internet but none say why it is difficult to use. There are several reasons. First the viewer must be held in exactly the right position with a steady hand. Many people, even young people, do not possess that steady hand. This problem was solved many, many years ago by the military when they realized that the viewer must be in a correct position to find small details on aerial reconnaissance photographs: they added small foldable wire legs. The legs could be easily folded so the viewer was compact and could simply be carried in a shirt pocket. When extended it would hold the viewer in three dimensions orientated exactly over the photograph at the proper height; something most people who have never used a viewer don't realize is that the photograph must be flat to achieve the three-dimensional effect over the entire picture. When a large book is open flat on a table the pages will be bowed. The legs press the photograph flat permitting the full three-dimensional effect to dazzle your eyes. Another problem is the placement of the viewer in the back of the book. The viewer is held in place by a cardboard strip. I managed to slip it in and out without cutting that strip. Most people, however, will probably cut it. Over the years the viewer will most likely get lost, making it difficult for future owners to view these outstanding and timeless pictures. The solution, however, is easy: a space-age invention from the space programme is Velcro, invented so objects floating in weightlessness could immediately be stuck to the wall out of the way. There were Velcro straps attached all over the interior of the command module and the lunar lander — so, why not in the book? It's part of Apollo history! I also would recommend good crown glass instead of plastic for the lenses: my years of experience with optics has shown that plastic lenses eventually fog up.

One last thought: on page 9, paragraph 2, in the preface by David Eicher, 'free viewing' is described. This technique is fine for most people, but some people with weak eye muscles may need professional help to re-adjust their eye muscles. This, however, is very rare.

To sum up, the photographs are outstanding and for this alone the book is well worth the price. However, when writing a history of the flight to the Moon all aspects of the period must be studied — the cold war, military, the politics of the time, *etc*. They are completely intertwined and it is impossible to separate different aspects of history. Also research should be done by referring to the original hard-copy books and documents. (Although the internet is good for quick reference it is by no means adequate for scholarly work. I have found that it is loaded with misinformation, missing many publications, and possesses many opinionated articles disguised as scholarly works. It is in effect a secondary source of information because everything is copied from originals and many things are missed.) I believe that this work, after some revisions and the replacement of the stereo viewer so all can view the photos in their full glory, may very well be a landmark publication. I shall be the first in line to purchase the next edition. — LEONARD MATULA.

**The Space-Age Presidency of John F. Kennedy: A Rare Photographic History**, by John Bisney & J. L. Pickering (University of New Mexico Press), 2019. Pp. 205, 31 × 23·5 cm. Price £47·50/$45 (hardbound; ISBN 978 0 8263 5809 7).

John F. Kennedy, WWII hero and 35th President of the United States, was one of the most charismatic statesmen of recent times. He came to power early in 1961 when tensions with the communist regimes, particularly the Russia of Nikita Khrushchev and the Cuba of Fidel Castro, were running high. Indeed by late 1962 the world was on the brink of nuclear war, but Kennedy's resolute stand de-fused the crisis and the 'Cold War' remained cold. However, JFK's concern over Soviet supremacy in space — *Sputnik 1* was launched in 1957 and the first orbital flight by Russia's Yuri Gagarin took place on 1961 April 12 — compelled him to put America's space programme at the top of his agenda.

Thus, although the USA's security dominated JFK's short presidency (which ended tragically with his assassination on 1963 November 22), he is famously remembered (especially this year) for his speech on 1961 May 25: "… I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon, and returning him safely to the Earth."

This period is brilliantly documented in the present coffee-table volume, with hundreds of photographs of people (politicians, project staff, astronauts, *et al.*, and including James Webb and Werner von Braun), space craft and facilities, and mementoes, each accompanied with explanatory notes outlining the numerous projects on-going at the time, such as Alan Shepard's sub-orbital flight on *Freedom 7*; John Glenn's orbital flight aboard *Friendship 7*; Scott Carpenter's voyage on *Aurora 7*; and the development of the Minuteman defence rockets. For the space buff and/or science historian it is a treasure trove, and for those of a certain age it's a nostalgic walk down memory lane and a sad reminder that the excitement of yesteryear has today rather faded. — DAVID STICKLAND.

**Early Exploration of the Moon: Ranger to Apollo, Luna to Lunniy Korabl**, by Tom Lund (Springer), 2018. Pp. 391, 24 × 17 cm. Price £24·99/$37·99 (paperback; ISBN 978 3 030 02070 5).

This volume is one of many books and documentaries that have been released to mark the 50th anniversary of the historic *Apollo 11* mission — the first time that humankind set foot on another world. However, this book differs from most of the others by concentrating on the technology that was developed between the late 1950s and the mid-1970s, in order to explore Earth's neighbour in space.

Aerospace engineer Tom Lund, who was actively involved in NASA's monumental endeavour to land people on the Moon, avoids discussion of personalities, or the political, diplomatic, and financial motivations and repercussions behind early lunar exploration. Instead, he describes in considerable detail the hardware that enabled both the United States and the Soviet Union to pioneer exploration of an alien world.

Lund includes the ingenious automated craft that orbited the Moon and observed its unseen far side for the first time, landed on its surface, and returned surface samples to laboratories on Earth. However, not surprisingly, some two thirds of the book is devoted to the Apollo hardware — the technologies that resulted in "one giant leap for mankind". Developed in less than a decade, most of this hardware was truly revolutionary and innovative. The road was not always smooth, but the achievements were remarkable, eventually enabling astronauts to leave their footprints in the lunar dust and drive many kilometres across the cratered plains in a battery-powered roving vehicle.

The author seems particularly comfortable describing the technical details of American spacecraft, from the relatively primitive Ranger series to the Lunar Orbiter and Surveyor craft that paved the way for the successes of Apollo. The final chapters on the Soviet robotic missions and the failed efforts to send cosmonauts to the Moon have been covered in more depth in other publications.

For anyone interested in learning more abut the technology behind Apollo and its predecessors, I would recommend this book as an interesting and useful reference. — PETER BOND.

**More Things in the Heavens: How Infrared Astronomy is Expanding our View of the Universe**, by Michael Werner & Peter Eisenhardt (Princeton University Press), 2019. Pp. 282, 24 × 16·5 cm. Price £27 (hardbound; ISBN 978 0 691 17554 6).

The authors of this excellent book could have included *Spitzer* in its subtitle because it is essentially a celebration of the significant impact of *Spitzer* observations on almost all branches of astronomy. Certainly, there is much to celebrate, especially given the long gestation of the mission, known as *SIRTF* for decades. The saga of its development, in which the authors played significant roles, is summarized in an appendix, followed by another appendix describing the telescope, its instruments, and operation.

The book begins by highlighting the advantages and difficulties of observing in the infrared, and introducing *Spitzer* in the context of infrared space missions. The second chapter gives readers a whirlwind tour of 'the sky as seen by *Spitzer*', the space covered in detail in the following 13 chapters. The authors write lightly, for a wide readership, explaining possibly unfamiliar terms and giving more detail in the most informative notes to each chapter.

The next five chapters describe observations of YSOs and proto-planetary discs, leading on to debris discs, exoplanets, and the constituents of our Solar System. I found the results in these chapters, particularly the inferences about conditions on exoplanets, real eye-openers. There are many more, *e.g.*, the previously unknown large ring about Saturn, the 'V-ring', related to Phoebe, and the 2006 24-μm image of the fragments of Comet Schwassmann–Wachmann 3 broken up after its 1995 perihelion passage. The authors describe observations of NEOs during the *Spitzer* 'Warm Mission' but could have mentioned the discovery of NEOs and comets in the post-cryogenic phase (NEOWISE) of the *WISE* mission and its long-term reactivation. The two instruments work at very similar wavelengths, but the low orbit of *WISE* provides an observing cadence well suited to the discovery of fast-moving, nearby objects. The authors conclude this section of the book by examining the connections between Solar System, exoplanetary systems, and debris discs. Similar connections between phenomena in different environments are made throughout the book and hold it together well.

The following chapters take us through the Galaxy and Local Group, with iconic 8-μm images showing PAH and dust emission, including the inner ring in M31. Right from the beginning, surveys were an important part of the *Spitzer* programme, generating legacy data sets which provide foundations for a range of investigations. These, particularly the extra-galactic surveys, are discussed in Chapter 11, where the authors give a striking example of the huge advantage of space over ground-based observations by comparing the *IRAC* 3·6-μm survey sensitivity with that from several nights' ground-based (*Keck*, no less) observations at 3·2 μm. Ground-based observations do, however, provide higher spatial resolution than space instruments, but don't get much of a look-in here. And so we move on to the history of star and galaxy formation and (ultra) luminous IR galaxies, along with the uses of mid-IR spectra to distinguish the effects of starburst and AGN activity.

Altogether, this is a most impressive story, not just for specialists, clearly told and profusely illustrated. I found it a pleasure to read and recommend it strongly. — PEREDUR WILLIAMS.

**Astrophysics with Radioactive Isotopes, 2nd Edition**, edited by Roland Diehl, Dieter H. Hartmann & Nikos Prantzos (Springer), 2018. Pp. 674, 24 × 16 cm. Price £129·99/$179·00 (hardbound; ISBN 978 3 319 91928 7).

My initial encounter with the book under review came in early 2012 when it appeared in the Springer series *Lecture Notes in Physics* as Volume 812 with the title 'Astronomy with Radioactivities'. I found the volume's ten chapters across the broad front of nuclear astrophysics exceedingly useful in preparing for my final graduate class on nucleosynthesis. The present volume, listed as the second edition of the 2011 book, has the new title *Astrophysics with Radioactive Isotopes* and appears in the Springer series *Astrophysics and Space Science Library* as Volume 453. The three editors explain in their preface that the change of title "reflects the new emphasis to discuss the astro-physical considerations, more than merely presenting them as background for the astronomical achievements only". Several chapters have been rewritten and "in some cases dramatic, insights of the past eight years were woven in".

I commend editors Roland Diehl, Dieter Hartmann & Nikos Prantzos for their extraordinary ability to convince the many authors to revise their contributions. The ten chapters from the 2011 edition appear again with the same authors. The present Chapter 11 on 'Cosmic Evolution of Isotopic Abundances: Basics' by Diehl & Prantzos is new and is a solid 50-page contribution. The final chapter on branching points along the *s*-process path formed an Appendix in the 2011 edition. The entire volume should surely once again find a place on a reading list for a graduate course on nucleosynthesis and related matters. Moreover, the volume under review deserves to be read by young and old astrophysicists.

One surprise! It's my recollection that the story of radioactive isotopes beyond the Solar System begins with Paul Merrill's 1952 discovery of technetium in S stars. Although this transformative discovery is listed in Appendix A of 'Milestones', Merrill's discovery is not found in the list of references at the end of the 12 chapters. That discovery may fairly be described as the key evidence that some stars were then synthesizing some elements internally — novel observational evidence in the 1950s. I invite — indeed, challenge — a young astronomer to track down the papers reporting the discovery of technetium. And then to reflect how, if the discovery had been made today, journal publication would be drowned by an extraordinary barrage of publicity releases across all possible platforms. Paul Merrill's discovery deserved considerable publicity and deserves to be remembered as a milestone. Indeed, the discovery was a breakthrough. Few of the targets of today's publicity barrages deserve to be identified as breakthroughs! — DAVID L. LAMBERT.

**Laboratory Astrophysics**, edited by Guillermo M. Muñoz Caro & Rafael Escribano (Springer), 2018. Pp. 237, 24 × 16 cm. Price £99·99/$139·99 (hardbound; ISBN 978 3 319 90019 3).

My understanding of what constitutes laboratory astrophysics does not match that of the editors of this volume. When I was asked to write this review, I was expecting a wide-ranging compendium of data measurements and experiments that need to be carried out to underpin our understanding of astrophysics. Examples in my mind were measurement of basic atomic/molecular physics to incorporate into stellar/planetary atmosphere models or physical properties for materials such as filters and sensors for use in astronomical instrumentation. Unfortunately, I found myself disappointed when I started to read this book as there is little of what I was hoping to see within the pages.

In contrast to my expectations, the series of contributed chapters focusses on dust and ice in the interstellar medium. Starting with chapters on the basic science of interstellar dust and ice and observational techniques, the following chapters do then look at the laboratory aspects of the science, including measurements of the properties of ice and dust, ranging from structural to optical properties. In this context, the book does deliver an excellent overview of an important subject. It is well organized and the chapters are all well-written and presented. The topics flow nicely from one to another. If the astrophysics of dust and ice were within the scope of my science, the volume would be a valuable reference, and I did indeed learn some interesting background to the subject. However, there is a risk that potential readers might spend a significant sum buying this volume and then be disappointed. I feel that a more appropriate title, one that more accurately signposts the content, should have been chosen. Please change it for the next edition. — MARTIN BARSTOW.

**The Monthly Sky Guide, 10th Edition**, by Ian Ridpath & Wil Tirion (Dover Publications), 2019. Pp. 77, 30 × 21 cm. Price $19·95 (about £16) (paperback; ISBN 978 0 486 83259 3).

It's an old adage, "if it ain't broke, don't fix it", and that seems to be true of *The Monthly Sky Guide*, which appears now in the tenth edition, although one notable change has been made — it's no longer published by Cambridge University Press; but Dover has fortunately picked up the baton. No less than six previous editions have been reviewed in these pages, all being accorded a warm welcome by the various reviewers (both amateur and professional).

The layout is familiar, starting with a gentle introduction to all those objects readily seen in the night sky by anyone with a dark sky and perhaps a pair of binoculars. We then progress to the (northern-hemisphere) user-friendly maps for each month, showing the 'fixed' stars but with supplementary information on principal constellations (one for each month) and meteor showers. For the 'wanderers' (planets) and other time-variable phenomena, such as eclipses, information is given for the years 2020 to 2024, the latter date presumably coinciding with the release of the eleventh edition.

The *Sky Guide* is a splendid companion for observers. — DAVID STICKLAND.

**Gravitational Wave Astrophysics: Early Results from Gravitational Wave Searches and Electromagnetic Counterparts**, edited by Gabriela Gonzalez & Robert Hynes (Cambridge University Press), 2019. Pp. 107, 25 × 18 cm. Price £98 (hardbound; ISBN 978 1 107 19259 1).

The (mythical) *Wit and Wisdom of Richard Nixon* is the supposed prototype of 'thin books'. The (real) *Gravitational Wave Astrophysics* is, however, in the running: Nixon at least was cheap, which this present volume, at about $1·24 per page of the 107 numbered ones is not.* The press conference announcing the first double-neutron-star merger (GW170817) coincided with the first day of the conference, whose proceedings have been delayed to permit incorporation of some papers on the optical counterpart of that event.

There were one hundred participants and 59 authors (not all participants), many representing teams (including *DECam*, *AGILE*, *GRAWITA*, *PanSTARRS1*, and *LIGO* itself). The volume has no indices except that of authors and no photograph of the participants. Richard C. Henry has provided the one cheerful chapter, 'How Einstein's Theory of Relativity Gives us $E = mc^2$ and the Atomic Bomb', in which he proclaims (*i*) that writing out equations is good for students; (*ii*) that in a properly regulated scientific universe both $c$ (the speed of light) and $h$ (Planck's constant) would be one (much simplifying the execution of item (*i*)); and (*iii*) that Minkowski's writing of special relativistic intervals as $s^2 = x^2 + y^2 + z^2 - t^2$ is the most important insight into the nature of the Universe in the history of human thought.

Conflict-of-interest statement: the time scale on which the IAU chooses which symposia to sponsor is such that, when Gravitational Wave Astrophysics was proposed, not even GW150914 had been announced, and your reviewer was among the minority of low-level voters who said the proposal was premature (though the co-SOC chairs Gabriel Gonzalez and Neil Gehrels — sadly no longer with us — might have had some advanced knowledge). I'm not sure what filled the four days of the symposium, but the thinness of the proceedings and its contents suggests the nay-sayers were right. *IAUS349*, from 2018 August, runs to 542 pages, and we contributors had to be beaten over our typing fingers to keep it that short. — VIRGINIA TRIMBLE.

* Other candidates are *Pretenders to the Throne of Switzerland*, *Great Quarterbacks of U California*, *Irvine*, and *Family-tested Recipes for Oleander Soup*.

**Relativistic Geodesy: Foundations and Applications**, edited by Dirk Puetzfeld & Claus Lämmerzahl (Springer), 2019. Pp. 479, 24 × 16 cm. Price £99·99/$139·99 (hardbound; ISBN 978 3 030 11499 2).

Geodesy is the science of measuring and modelling the Earth's shape and its gravitational field. The present volume is based on the invited lectures at a 2016 conference of the same name. The 15 chapters survey a variety of topics in geodesy and related areas from a general-relativistic perspective. As is typical of edited volumes, the individual chapters vary in style and level of technical detail, and can be read independently. Two chapters have glossaries, but there are no indices to either individual chapters or the volume as a whole.

The opening chapter by Andras Bauch is a fascinating survey of the contemporary technology of high-precision time and frequency standards, along with methods for comparing clocks in different locations. Because the gravitational redshift near the Earth's surface is on the order of one part in $10^{16}$ per metre of height, precise clock comparisons can be used for 'chronometric levelling'. As Pacome Delva, Heiner Denker & Guillaume Lion write in their chapter, "Now that the atomic clock accuracy reaches the low $10^{-18}$ in fractional frequency [...], the accuracy of chronometric levelling reaches the cm level and begins to be competitive with classical geodetic techniques". As discussed by the authors, reaching these extreme accuracy levels demands careful handling of the Sagnac effect, both solid-earth and oceanic tides, and various other perturbations.

The chapter by Aurélien Hees and co-authors is a review of the use of geodesy and geophysics measurements to constrain dark-matter models and various possible modifications of (or alternatives to) General Relativity and the standard model of elementary-particle physics.

Some of the other chapters focus on the philosophy and epistemology of relativistic measurement. For example, Bartolomé Coll's and Bruno Hartmann's chapters survey the logical frameworks of what an observer can measure and how to define such quantities as coordinates, redshifts, distances, inertial mass, and momentum based on locally-observed quantities. These chapters reminded me in some ways of Percy W. Bridgman's classic book *A Sophisticate's Primer of Relativity*[1].

Several theoretical chapters focus on how an observer can (in a *gedanken* sense) measure components of the Riemann curvature tensor, or how, given this, one can infer the space–time metric. Bahram Mashoon's chapter discusses what a local observer can learn from measurements of the local tidal field, *i.e.*, of projections of the Riemann curvature tensor on a local coordinate basis. Other chapters review the theoretical formalisms for operationally defining coordinate systems, multipole moments, world-line perturbations, and other such quantities in curved space–times, with particular applications to the vicinity of the Earth.

The final two chapters — one by Rolf König & Ignazio Ciufolini and the other by Ciufolini and eight co-authors — both discuss the experimental measurement of Lense–Thirring frame dragging, where a massive spinning object 'drags' nearby local inertial reference frames into rotating with respect to distant inertial observers. Using the Earth as the rotating source this effect is very small (about 30 to 40 milliarcseconds/year), so measuring it requires exquisite experimental precision and control of systematic errors. There have been two relatively 'clean' measurements of this effect, one by Everitt *et al.* (using the *Gravity Probe B* satellite, hereinafter *GP-B*)[2], and one by Ciufolini *et al.*[3–5] using the *LAGEOS*, *LAGEOS 2*, and *LARES* satellites.

The *GP-B* group measured the precession of the spin axes of four cryogenic gyroscopes in Earth orbit, confirming the General Relativity prediction of Lense–Thirring frame dragging to an accuracy of roughly 19%. This experiment was intended to reach about 1% accuracy, but suffered from static-charge effects in the gyroscopes and their housings which greatly impaired the accuracy. While of modest accuracy, this measurement was very robust, with excellent consistency between two independent analysis methods for the static-charge effects, and between the individual results for the four gyroscopes.

The *LAGEOS/LARES* group measured the *orbital* precession of these Earth-orbiting satellites, confirming the General Relativity prediction to an accuracy of roughly 20%[3], 10%[4], and 5%[5] in successive refinements of the experiment. The main difficulty with this experiment is that the non-sphericity of the Earth causes Newtonian-gravity orbital perturbations on the order of $10^7$ times larger than the Lense–Thirring effect. The measurement of the Lense–Thirring effect thus depends very sensitively on the construction of observables which combine the orbital parameters of multiple satellites so as nearly to cancel the dominant Newtonian-gravity orbital perturbations, together with the simultaneous estimation of certain key Newtonian-gravity-field parameters. The error budget for the Lense–Thirring measurement is dominated by hard-to-quantify systematic uncertainties in the Newtonian-gravity-field modelling. These issues, together with the expected improvements in accuracy from observations of the *LARES 2* satellite (planned for launch in late 2019), are nicely described in the two chapters by Ciufolini and his co-authors. But I was disappointed that one of these chapters contained no mention at all of the *GP-B* result, and the other chapter mentioned the *GP-B* result but did not cite the published *GP-B* paper[2]. (In their published works, both the *GP-B* group and the *LAGEOS/LARES* group do appropriately cite each other, *e.g.*, ref. 2 cites ref. 4, and ref. 5 cites ref. 2.)

A surprising omission from this volume is any in-depth discussion of the modern satellite navigation systems *GPS*, *Galileo*, and/or *GLONASS*. Rather, these — and the many Special- and General Relativistic effects which are accounted for in their software — are simply 'taken for granted', with various chapters describing these systems' use for various measurements. (For a fascinating and highly readable survey of relativistic effects in the *GPS* system, see Ashby's review paper[6] (open-access online).)

In conclusion, this volume surveys a broad range of topics in modern geodesy where relativistic effects are important. The technical background required of the readers varies from chapter to chapter: a few chapters require only a knowledge of Special Relativity, but most make at least some use of General Relativity. For about half of the chapters using General Relativity I think a reader with lesser background could reasonably 'read around' the General Relativity material; for the remaining chapters the use of General Relativity is pervasive. Readers with the appropriate background and interests will find much to learn from this volume. — JONATHAN THORNBURG.

### *References*

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(2) C. W. F. Everitt *et al.*, *Physical Review Letters*, **106**, 221101, 2011.
(3) I. Ciufolini *et al.*, *Science*, **279**, 2100, 1998.
(4) I. Ciufolini & E. C. Pavlis, *Nature*, **431**, 958, 2004.
(5) I. Ciufolini *et al.*, *European Physical Journal C*, **76**, 120, 2016.
(6) N. Ashby, *Living Reviews in Relativity*, **6**, 1, 2003.

**Astronomical Spectroscopy: An Introduction to the Atomic and Molecular Physics of Astronomical Spectroscopy, 3rd Edition**, by Jonathan Tennyson (World Scientific), 2019. Pp. 264, 23 × 15·5 cm. Price £40 (paperback; ISBN 978 1 78634 707 7).

The first two editions of this textbook have received well-deserved high acclaims, and this — the third edition — deserves no less. Its explanations of the whole gamut of atomic and molecular spectroscopy provide a solid grasp of the theory as well as how to understand such spectra in practice. It thus makes an ideal companion to books that start from the observational aspect of spectroscopy, whether in the lab or at the telescope.

The contents guide one through the maze of spectroscopic notation by starting with the simple (hydrogen-like) case and progressing along the periodic table: helium, alkali, and more complex atoms in turn, with important discussions of those issues where the laboratory provided by the stars is more powerful than any on Earth. A fine example of the latter situation, as Tennyson explains, involved the mystery, and eventual solution, of emission lines in spectra of nebulæ, for some time attributed to an unknown element 'nebulium', and correctly recognized only much later as originating from excited metastable states of [O III]. Successive editions of the book have advanced the contents so as to emphasize current topics. The second edition gave specific attention to nebulæ, while this newer one addresses line broadening with a view to aiding the interpretation of spectra of exoplanetary objects. The book also deals with the influences of a magnetic field upon spectra (introduced into the 2nd edition), the many complexities of X-ray spectra, and expands the previous cover of molecular spectra into four chapters. One finds numerous 'worked examples', which are definitely helpful, and each chapter ends with a number of set problems, whose solutions are given at the end of the book. In all, it is comprehensive and authoritative.

The text is generally well-written, but deserved rather better proof-reading. The figures of observed astronomical spectra are adequate, but would have made better illustrations if on a larger scale. Borrowing spectra from assorted sources and publications has inevitably led to rather inconsistent styles and very inconsistent axis labelling — some vague, some unsuitable, some absent. Most of the observed spectra date back nearly 20 years; examples with higher S/N could surely be found now in the literature or a public database. I was a bit surprised that isotopic splitting is not addressed until the chapter on X-rays, where it lies a bit hidden despite its undoubted importance to optical and IR spectroscopy, and its relevance seemed to be downplayed under the questionable supposition that most current spectroscopy does not routinely engage sufficiently high resolution (and what about lithium??). A valuable astrophysical application involves $^{12}$CN and $^{13}$CN in the red (optical) CN system, but is not mentioned. Even in the long section devoted to spectroscopy of molecules, CN gets rather short change despite its foundational significance (along with CH) for stellar classification and stellar CNO evolution. Hyperfine broadening, too, receives only rather slender mention in the new chapter on line broadening, although its recognition and treatment — particularly in common elements like V, Mn, and Co — is essential if bad systematic errors in abundances derived from them are to be avoided.

But those are fairly minor grumbles. This new edition of Tennyson's book ought to be in the library (if not already in student reading-lists) of every astronomical department. — ELIZABETH GRIFFIN.

## Other Books Received

**Formation of the First Black Holes**, edited by Muhammad Latif & Dominik Schleicher (World Scientific), 2019. Pp. 365, 24 × 15·5 cm. Price £105 (hardbound; ISBN 978 981 3227 94 1).

An up-to-date summary of research on the formation of supermassive black holes in the early Universe from a fluid-dynamical, stellar-dynamical, and chemical perspective, providing a foundation for the comparison of observations and theory, both now and in the light of future instrumental developments.

**Science with the Cherenkov Telescope Array**, by The CTA Consortium (World Scientific), 2019. Pp. 338, 25 × 17·5 cm. Price £115 (hardbound; ISBN 978 981 3270 08 4).

A summary of science to be undertaken with the *Cherenkov Telescope Array* (*CTA*), the next generation of major detectors for gamma-ray research due to be completed in the next decade.

## ASTRONOMICAL CENTENARIES FOR 2020

*Compiled by Kenelm England*

The following is a list of astronomical events, whose centenaries fall in 2020. For events before 1600 the main source has been Barry Hetherington's *A Chronicle of Pre–Telescopic Astronomy* (Wiley, 1996). For the 17th to 19th Centuries lists of astronomical events came from wikipedia and other on–line sources, supplemented by astronomical texts. Discoveries of comets, asteroids, novae and other objects for 1920 appeared in the February issue of *Monthly Notices of the Royal Astronomical Society* in the following year. There were also references from *Popular Astronomy*, *Journal of the British Astronomical Association*, and *Publications of the Astronomical Society of the Pacific*. Professional discoveries and observations were followed up in *Astronomische Nachrichten* and *Astronomical Journal*. Details of individual astronomers were supplemented by articles published in *Biographical Encyclopedia of Astronomers* (Springer, 2007). Gary Kronk's *Cometography* Volumes 1–3 (Cambridge, 1999–2007) provided details on all the comets. Finally NASA's Five Millennium Canons of Eclipses and planetary tables were consulted for information on eclipses and planetary events.

*1920*

*January 2*: Birth of George Howard Herbig. He was an American astronomer specializing in the study of the interstellar medium and the early evolution of stars (Herbig Ae–Be stars and Herbig–Haro objects); died 2013.

*January 2*: Approximate date of the birth of Isaac Asimov in Russia. His family emigrated to the United States, where he became a biochemist and a famous writer of science fiction. He made his name with the *Foundation* and *Robot* stories and numerous short stories, such as *Nightfall*. He was a prolific writer on science topics, including astronomy; died 1992.

*January 20*: Death of Jane Lassell. Born in 1831, the daughter of the astronomer William Lassell (1799–1880), she had a lifelong interest in astronomy with her sister Caroline (1833–1911) and accompanied her father to Malta and Maidenhead, Berkshire; founder member of the BAA.

*February 1*: Death of Pavel Karlovich Shternberg. Born in 1865, he was a Russian astronomer and physicist, interested in measuring the Earth's gravitational field. He was Director of the Moscow University Observatory before joining the Bolsheviks in the October Revolution. In 1931 the Moscow astronomical groups were combined to form the Shternberg State Astronomical Institute.

*February 8*: Maximilian Franz Joseph Cornelius 'Max' Wolf (Heidelberg Observatory) discovered a supernova ($12^{m}\cdot 9$) in the barred spiral galaxy NGC 2608 in Cancer. The discovery was confirmed by Wilhelm Heinrich Walter Baade (Hamburg Observatory) on the 15th. The supernova faded slowly and was last seen on April 8 ($14^{m}\cdot 4$), as it entered solar conjunction. It was recovered on October 18 ($15^{m}\cdot 6$) and last seen on 1921 April 3 ($17^{m}\cdot 5$) [supernova 1920A; atypical and very bright].

*February 16*: Death of Paul Friedrich Ferdinand Kempf. Born in 1856, he was a German astronomer at the Potsdam Astrophysical Observatory specializing in the study of the Sun. He observed the Transit of Venus in 1882 and the total solar eclipses of 1887 and 1914 in Russia.

*February 20*: Death of Robert Edwin Peary. Born in 1856, he was an American polar explorer who claimed to have reached the North Pole on 1909 April 6. Although this claim is now disputed, it was generally accepted for a long time. At Savissivik, Greenland, in 1894 he found three large pieces of iron meteorite, which the local Inuit had been using as a source of iron metal. Known as 'The Tent', 'The Woman', and 'The Dog' they are now in the American Museum of Natural History, New York. Other fragments of the Cape York iron meteorite have been found.

*March 13*: Death of Thomas William Backhouse. Born in 1842, he was a British amateur observer of variable stars, meteors, and comets. He was one of the first to note the *Gegenschein* in the Zodiacal Light and the nebulosity around the star Merope in the Pleiades.

*April 8*: Death of John Alfred Brashear. Born in 1840, he was an American instrument maker producing high-quality reflecting mirrors, object glasses and eyepieces; acting Director of the Allegheny Observatory, Pittsburgh.

*April 26*: The Great Debate was held at the Smithsonian Museum of Natural History, Washington DC. Heber Doust Curtis proposed that spiral nebulae were independent galaxies (island universes), while Harlow Shapley considered them part of the Milky Way. Although both views had observational support at the time, Hubble's observations of variables in galaxies soon proved Curtis correct.

*May 5*: Death of the Reverend Philip Henry Kempthorne. Born in 1841 on St. Helena, he was a schoolmaster and clergyman and an amateur observer of the Moon and planets. A member of the RAS and BAA, he was the driving force with Samuel Saunder (1852–1912) behind the construction of the Wellington College Observatory, Berkshire.

*May 8*: The AAVSO awarded Nova Medals to Ida Elizabeth Woods and *in absentia* Joanna Crighton Stephens Mackie for their discoveries of novae in 1919.

*May 18*: Comet 21P/Giacobini–Zinner, discovered in 1900 and again in 1913, reached perihelion ($q$ = 0·980 AU) but was not observed at this unfavourable return. The comet was recovered at its next return in 1926.

*May 24*: Comet 11P/Tempel–Swift–LINEAR, last seen in 1908, returned to perihelion ($q$ = 1·236 AU) but was not observed. Close approaches to Jupiter and unfavourable returns led to the comet remaining lost until 2001.

*May 25*: Kyoyu Kudara (Kyoto Observatory) recovered comet 10P/Tempel 2 as an 11th-magnitude object close to the predicted position. Unfortunately an error in transmission of the announcement led to no follow-up observations. On July 19 Alexandre Schaumasse (Nice Observatory) found the comet still magnitude 11 with a diffuse coma, at first thought to be a different comet from Kudara's comet. It had reached perihelion on June 10 ($q$ = 1·316 AU). The comet slowly brightened to magnitude 10 at the end of July and then faded, at first slowly and then more rapidly, until it was last seen on November 17. It was recovered at its next return in 1925.

*June 20*: Death of John Grigg. Born in England in 1838, he emigrated to New Zealand in 1863 and observed the Transit of Venus in 1874. He discovered three comets: 26P/1902 O1 (Grigg–Skjellerup), C/1903 H1 (Grigg), and C/1907 G1 (Grigg–Mellish). He often continued observing comets when they became unavailable to observers in the Northern Hemisphere.

*June 20*: Comet 54P/de Vico–Swift–NEAT, discovered in 1844 and 1894, had become lost for the second time, when it returned to perihelion ($q$ = 1·712 AU) and so was not observed. Orbital calculations led to the comet being recovered in 1965.

*July 21*: Death of Fiammetta Wilson née Helen Frances Worthington. Born in 1864, she was a British meteor observer, joining the BAA in 1910. On 1916 January 14 she was one of a group of five women who were the first to be elected Fellows of the RAS. She was Acting Director of the BAA Meteor Section and was awarded the Edward C. Pickering Fellowship for Women 1920–1 but died before taking up the award.

*August 9*: Birth of Albert Francis Arthur Lofley Jones. He was a New Zealand variable-star observer, making more than half-a-million observations. He discovered comets C/1946 P1 (Jones) and C/2000 W1 (Utsonomiya–Jones) and was an independent discoverer of supernova SN 1987A in the Large Magellanic Cloud; died 2013.

*August 12*: Death of Karl Hermann Struve. Born in 1854, he was the elder son of the Russian astronomer Otto Wilhelm Struve (1819–1905) and grandson of Friedrich Georg Wilhelm Struve (1793–1864). He specialized in optics and observing planetary satellites. He observed the Transit of Venus in 1874 from Eastern Siberia. He moved to Germany, becoming Director of the Königsberg Observatory in 1895 and the Berlin Observatory in 1904; awarded the RAS Gold Medal in 1903.

*August 16*: Death of Sir Joseph Norman Lockyer. Born in 1836, he was a British solar astronomer who investigated the Sun and its spectrum during eclipses, discovering helium in the solar spectrum in 1868. In 1879 he established a solar observatory at South Kensington, which was moved to Sidmouth, Devon, in 1912 (now the Norman Lockyer Observatory). He also noted that ancient monuments might have astronomical alignments; knighted in 1897.

*August 17*: Death of Giovanni Celoria. Born in 1842, he was an Italian astronomer at the Brera Observatory in Milan from 1864 to 1917 and Director from 1900. He calculated the orbits of asteroids and comets, studied 220 double stars, and worked on the statistics of stars in the Milky Way. He also investigated ancient solar eclipses.

*August 20*: William Frederick Denning (Bristol, England) discovered a nova in Cygnus ($3^{m}\cdot7$). The nova brightened quickly to magnitude 1·9 on the 23rd, and was independently discovered by a number of observers. Prediscovery images were found on photographs taken on the 16th ($7^{m}\cdot0$) and 19th ($4^{m}\cdot8$). As the nova was relatively bright, a number of spectra were taken, revealing the ejection of a gas cloud. The nova faded to magnitude 4 at the end of August and magnitude 6 by mid–September. It took several years to return to magnitude 17 [V476 Cygni].

*August 22*: Birth of Ray Douglas Bradbury. He was a prolific American writer of science fiction, famous for *The Martian Chronicles*, *The Illustrated Man*, and *Fahrenheit 451*; died 2012.

*October 10*: John Charles Duncan (Mount Wilson Observatory) discovered a nova (magnitude 17·2) in the Andromeda Galaxy, which faded to magnitude $17^{m}\cdot6$ by the 14th and disappeared [Nova N18 in M31].

*October 23*: Death of Arthur Searle. Born in London in 1837, he was an American astronomer at Harvard College Observatory in 1868 and Phillips Professor of Astronomy at Harvard from 1887 to 1912. He studied the brightnesses of stars, doubles, and variables, as well as the Zodiacal Light. His wife Emma Wesselhoeft, daughter Katherine, and brother George Mary were also astronomers at Harvard.

*October 26*: Birth of Sarah Lee Lippincott. She was an American astronomer who studied binary stars and in 1951 reported a planet 30 times the mass of Jupiter orbiting the nearby star Lalande 21185; this was disproved in 1974. Died 2019.

*October 30*: Harlow Shapley (Mount Wilson Observatory) discovered a nova ($15^{m}\cdot7$) in the Andromeda Galaxy, which faded to $16^{m}\cdot5$ on 31st and then disappeared [Nova N17 in M31].

*October 31*: Wilhelm Heinrich Walter Baade (Bergedorf Observatory, Hamburg) discovered the unusual asteroid (944) Hidalgo. It was orbiting the Sun from 1·9 AU to 9·5 AU in a period of 13¾ years, and remained the most distant asteroid known until the discovery of the Centaur (2060) Chiron in 1977 [1920 HZ].

*November 4*: Death of Gustav Wilhelm Ludwig Struve. Born in 1858, he was the younger son of the Russian astronomer Otto Wilhelm Struve (1819–1905) and grandson of Friedrich Georg Wilhelm Struve (1793–1864). He worked on the positions and proper motions of stars to calculate the rotation rate of the Milky Way. He became Professor of Astronomy at Kharkov University (1897–1919) but during the October Revolution fled to the Crimea, where he died.

*November 16*: While searching for the return of comet 25D/Neujmin 2, Grigory Nikolayevich Neujmin (Simeis Observatory, Crimea) recorded a trailed object on two 4-hour plates. At first thought to be the comet, it was proved not to be the same object when comet 25D/Neujmin 2 was recovered in 1926.

*November 20*: Comet 17P/Holmes, last seen in 1906, returned to perihelion ($q$ = 2·353 AU) but was not observed after a close approach to Jupiter. It remained lost until 1964.

*November 28*: There was a report of a very bright fireball over Howesville, West Virginia (about 150 km south of Pittsburgh), which travelled northeast and exploded, damaging windows.

*November*: Formation of the New Zealand Astronomical Society, which became the Royal Astronomical Society of New Zealand in 1946.

*December 2*: Death of Sir William de Wiveleslie Abney. Born in 1843, he was a British pioneer of scientific photography, extending plate sensitivity into the near infrared and predicting the broadening of spectral lines in fast-rotating stars; President of the RAS (1893–5); knighted in 1900.

*December 8*: Clement Jennings Taylor (Claremont, South Africa) discovered a comet in the Head of Hydra but made a mistake of 1 hour in Right Ascension when reporting his discovery. He observed it again on the 13th, by which time James Francis Skjellerup (Cape Town) had independently found the comet on the 11th as magnitude 11 with a diffuse coma. The comet reached perihelion on December 11 ($q$ = 1·148 AU) and was magnitude 10 later in December, when it displayed a coma 8 arcminutes in diameter. Then it began to fade at the beginning of 1921 and was last seen on March 9 [Comet 1920 X1 (Skjellerup)].

*December 10*: John Charles Duncan (Mount Wilson Observatory) discovered a nova ($16^{m}$·3) in the Andromeda Galaxy. The nova remained under observation until 1921 January 8, when it was magnitude 19 [Nova N19 in M31].

*December 10*: John Charles Duncan (Mount Wilson Observatory) discovered a second nova ($17^{m}$·7) in the Andromeda Galaxy. It also remained under observation until 1921 January 8, when it had barely faded to $17^{m}$·8 [Nova N20 in M31].

*December 13*: Albert Abraham Michelson and Francis Gladheim Pease (Mount Wilson Observatory) measured the diameter of Betelgeuse, using an interferometer attached to the 100-inch reflector. They obtained a value of 0·047 arcsecond, giving a radius of 1·29 AU, but allowing for the effect of limb darkening revised this to 0·055 arcsecond (1·50 AU) with an accuracy of about 10 percent.

*December 27*: Death of Jean Louis Niesten. Born in 1844, he was a Belgian astronomer at the Royal Observatory in Brussels and was mainly involved in the observation of planets. He independently discovered the Great Red Spot on Jupiter in 1878.

*Winter*: Jacobus Hermanus Brits discovered a large iron meteorite, while ploughing or hunting at the Hoba West farm, 20 km west of Grootfontein, Southwest Africa (now Namibia). The meteorite (81% iron, 17% nickel) had a mass of about 66 tons and remains in its original position, now on display and protected as a National Monument.

*1820*

*January 12*: Meeting of 14 scientists at the Freeman's Tavern, Lincoln's Inn Fields, City of London to discuss the formation of an astronomical society.

*February 29*: Birth of Lewis Swift. He was an American amateur astronomer living in New York State who discovered 13 comets and 1248 new nebulae, so many that Dreyer gave up revising NGC and began compiling the Index Catalogue. During the total solar eclipse of 1878 he claimed to have observed Vulcan, an intra-Mercurian planet predicted by Le Verrier; died 1913. His son Edward Doane Swift (1870–1935) also discovered and observed comets.

*March 10*: First meeting of the Astronomical Society of London, which would become the Royal Astronomical Society in 1831.

*May 5*: J. Reeves (Macao, Portuguese China) reported discovering a comet near α and β Centauri, which disappeared to the northeast. No other observer confirmed this report.

*May 24*: Birth of William Chauvenet. He was an American scientist who was the driving force behind the establishment of the US Naval Academy at Annapolis, Maryland. He taught mathematics, astronomy, and navigation; died 1870.

*July 2*: Death of Peter Dollond. Born in 1730 the son of the English optician and telescope maker John Dollond (1706–61), he produced many achromatic telescope lenses invented by his father and designed his own triplet achromatic lens. He supplied telescopes to many observatories and navigational instruments to the Royal Navy.

*July 5*: Birth of William John Macquorn Rankine. He was a British engineer who wrote down equations connecting the density, pressure, and temperature of gases on either side of a shockwave, as, for example, in a supernova remnant (Rankine–Hugoniot relations); died 1872.

*August 20*: Death of Andrew Ellicott. Born in 1754, he was an American mathematician who surveyed state and international boundaries in eastern North America. He observed the Leonid meteor storm of November 1799.

*October 7*: Birth of Jean-Charles Hippolyte Joseph Houzeau de Lehaie. A member of an aristocratic Belgian family but politically a radical, he had a lifelong interest in astronomy during his travels around the world and observed the Transit of Venus in 1882. He became Director of the Royal Observatory in Brussels and compiled *Bibliographie générale de l'astronomie*, listing all astronomical publications from Antiquity to 1880; unfinished at his death in 1888.

*October 17*: Birth of Édouard Albert Roche. He was Professor of Mathematics at the University of Montpellier in France. His calculations indicated the form of equipotential regions in binary stars (Roche lobes) and the distance from a planet where satellites could not form (Roche limit); died 1883.

*October 26*: Fearon Fellows was selected by the British Admiralty Board to establish an astronomical observatory at the Cape of Good Hope as His Majesty's Astronomer.

*1720*

*December 29*: Death of Maria Margaretha Kirch née Winkelmann. Born in 1670, she married the German astronomer Gottfried Kirch (1639–1710). She was already interested in astronomy and helped her husband calculate annual calendars in Berlin. On 1702 April 21 she independently discovered comet C/1702 H1 just a day after it was found by observers in Rome. Denied an official post on Gottfried's death, she continued her observations and calculations until her son Christfried Kirch (1694–1740) became Director of the Berlin Observatory in 1716. Her daughters Christine (1696–1782) and Margaretha (1703–44) were also astronomers.

Edmond Halley was appointed the second Astronomer Royal.

Death of David Gregory. Born in Scotland in 1625, he was a Scottish doctor and scientist with an interest in weather forecasting using atmospheric pressure. His sons David (1661–1708), James (1666–1742), and Charles (1681–1754) were professors of mathematics and astronomy and his younger brother James (1638–75) invented the Gregorian reflecting telescope.

*1620*

*March–April*: Death of Simon Stevin. Born in 1548, he was a Dutch writer of textbooks on mathematics and astronomy. In 1586 he published his experiments on gravity, dropping lead spheres of different masses (Galileo mentioned these experiments in 1638).

*July 21*: Birth of Jean Picard. He was a French astronomer who travelled across Europe and made numerous astronomical observations. He used the timing of eclipses of Jupiter's satellites to calculate differences in longitude between cities and used this survey to create an improved map of France; died 1682.

Birth of Jacques Rohault. He was a French mathematician and popularizer of natural philosophy based on René Descartes' work, with the emphasis on experiment and observation to explain the Universe; died 1665.

Francis Bacon noted the jigsaw fit of continents on either side of the Atlantic Ocean.

The Congregation of the Index at the Vatican published an edited version of Copernicus' works, deleting references to the heliocentric model of the Solar System.

*1520*

*January–February*: The Chinese observed a comet with a tail.

*March 9*: Korean astronomers observed some sunspots, when "within the sun there were black vapours agitating one another".

Ganesa published *Grahalaghava*, a set of Indian planetary tables for calculating eclipses and the position of planets.

Birth of Johannes Acronius at Akkrum, Holland. He wrote *De Sphaera* (*On the Heavens*), *De Astrolabiis et Annuli Astronomici Confectione* (*On the Astrolabes and the Arrangement of Astronomical Circles*), and *Prognosticum Astronomicum* (*Future Astronomical Events*); died 1564.

*Birth of Leonard Digges. He was an English astronomer, who wrote *A Prognostication Everlasting* on the sizes and distances of the Sun, Moon, and planets. He also wrote an unfinished book on optics, including lenses and mirrors that could be seen as a precursor of the telescope; died 1571.

*Approximate date; and on subsequent pages.

*Birth of Jeronimo Muñoz. He was a Spanish astronomer and geographer, who was Professor of Mathematics at the University of Valencia and observed the position of stars. He wrote *Libro del Nuevo Comet* (*Book of the New Comet*), actually on the Tycho Supernova of 1572, but realized that the Aristotelian principle of unchanging heavens was not tenable. He never adopted the Copernican system; died 1592.

*1420*

Muhammad Taraghay ibn Shahrukh ibn Timur Ulugh Beg, the Timurid governor of Turkestan, began the construction of an astronomical observatory just outside Samarkand. As well as various astrolabes and quadrants, the observatory was equipped with a sextant 40 metres in radius.

Death of Pierre d'Ailly (Petrus de Alliaco). Born in 1351, he was a French theological scholar, becoming a bishop and cardinal. He wrote extensively on astrology and cosmology. He noted that the calendar was out of step with the seasons and required reform by the Church.

*1320*

Birth of Shams al-Din Abu Abd Allah Muhammad ibn Muhammad al–Khalili. He was a Syrian astronomer and mathematician at the court in Damascus, acting as timekeeper and compiling extensive astronomical tables; died 1380.

*Birth of Nicole Oresme. He was a French mathematician and astronomer, who wrote on the rotation of the Earth and the motion of the planets, which he considered not to be predictable exactly and so undermined the basis of astrology. His writings significantly influenced later medieval scholarly thought; died 1382.

*Death of George Chioniades. Born about 1240 in Constantinople, he was a Byzantine doctor who studied Persian and Arabic astronomical texts at Tabriz, capital of the Ilkhanate, and translated them into Greek. He was orthodox Bishop of Tabriz (1305–10) before retiring as the monk Gregory.

Étienne Arblant was writing *C'est la Roe á savoir la conjunction et la distance du soleil et de la lune* (*That is the way to know the conjunction and distance of the Sun and the Moon*).

Death of Kamal al-Din Hasan ibn Ali ibn Hasan al-Farisi. He was a Persian mathematician and astronomer, writing Tanqih al-Manazir (*Correction of the Optics* of ibn al Haytham) on the refraction of light and observing eclipses with a camera obscura.

Birth of Theodoros Meliteniotes. He was a Byzantine astronomer who wrote *Astronomy* in three volumes, based on the works of Ptolemy and Theon of Alexandria as well as Persian and Arabic sources. He also wrote on constructing an astrolabe; died 1393.

*1220*

*January 25*: Japanese astronomers saw a reddish comet in the northwest after sunset.

*February 6*: The Koreans observed a comet in Cepheus, with its tail pointing to the northwest. This may be the same comet seen by the Japanese.

*March 21*: Korean astronomers saw a comet in Leo. This may also be the same as the two previous comets.

*1120*

*June 7*: The Chinese observed a large sunspot, for "within the Sun there was a black spot as large as a date". An aurora appeared.

*Birth of Abu Ali al-Hasan ibn Ali ibn Khalaf al-Umawi. He was a Spanish Arab religious scholar who collected traditional astronomical and meteorological observations for the timing of prayers; died 1205/6.

Plato of Tivoli was working on translating the astronomy of Al-Battani into Latin.

Construction of an astronomical observatory in Cairo, Egypt.

*1020*

*January 26*: At sunrise the Koreans observed a comet in the morning sky in Ophiuchus. This report could be dated to 1019 February 6.

*July 18*: In France halos were seen around the Sun for several hours.

*September 5*: A lunar eclipse was seen from Cologne. The eclipse was total across Europe [Saros 102].

*December 6*: Chinese astronomers observed Mars occulting θ Virginis.

Birth of Su Song. He was a Chinese astronomer at the court of the Northern Song in Kaifeng. In 1092 he constructed a water–driven armillary sphere, 11 metres high, called *Shuiyun yixiang tai* (*Tower of water-driven instrument*) and wrote a monograph on its construction, *Xin yixiang fayao* (*Outline of the method for a new instrument*), which included five star maps of Chinese constellations; died 1101.

*Death of Abu Sa'id Ahmad ibn Muhammad ibn Abd al-Jalil al-Sijzi. Born in about 945, he was a Muslim mathematician and astronomer who noted that the Earth rotated on its axis.

*820*

*November 23*: A total eclipse of the Moon was observed from France, recorded in *Annales Sithienses*. The eclipse was total over most of Europe as well as the Middle East and Asia [Saros 87].

*Dicuil flourished. He was an Irish monk, who wrote on astronomy and geography in France.

Abu Ali Yahya ibn Abi Mansur al-Munajjim was a Persian astronomer and astrologer to the Abbasid Caliph Ma'mun. He was making astronomical observations and calculations at the *Bayt al–Hikmah* (House of Wisdom) in Baghdad*, testing the predictions made by Ptolemy's *Almagest* and *Handy Tables*; died 830. Other members of his family were also astronomers to the Abbasid Caliphs.

*520*

*October 1* (*or 7*): The Chinese discovered a comet 'as bright as a flame' in the east before sunrise. It remained visible until November 25. The comet was seen from Italy in the east. It was also recorded by John Malalas of Antioch at Constantinople.

Chinese astronomers calculated the year as 365·2437 days long.

*420*

*May*: The Chinese observed a comet that stretched across the sky.

*Birth of Martianus Felix Capella in Madaura, Roman Province of Africa. He wrote an encyclopedia *De Nuptiis Philologiae et Mercurii et de Septem Artibus Liberalibus Libri Novem* (*Nine Books on the Wedding of Philologia and Mercury and the Seven Liberal Arts*). Book 8 dealt with astronomy, which was mainly geocentric but included the idea that Mercury and Venus circle the Sun, as they remained close to the Sun in the sky; died about AD 490.

*220*

Sextus Julius Africanus was writing *Chronicon*, an ecclesiastical chronology from Creation to the year AD 221 with information on the calendar.

*120*

*January 18*: Chinese astronomers at the Chinese capital Luoyang observed a nearly total solar eclipse, when 'on earth it was like evening'. The eclipse was total across central China, but the line of totality passed just south of the city [Saros 62].

*Death of Plutarch. Born in Chaeronea, Boeotia in AD 46, he was well-known for his ancient biographies but also wrote *On the Face of the Moon* as part of his Platonic philosophical writings, where he considered the Moon as Earth-like with mountains and depths casting shadows.

*AD 20*

*Birth of Hero of Alexandria. Known for his engineering achievements, he wrote a book on optics where he stated the (mistaken) theory that vision resulted from light emitted by the eyes and reached the object instantaneously; died about AD 70.

*181 BC*

*March 4*: The Chinese observed a solar eclipse from Chang'an, when the sky became dark. The eclipse was total across central China with Chang'an just north of the centre line [Saros 56].

Livy recorded that an auroral display was seen from Rome.

*481 BC*

*April 19*: The Chinese observed a solar eclipse. The eclipse was total across southern and eastern China [Saros 50].

*Winter*: Chinese astronomers observed a comet with a tail.

## *Here and There*

SOME MONSTER!

M87 is a monster, one of the largest galaxies known. It has a spherical shape measuring 240 light years in diameter. — *The Telegraph*, The Night Sky in May, 2019.

PURPLE HAZE

A new tandem solar cell … absorbs energy from blue and purple photons … . — *Science*, 2019 April 12, p.116.

THRIVED EVEN

Microbial life sexisted on this oxygen-poor Earth. — *Astronomy Now*, 2019 May, p. 24.

LIES AND STATISTICS

A survey of doctoral students at the University of Arizona in Tucson found that about three-quarters were under 'more than average' stress. — *Nature*, 2019 May 16, p. 307.

O DEAR

The planet HD201749c orbits star HD21749 every 7·8 days. — *A&G*, **60**, 3.7, 2019.