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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2022 March 11 at $16^{h}\ 00^{m}$

EMMA BUNCE, *President*
in the Chair

The President. Welcome everyone and thanks for joining us this afternoon for our Open Meeting. And as usual we have two great talks coming up this afternoon for you to listen to. Questions can be asked at the end of each of our presentations today, but as you will be muted, please could you use the Q&A facility rather than the chat, which is found at the bottom of your screen and your questions will go to the panellists only. The questions today will be read out by a member of the RAS editorial team, Dr. Sean Hodges. So thanks, Sean, for helping us with that today.

Before we have our talks this afternoon, I'd like to announce the winners of the RAS GCSE poster competition which has been sponsored by Winton. The third-prize winner, which attracts a £25 book token, is Alexandra Campant and Alexander Pang for their poster on 'Kepler's Laws of Planetary Motion'; they are from Westminster School and their poster includes both history and, of course, details of Kepler's laws of planetary motion. The second prize today and a £50 book token is awarded to Bianca Phoenix Ante-Ferko whose poster is called 'Life Cycle of a Star (Stellar Evolution)'. Bianca is from Grey Coat Hospital School, and so congratulations to Bianca. Her poster is on the life cycle of a star, and I'd just like to point out that all of these wonderful, cheerful diagrams are actually drawn by the person who created the poster, which is really lovely. For the first-prize poster a £100 book token is awarded to George Plaistowe, and George's poster asks the question, 'Does the Aurora Differ from Year to Year?' George comes from Marlborough College. So many congratulations to you. George's poster is a very professional-looking poster all about the aurora, with lots of detail and discussion about the aurora, how it works, the dependence on the solar cycle, and explaining the different colours that we see in the aurora. I've had a good look at all of these posters and they're really fantastic.

On to the main part of our programme this afternoon. I would like to introduce our first speaker, Dr. James Owen, from Imperial College London, who was the recipient of the Fowler Award for Astronomy. Dr. Owen is a senior lecturer and Royal Society University Research Fellow in Astrophysics at Imperial College London, and he also leads the European Research Council project on planetary evaporation as a window into exoplanetary origins, which aims to model the formation and evolution of exoplanetary atmospheres. James was awarded a PhD from the University of Cambridge in 2012 and has worked as a postdoctoral fellow at the Canadian Institute for Theoretical Astrophysics. He was then awarded a Hubble Fellowship at the Institute of Advanced Study in Princeton before moving to Imperial College. This afternoon, James is going to be giving a lecture on 'The origin of the exoplanet radius gap.' I'm very much looking forward to your presentation James, and I'm going to hand over to you now for you to share your screen.

Dr. James Owen. Exoplanet-discovery missions have been enormously successful, detecting thousands of planets over the last decade. These detections have primarily come from the transit technique. The periodic dip in the stellar brightness due to a planet's orbit allows its radius and orbital period to be measured. We now know the most common type of planet discovered to date has a radius in-between that of the Earth and Neptune (known as super-Earths and sub-Neptunes), yet orbits its host star closer than Mercury to the Sun. Most sun-like stars host at least one, and in many cases, several of these planets. With no previously known analogue, the nature of these planets was uncertain. Density measurements indicated that some were so dense they must be terrestrial, while others were so low density, they must contain voluminous envelopes of hydrogen gas.

The planets that host a hydrogen-dominated atmosphere are vulnerable to mass loss. High-energy stellar photons can heat the upper atmospheres of these planets to temperatures approaching the escape temperature. This heating allows the atmosphere to lose mass through a thermally driven hydrodynamic outflow. This mass loss results in a bimodal evolution: lower-mass planets close to their star cannot hold onto their atmospheres, while more massive planets that are further away can retain them. A prime example of this outcome is the Kepler-36 system. This system hosts two planets that are only separated in orbital distance by about 0·01 AU. Yet, the lower-mass planet has no hydrogen atmosphere, but the more massive planet has a hydrogen atmosphere that makes up about 10% of its mass.

Considering this mass-loss-driven evolution for a population of planets, one finds two distinct populations of planets: those that retain an atmosphere of a few percent hydrogen by mass, and those that have completely lost them. This outcome produced a region of low occurrence for planets with radii of order 1·8 times Earth's. This 'photoevaporation' valley was a distinct prediction of this model; however, in the early transit studies, precise knowledge of the planet's radius was not possible due to the significant errors in a host star's radius (around 40%). In 2017, spectroscopy of thousands of exoplanet host stars from the California Kepler Survey provided more-precise stellar radii measurements, allowing the precision of the planetary radii to be increased by a factor of about four.

The California Kepler Survey revealed that the population of discovered transiting planets contained two sub-populations: planets either have radii of around 1·3 Earth radii or 2·6 Earth radii, planets with radii in the range of 1·8–2 Earth radii being rare. This work confirmed the theoretical prediction of mass loss from a population of planets born with large hydrogen-dominated envelopes.

Modelling the mass loss allows us to account for the loss from a planet's natal hydrogen atmosphere and enables us to derive the initial properties of the planets at the end of their formation. The key results of this work are that these planets have rock–iron cores, indicating formation inside the 'snow-line' (the location in the protoplanetary disc where water condenses into ice, significantly enhancing the mass in solids). Based on explaining the Solar System, previous planet-formation models suggested that for planets to grow massive enough to acquire a hydrogen atmosphere, they should form outside the snow-line. In addition, most terrestrial planets discovered acquired a large hydrogen-dominated atmosphere which they subsequently lost through mass loss. This formation pathway is distinctly different from the origins of the terrestrial planets in our Solar System. Our Solar System terrestrials finished forming after the protoplanetary disc dispersed and never acquired large amounts of hydrogen.

The discovery of super-Earth and sub-Neptune exoplanets has revealed a previously unidentified planet-formation pathway distinct from the origin of our Solar System. Given the ubiquitous nature of these exoplanets, it appears this new planet-formation pathway is a dominant one.

The President. Thank you so much James, for that really fascinating talk; it was very interesting to hear all about your work and the latest on those planets. I'm going to hand over to Sean and I can see at least one question that's coming, which is exactly the question that I was going to ask.

Dr. Sean Hodges. I have two questions. First, from Roger: "The description of exoplanets is all very interesting, even exciting. But how does one explain its importance to a sceptic?"

Dr. Owen. It's a difficult question to answer, and it depends on what sceptical point of view you're taking on this. I would say that I'm extremely interested in the formation and evolution of planets in general, and that includes Earth. Understanding how Earth has evolved is an extremely important problem. It even matters to us today, and the fact is that you can't do experiments. We can't take another Earth and change things such as our geology and see how Earth may have evolved in a different way, but you can do that through exoplanets. They provide a statistical ensemble about how planetary systems evolved, so it's extremely important to understand exoplanet evolution, because it provides an understanding for geophysical evolution. By understanding how exoplanets evolve hopefully we gain a better insight into how the Earth evolved.

Dr. Hodges. The next question is: "What impact does the magnetic field of the planet core have on the loss of the atmosphere? The magnetic field of the Earth appears to be responsible for retaining the atmosphere, and Mars appears to have been stripped after the magnetic field decayed."

Dr. Owen. That's an excellent question and the analogy you have of Earth and Mars is exactly the same analogy we would have for these exoplanets. If these planets had a strong magnetic field that did not decay away, this would have suppressed the mass-loss process. The interesting thing is that we can only fit this model to the data successfully if the magnetic fields are weak and did not play a strong role in retaining the atmosphere, and by weak, I mean roughly that the planets have a magnetic field that is weaker than about one Gauss at their surface.

Dr. Hodges. I've got time for one quick question and I apologize to everyone who didn't get theirs answered: "How exceptional is the Solar System and how come?"

Dr. Owen. The first question is a little bit easier to answer. From the perspective of having a giant-planet system, we know that giant planets with giant-planet-like orbits, similar to a Jupiter-like orbit, have about a 10% occurrence. We also know that not having one of these super-Earth or sub-Neptune-style planets is around 10 to 20%. So the best outcome for the Solar

System is a roughly 10% outcome of planetary-system formation. At worst, it's 1%, so the Solar System is rare, but not very rare. How come? I could speculate probably for another hour, but the best answer I can give you is no-one has a convincing argument at the moment.

The President. Thank you so much, Sean, and thanks again, James, for a fantastic talk and for answering those questions. We're going to move on to our next speaker this afternoon. I'd like to introduce Dr. Julia Stawarz from Imperial College London, who was the recipient of the Winton 'G' Award for 2021. Dr. Stawarz is a Royal Society University Research Fellow in the Space and Atmospheric Physics Group at Imperial College London. She received her PhD from the University of Colorado in Boulder in 2016 where she held a National Science Foundation graduate research fellowship. She was recently awarded the Winton Geophysics Award from the Royal Astronomical Society and the Basu US Early Career Award for research excellence in Sun–Earth Systems Science at AGU in 2018. The title of Julia's presentation this afternoon is 'Turbulence driven magnetic reconnection in collisionless plasmas; new insights from NASA's *Magnetospheric Multiscale* mission.'

Dr. Julia Stawarz. I will be talking about some of the new insights that we have been gaining about the role of magnetic reconnection in turbulent plasmas using cutting-edge observations from NASA's *Magnetospheric Multiscale* (*MMS*) mission. Much of this work was published in a recent study in *Physics of Plasmas*.

Turbulence is the complex, highly nonlinear behaviour of fluid and plasma systems. As well as occurring in the neutral fluids found here on Earth, turbulence also occurs in the charged plasmas found throughout the Solar System including those within the heliosphere, such as the solar corona and solar wind and the magnetospheres of the Earth and other planets; and in more exotic astrophysical systems, such as the interstellar medium, accretion discs, and galaxy clusters. Turbulence generates fluctuations across a wide range of length scales and these fluctuations play a role in the formation of the structure we see throughout the Universe, the mixing of different plasma populations, and the dissipation of the fluctuations is responsible for heating the plasma and accelerating particles. Due to the complex nature of the turbulent dynamics and nearly collisionless nature of many space and astrophysical systems, a complete theoretical understanding of the behaviour of the turbulent fluctuations and the mechanisms responsible for turbulent dissipation remain key unsolved problems. The high-quality *in-situ* measurements that are now available from spacecraft in near-Earth space, such as *Magnetospheric Multiscale*, provide one avenue for solving these problems.

Magnetic reconnection is a process that has long been thought to play a role in both the energy dissipation and nonlinear dynamics in plasma turbulence. Magnetic reconnection occurs when sheared or twisted magnetic-field lines change connectivity due to the cancellation of oppositely directed components of the magnetic field, resulting in the release of energy that has been stored in the magnetic field and conversion of that energy into fast jets of plasma, particle heating/acceleration, and the excitation of waves. This process requires the charged particles that are tied to the magnetic-field lines in a plasma to decouple from the field lines and, therefore, it requires the formation of small-scale gradients, which turbulence is particularly good at generating. There are a few different ways that turbulence can affect magnetic reconnection at large-scale current sheets in a system can drive turbulence through the instability of the reconnection jets; and turbulent fluctuations can drive small-scale reconnection events at the multitude of thin current sheets generated by the turbulent dynamics. In this talk, I will be discussing new advances in understanding this later scenario of turbulence-driven reconnection, which have been enabled by new high-resolution spacecraft measurements.

NASA's *MMS* mission is a multi-spacecraft formation of four Earth-orbiting satellites launched in 2015 that provide a unique dataset for studying turbulence-driven magnetic reconnection. Each spacecraft carries a suite of plasma instrumentation capable of making a full range of *in-situ* plasma measurements, including measuring the 3-D electric and magnetic fields and the full 3-D particle-distribution functions for positively-charged ions and negatively-charged electrons. The particle measurements, in particular, are made at particularly high temporal resolutions of 150 milliseconds for the ion and 30 milliseconds for the electron, which are up to 100 times faster than for previous missions. Additionally, the orbits of the spacecraft are designed such that the four spacecraft typically form a small-scale tetrahedral formation at the apogee of the orbit with separations approaching the characteristic electron length scales in the plasma. These multipoint measurements allow the direct estimation of 3-D gradients in plasma.

Recent theoretical studies, motivated by *MMS* observations, suggest that in collisionless plasmas, magnetic reconnection can take on different behaviours. While in the standard picture of reconnection, both ions and electrons are accelerated to form fast jets by the newly-reconnected magnetic-field lines, if the length of the reconnecting current sheet along the jet direction becomes comparable to the characteristic scale of the ions, then there will not be enough space for the newly reconnected magnetic-field lines to accelerate the ions before the magnetic-field lines fully relax. This latter scenario has come to be known as electron-only magnetic reconnection and idealized numerical simulations have shown that the transition from the more traditional ion-coupled reconnection and electron-only reconnection occurs for current-sheet lengths between roughly 40 ion inertial lengths and 10 ion inertial lengths. In the context of a turbulent environment, the length of the current sheets formed by the turbulent environment will be constrained in an average sense by the correlation length of the magnetic fluctuations, which can be thought of as the average size of the magnetic structures formed by the turbulence and is related to the scale over which the turbulent fluctuations are 'stirred-up'. Therefore, it is expected that in turbulent environments with longer correlation lengths ion-coupled reconnection will be more prevalent, while in turbulent environments with shorter correlation lengths electron-only reconnection will be more prevalent, which may have an impact on both the nature of the nonlinear dynamics and how any dissipated energy is partitioned between ions and electrons.

In recent work, we have used *MMS* observations systematically to examine turbulence-driven magnetic reconnection in the region of shocked solar-wind plasma downstream of a bow shock, known as the magnetosheath. To do this, we used a partially automated procedure to look at each of the most intense current structures across 60 intervals of turbulence in the magnetosheath to identify electromagnetic field and particle-flow signatures consistent with magnetic reconnection. After manual verification of each event, a database of 256 reconnection events was identified. The reconnection events identified in the magnetosheath contained examples of both reconnection events with and without ion jets, with most events having no clear evidence for ion jets. Comparison of individual events with reconnection events self-consistently generated in simulations of a bow shock also shows that the 1-D trajectories through the reconnection events observed by *MMS* appear to be consistent with electron-only reconnection in some cases, with possible evidence of particularly high reconnection rates compared to expectations for traditional reconnection.

Using the database of reconnection events, we tested whether there was evidence of a variation in the prevalence of electron-only reconnection relative to ion-coupled reconnection depending on the magnetic correlation length of the turbulent fluctuations. The observations suggest that there is a tendency for thinner sub-proton-scale current sheets to have faster super-Alfvénic electron jets, while observations of ion jets tended to occur at current sheets with proton-scale thicknesses. Additionally, when comparing with the magnetic correlation lengths of the 60 intervals of magnetosheath turbulence, there is a tendency for thin sub-proton current sheets in intervals with magnetic correlation lengths less than approximately 20 ion inertial lengths. These observations are consistent with the expectation that electron-only reconnection becomes more prevalent for short correlation lengths and suggest the properties of the turbulent fluctuations and driving mechanisms may influence the nature of magnetic reconnection, and potentially turbulent dissipation, in collisionless plasmas.

This recent work motivates a number of open questions, which we are continuing to explore using a combination of spacecraft observations and numerical simulations in on-going work: What happens in turbulent plasmas, such as the solar wind, that have much larger correlation lengths than those found in Earth's magnetosheath? How does the presence of magnetic reconnection influence the nonlinear dynamics in turbulent systems? How important is magnetic reconnection for turbulent dissipation and how does it partition energy?.

The President. Julia, thank you so much for that fantastic talk. A very complex topic, but you've explained your work and the field very clearly indeed, so thank you very much for that. I'm going to hand over to Sean to see if there are any questions.

Dr. Hodges. I have one quick question: "Is there a planned successor to *MMS* for improved measurement?"

Dr. Stawarz. Well, *MMS* was four different spacecraft in a small-scale formation, so that lets you compute three-dimensional gradients, but you can only really look at one scale length at any given time, and then you're relegated to trying to sort out the temporal evolution *versus* the spatial evolution as structures get adapted over time. To get around that, the idea would be to have larger constellations of spacecraft, so you might go up to nine spacecraft or so, and make measurements at multiple points all at once. In fact, there is a mission called *Helios One* that was recently selected by NASA, that is expected to launch in 2028, I believe, and that will be focussed on looking at link scales, in other words, MHD fluid scales in the solar wind in particular, but it will also encounter magnetosheets, so I'm quite looking forward to looking at those data and seeing what we can do with regards to turbulent reconnection with those new datasets.

Dr. Hodges. If we have time, we have one question now from the audience: "Does reconnection increase during geomagnetic storms due to increased turbulence, greater amounts of plasma, or a combination of both?"

Dr. Stawarz. In terms of geomagnetic storms, usually you're thinking more about the kind of large-scale cycle of reconnection in the magnetosphere, which we call the Dungey Cycle. You have a southward IMF in the solar wind that impinges on the Earth's northward magnetic field and you get reconnection on the dayside that then brings flux into the magnetotail and you get reconnection there that can accelerate particles back towards Earth. That is a really interesting question, so in that sense it's a little bit different from the small-scale reconnection we're looking at within the turbulence, but I think there is a really interesting question of how the turbulent dynamics in, say, the magnetosheath or other regions impact the kind of overall dynamics of the magnetosphere. You can imagine that the turbulence is going to perturb the magnetopause and it may lead to more patchy magnetic reconnection and lead to Kelvin–Helmholtz instabilities that may have an impact on the more large-scale geo-effective magnetic reconnection that's going on in the magnetosphere. That's an area that hasn't been looked at as extensively, and so I think there's a lot of opportunity to look at the kind of space-weather impacts on plasma turbulence.

Dr. Hodges. Thank you very much. I think I'll hand back to Emma.

The President. Thank you very much, Sean, for doing that. And thanks again Julia for your talk and also for answering those interesting questions. That brings us to the closing remarks for our meeting this afternoon, and finally I would just like to give notice that the next monthly A&G Open Meeting of the Society will be on Friday the 8th of April. I look forward to seeing many of you at that meeting.

[Eds. note. The February meeting was not transmitted due to technical difficulties. The scheduled speaker, Professor Giovanna Tinetti, who was due to give the Eddington Lecture will instead speak at the April 8th meeting.]

THE FIRST (ROYAL) ASTRONOMICAL SOCIETY PUBLICATION

By Steven Phillipps

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As is well-known, the Royal Astronomical Society was founded in 1820, as the Astronomical Society of London[1]. However, its first publication was not printed until 1822[2]. This was Part 1 of *Memoirs of the Astronomical Society of London, Volume 1*. Part 2 was published in 1824[3] and Volume 2 appeared in 1826[4]. Here, we explore the content of the first publication and the contributors to it.

Published by Baldwin, Craddock and Joy of Paternoster Row and printed by R. and A. Taylor, Shoe Lane, London, this first issue began with an 'Advertisement'. "The Council of the Astronomical Society of London take this opportunity of acquainting the public, that a committee is, from time to time, appointed to consider and report on the Papers read before the Society: and the Council afterwards select such as they judge most proper for publication in the Memoirs". Not all papers passed this scrutiny, thus "the thanks, which are usually proposed from the Chair, to be given to the authors of such Papers as are read at their accustomed meetings … are to be considered in no other light than as a matter of civility". As we shall see below, by 1822 they had adjudged seventeen papers to be sufficiently proper.

There followed the 'Address of the Society', the 'Regulations of the Society', and the 'First Report of the Council to the Society'. The 'Address', which had been circulated prior to their first public meeting (in 1820 February[1]) and also published in the *Philosophical Magazine*, was "explanatory of their views and objects". It had been prepared by John Herschel, though not without some disagreement with Francis Baily, the Secretary, who produced the printed version[1]. It was noted that the Society had "for one of its objects the formation of a collection or deposit of manuscript observations … to which the industrious observer may consign the result of his labours". "It will also be an object worthy of the Society, to promote an examination of the heavens in minute detail; by parcelling them out, in proportions of a very moderate extent, among those members who may find leisure and inclination to direct their attention more peculiarly and constantly to such portions".

The 'Regulations' covered the organization of the Society, specifying details of its constitution, the election of officers and Council, the election, admission, and expulsion of members, the contribution of members (4 guineas for the first year and 2 guineas for every subsequent year if residing within 50 miles of the metropolis, a one-off fee of 8 guineas for more distant members), Associates ("person[s], eminent in astronomy, not being a British subject, nor having a residence in any of the British dominions"), the Council, the Ordinary Meetings, the Annual General Meeting, Special General Meetings, the altering of Regulations, Scientific Committees, the President and Vice President, the Treasurer, the Secretaries, the property of the Society, and donations and bequests. Appendices provided the forms necessary for admission to the Society.

The 'Report' was that to the Annual General Meeting of 1821 February 9, in which "the Council cannot but congratulate the Members on the success which has attended the first attempt to establish, in this country, a Society for the promotion of so important a branch of science as astronomy". The Council also noted their intention to present "Medals in gold, silver and bronze" to "such persons as may, from time to time, distinguish themselves by any material discovery, or improvement in the science". In particular, "they recommend the proposal of the Society's gold medal and twenty guineas for the solution of the following prize question: for the best paper on the theory of the motions and perturbations of the satellites of Saturn". It was also noted that the number of resident members was 82 and the number of non-residents (*i.e.*, those outside the London area) was 37.

The main scientific content of the Report concerned one of the members. "At the close of the last session, the Council received a communication from Capt. Basil Hall, expressing his readiness to attend to any instructions on subjects wherein he might be of service to the science of Astronomy, in his intended voyage[5] to the South Seas". They note that they "availed themselves of the offer of this intelligent and enterprising officer", but Hall[6], a distinguished Royal Navy captain, explorer[7], and FRS, may have wished he had been less enterprising, as there followed four pages of instructions for suggested observations!

Seventeen papers

Rules for the printing of papers had only been adopted at the 1821 May meeting and at a special meeting two weeks later six of the papers previously given at meetings were submitted for approval, only three of which were accepted[1]. The first was a lengthy one (22 printed pages):

'An Account of the Repeating Circle, and of the Altitude and Azimuth Instrument; describing their different constructions, the manner of performing their principal adjustments, and how to make observations with them; together with a comparison of their respective advantages. By Edward Troughton Esq., F.R.S., and Member of the American Philosophical Society. Read January 12, and March 9, 1821.'

Troughton[8], born in 1753, was a noted builder of navigational and astronomical instruments, based in Fleet Street at 'The Sign of the Orrery'. He constructed the transit circle which Groombridge used for his star catalogues (see below) and became a member of the Astronomical Society at its first public meeting in 1820 February[9]. His paper concluded that the Altitude–Azimuth instrument was much superior. He founded Troughton & Simms in 1826 and subsequently became embroiled in a famous (and successful) court case with Sir James South (below) concerning non-payment for a mounting Troughton had built for South's new telescope[1].

Next was a much shorter one (just four pages) by George Dollond on 'The Description of a Repeating Instrument upon a new construction'. Born in 1774, Dollond, who had also joined at the first meeting[9], was another famous optical-instrument maker (and FRS) and presented his new version of the repeating instrument for accurate measurement of angular separations — which appears to have been effectively a combination of the two types discussed by Troughton — at the 1821 April meeting. Dollond[10], with premises at St. Paul's Churchyard, built instruments for many of the prominent early Astronomical Society members such as Admiral Smyth and Lord Wrottesley.

The third paper, read in 1821 June, was by Francis Baily 'On a Method of fixing a Transit Instrument exactly in the Meridian'. Baily was a founder member and secretary of the Society[11]. Born in 1777, he was a successful stockbroker, based in Gray's Inn, wealthy enough to retire in 1825. He twice won the Society's Gold Medal and was President four times[12]. His astronomical work spanned star catalogues to eclipses ('Baily's Beads') to the figure of the Earth.

Subsequent meetings of the relevant committee and the Council approved further papers for publication (noticeably, not in the order that they had been read at Society (hereafter AS) meetings). The next three were all from the pen of the Rev. William Pearson LL.D., F.R.S. They were 'On the doubly-refracting property of Rock Crystal, considered as a principle of Micrometrical measurements, when applied to a telescope' (read 1820 March); 'On the construction and use of a Micrometrical Eye-piece of a Telescope' (1820 April); and 'On the construction of a new Position-Micrometer, depending on the doubly-refractive power of Rock Crystal' (1821 June).

Pearson is generally credited with being the first to suggest, in 1812, the creation of an astronomical society in London[1,13] and was the Society's Treasurer for its first ten years. Born in 1767, he was first a teacher, then took holy orders. Nevertheless, he continued his career as a partner in, and then owner of, private schools, building an observatory at Temple Grove in East Sheen. He was subsequently rector of a parish in Leicestershire, where he had a further observatory housing one of Troughton's telescopes. He was particularly known for building orreries and other mechanisms and for observations of star positions and occultations. He won the Society's Gold Medal in 1829 on the completion of his two volume *Treatise on Practical Astronomy*[14].

Seventh in the list of papers was 'Observations on the best mode of examining the double or compound Stars; together with a Catalogue of those whose places have been identified. By James South F.R.S. F.L.S. Honorary Member of the Cambridge Philosophical Society, &c.' (read 1820 May; there are 14 pages of star positions). Born in 1785 and originally a chemist and then surgeon before a marriage which "rendered him comparatively opulent", South was another founder member[15]. He won the Gold Medal in 1826 and became President in 1829[16]. He was knighted in 1830. However, the following year he became embroiled in a lawsuit after refusing to pay Troughton for the mounting for his new 12-inch objective lens, which the increasingly fractious South claimed had ruined the telescope[1]. As well as double stars, he also observed planets and comets.

The next paper (read 1820 November) was the first from an Associate (*i.e.*, overseas member), 'On the new Meridian Circle at Göttingen. Communicated by Professor Gauss, in a letter to the Foreign Secretary, of which the following is an abstract'. The distinguished German mathematician Carl Friedrich Gauss[17] (he anglicized his name to Charles Frederick in the letter), born 1777, was the director of Göttingen Observatory and amongst his other work had made significant contributions to celestial mechanics. He had been elected an Associate in 1820 November[18].

The 'Foreign Secretary' was John Herschel FRS, as above one of the instigators of the Society[19]. He had been Senior Wrangler in 1813 and his mathematical work had won him the Royal Society's Copley Medal in 1821. From 1816 he worked with his father, Sir William, building telescopes and re-observing double stars before moving on to his famous studies of the southern skies. He won the Society's Gold Medal twice and was the President three times[20]. He was knighted in 1831.

Francis Baily added his second paper (actually read earlier than the one above, in 1820 December), 'On the Solar Eclipse which took place on September 7, 1820'. He described the partial solar eclipse which had "excited general attention throughout Europe, on account of its magnitude" as observed "at Kentish Town, near the bottom of Highgate Hill". Baily also appended reports from other observers including Dollond, Groombridge, and Pearson, as well as M. Nicolai, director of "the observatory of the Grand Duke of Baden at Man[n] heim". All European astronomers appear to have been referred to as Monsieur, even if, as in this case, they were not French. Professor Bernhard Nicolai[21] had also published in the first ever issue of *Astronomische Nachrichten* in 1821[22].

A separate contribution followed, also 'On the Solar Eclipse which took place on September 7, 1820. Communicated in a letter to J. F. W. Herschel, Esq., Foreign Secretary, from Professor Moll of Utrecht'. The paper (read in 1821 May) summarized observations made in Amsterdam (where the eclipse was annular), Leyden [*sic*], Utrecht, and Groningen, amongst others. Gerrit Moll (rendered as Gerard in his RAS obituary[23]; he used the Latinized Gerardi in some of his own works) was born in Amsterdam in 1785, "a young gentleman of independent fortune", and became Professor of Mathematics and Natural Philosophy at the University of Utrecht in 1812, as well as director of the observatory. He had visited John Herschel immediately before the 1820 eclipse and was elected an Associate of the AS in 1820 December. He was also a friend of Humphry Davy and Michael Faraday and became involved in the arguments with Babbage 'On the Alleged Decline of Science in England'.

Next were two related overseas reports (both read 1821 April): 'On the Comet discovered in the Constellation Pegasus, in 1821. Communicated in a letter to J. F. W. Herschel, Esq., Foreign Secretary, from M. Nicollet of Paris' and 'On the Comet discovered in the Constellation Pegasus in 1821: and on the luminous appearance observed on the dark side of the Moon on February 5, 1821. Communicated in a letter to J. F. W. Herschel, Esq., Foreign Secretary, from

Dr. Olbers of Bremen'. Nicollet stated that he had discovered the comet on January 21st and reported the elements of its orbit as calculated from observations made at the Royal Observatory in Paris. Olbers reported his observations from his home between January 30 and March 6, and the recipient of his letter, John Herschel, appended his own description of the comet.

Born in 1786, Joseph Nicolas Nicollet was primarily a mathematician and cartographer and was made an Associate of the AS by 1826. He later attempted to use his mathematical skills to make his fortune on the stock market but was ruined by the Revolution of 1830 and emigrated to the USA where he produced much improved maps of the Mississippi River basin[24]. Wilhelm Olbers (like his friend Gauss, he anglicized his name to William in the letter), born in 1758, was a medical doctor in Bremen. He was already well-known for his discovery of the asteroids Pallas and Vesta and had also discovered a comet of his own in 1815. He is now most remembered for his discussion of what is usually referred to as Olbers' Paradox[25], though this is not mentioned in his RAS obituary[26]. He had been admitted as an Associate in January 1821 and was also an FRS.

The second part of Olbers' letter had concerned a "luminous appearance" on the dark side of the Moon, near Aristarchus, and a similar event was also the topic of the next contribution (read 1821 May), 'On a luminous appearance seen on the dark part of the Moon in May 1821. Communicated in a Letter to the Rev. Dr. Pearson, from the Rev. M. Ward'. Ward also saw a bright region around Aristarchus and in a footnote, Francis Baily confirms that he, too, saw the effect the following night. Michael Ward LL.B. (born 1769) had become a member of the AS at the postponed meeting at the end of February 1820. He lived in Tamworth and was vicar of a parish near Stafford. His RAS obituary[27] was exceedingly brief; "The Rev. Michael Ward had been a fellow of the Society for a long period. He was fond of astronomy and possessed a small observatory".

Next in the list (read 1821 June) was another overseas contribution 'On the Occultations of Fixed Stars by the Moon: on the Repeating Circle: on the Perturbations, &c. of the new Planets: and Observations of the late Comet and of the Planet Vesta. Communicated in a Letter to the Rev. T. Catton F.R.S., from Professor Littrow of Vienna'. Littrow added his observation of an occultation which Catton had earlier reported and listed a number of other occultations observed from Vienna. He also stated his agreement with Troughton on the poor results from repeating circles (see above), discussed Gauss' work on planetary perturbations and implied masses, and presented his own observations of a recent comet and of Vesta.

Joseph Johann von Littrow, born in Bohemia in 1781, was professor of astronomy and director of the Imperial Observatory in Vienna from 1819[28]. He became an Associate of the AS in 1821 November[29]. He contributed widely on optics, telescopes, and observations of planetary positions. His son Carl Ludwig succeeded him as the director in Vienna and also became an Associate of the RAS. His correspondent Rev. Thomas Catton B.D., born *c.*1758, was a fourth Wrangler and fellow of St. John's College Cambridge (John Herschel's *alma mater*) where he ran the college observatory from 1791 to 1832. He became a member of the AS in 1820 April[23] and an FRS the following year. He left ten volumes of observations which the Astronomer Royal Airy had published in 1853[30].

Perhaps prodded by South's new observations of double stars (above) which, South suggested, had been ignored since Herschel's work forty years earlier, William Herschel, the AS President[1], responded with a paper read in 1821 June 'On the places of 145 new Double Stars'. These had been observed during "sweeps of the heavens" in the years from 1784 to 1809. This was the 82 year-old Herschel's only contribution to Astronomical Society publications (he died later in 1822[31]), all his famous work on 'star gauging', the Milky Way, nebulae, *etc.*, predating the Society and being published in *Philosophical Transactions of the Royal Society of London*[32].

The 16th paper, read 1820 November, was 'Universal Tables for the reduction of the Fixed Stars' by S. Groombridge. The tables (30 pages of them, with instructions for their use) were designed to facilitate the task of reducing positional observations "to a certain epoch; whereby the places thereof may be compared with the observations of other astronomers, and their several stations be correctly determined". Stephen Groombridge FRS and SRA Nap. (*i.e.*, associate of the Royal Academy of the Kingdom of Naples) was a founder member of the AS[33] with an observatory in Blackheath. His catalogue of 4200 stars, which he had been observing since 1806, was later published by Airy[34]; the star Groombridge 1830 has the third-largest proper motion known. He also made large numbers of planetary observations. Born in 1755, he had started out as a draper but made his fortune as a merchant trading with the West Indies[35].

The final paper printed in the first issue of *Memoirs* was 'Observation of the Solar Eclipse which took place on Sept. 7, 1820 at Naples. Communicated in a letter from M. Piazzi to the Foreign Secretary'. Read at the meeting of 1821 November, this reported very briefly on observations of the recent annular eclipse made at the Royal Observatory of Naples at Capodimonte. Father Giuseppe Piazzi, a catholic priest of the Theatine order, had lectured widely in mathematics, starting at the University of Malta in 1770, and was professor of astronomy at Palermo for many years[36]. He was then appointed General Director of the Naples and Sicily Observatories in 1817, when aged 70. He had spent 1787 to 1789 visiting British and French astronomers and was made an Associate of the AS in 1820 December. He is most famous for his discovery of the first asteroid, Ceres, on 1801 January 1. He had the misfortune (though he was aged 80 by this point) to be one of the first three associates whose demise was reported in the newly established *Monthly Notices*[37] (the others were the equally well-known Bode and Fraunhofer) in 1827 February. (Earlier notices of the Astronomical Society had appeared within the *Philosophical Magazine*[1].) He was a friend of Society member Captain (later Admiral) Smyth and godfather to his son, the future Astronomer Royal for Scotland, Piazzi Smyth.

Presents, Members, and Associates

The remainder of the volume was taken up with further administrative material. First was a list of the Presents, almost all books — including some from the 17th Century given by Major Colby (see below) and Francis Baily — which had been received by the Society from 1820 March to 1822 January. This was followed by a list of all the Members of the Astronomical Society as of the Annual General Meeting in 1822 February, totalling some 160, and a list of the 21 Associates. (In all, 187 persons had been admitted by this point but at least three were deceased and the Duke of Somerset had resigned when caught in the middle of the acrimonious row between the AS and Sir Joseph Banks, the President of the Royal Society[1].)

Finally, there was the list of Officers of the Society for the year 1822. These were President — Sir William Herschel; Vice-Presidents — Major T. Colby, Sir H. C. Englefield, Davies Gilbert, D. Moore; Treasurer — Rev. W. Pearson; Secretaries — C. Babbage, F. Baily, J. F. W. Herschel (Foreign); Council — G. Birkbeck, B. Gompertz, O. G. Gregory, S. Groombridge, J. Horsburgh, Major General John Rowley, J. South, E. Troughton; Trustees — A. Baily, D. Moore, C. Stokes.

Of the Vice-Presidents, Thomas Colby FRS of the Royal Engineers[38] was director of the Ordnance Survey and a founder member of the Society[39]. Henry Englefield FRS, FSA was primarily an antiquary[40], though as well as studying the orbits of comets he also carried out research in mathematics, chemistry, and geology. He died in 1822 March, shortly after being elected. Davies Gilbert FRS (born Davies Giddy) was a Cornish engineer and politician (becoming High Sheriff of the Duchy and later an MP) who was President of the Royal Society from 1827 to 1830[41]. Daniel Moore FRS was a solicitor at Lincoln's Inn and a wealthy benefactor of numerous scientific societies and charities[42].

The third of the secretaries, alongside Baily and Herschel, was Charles Babbage FRS[20], a well-known mathematician and AS founder member[43]. He actually first presented the invention of his Difference Engine in a talk at the AS meeting in 1822 June: 'Note on the application of machinery to the computation of astronomical and mathematical tables'. This won him the Society's Gold Medal in 1824 and Baily published a discussion of the machine's utility in *Astronomische Nachrichten*[44].

Council member George Birkbeck MD became the co-founder of the eponymous college in London. He was earlier professor of natural philosophy at the Andersonian Institute in Glasgow and was a pioneer of scientific education for working men[45]. Benjamin Gompertz FRS was a self-taught mathematician (he was barred from attending university as he was Jewish) who was a noted actuary[46] and demographer. He was also a member of the Mathematical Society of Spitalfields which later merged into the RAS[47]. Olinthus Gilbert Gregory LL.D. was a prolific author[48] and from 1821 professor of mathematics at the Royal Military College, Woolwich. He was later involved in the foundation of a secular University of London[49]. (Despite his professorship, his election to the Council alongside numerous 'gentlemen' is intriguing, as Herschel[50] reputedly found Gregory, with his working class origins, "rather too coarse in his strictures and behaviours".) Captain James Horsburgh FRS was a naval officer who wrote several treatises on navigation. Another man with humble origins, he worked his way up to be official hydrographer of the Honourable East India Company from 1810[51]. Major-General John Rowley FRS, of the Royal Engineers, had served in the French Revolutionary Wars. He was the army's Deputy Inspector General of Fortifications from 1811[52].

Arthur Baily was a founder member[53] and a stockbroker at Gray's Inn, like his elder brother Francis[54], while Charles Stokes FRS was another successful stockbroker. Scientifically he was more geologist[55] than astronomer and studied minerals and fossils (several types of which are named after him). He was financial advisor and friend of Charles Darwin[56]. Notice that the Society were not taking any chances with their money: the three Trustees were two stockbrokers and a solicitor.

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UBV(RI)$_C$ APERTURE PHOTOMETRY FOR LARGE GALAXIES, GALACTIC GLOBULAR CLUSTERS, AND STARS

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Introduction

From 1982 January to 1988 October, I used the 76-cm and 91-cm (30-inch and 36-inch) reflectors at McDonald Observatory in West Texas for *UBV(RI)$_C$* observations of 239 galaxies, 18 Galactic globular clusters, 550 stars, and 11 miscellaneous objects. My primary goal for the programme was to provide large-aperture photometry for the 250 or so largest galaxies accessible from McDonald so total magnitudes and colour indices could be estimated more reliably. Along the way, I established a set of secondary *UBV(RI)$_C$* standard stars in the equatorial Selected Areas, measured stellar sequences to allow calibration of 'historical' supernova observations, several supernovae themselves, BL Lac objects, H II regions and star clouds in other galaxies, the globulars, and miscellaneous stars for colleagues' observing programmes. I intend this paper to be a brief introduction to the observing programme, and as a pointer to the observations themselves, currently at http://haroldcorwin.net/ubvri and perhaps soon at CDS as a 'permanent' on-line catalogue.

This paper will also serve as a brief introduction to the galaxy photometry by Robert Smyth at Siding Spring Observatory in 1980–81, and to the supernova observations and supernova comparison sequences made by Marian Frueh and Shireen Gonzaga at McDonald in 1985–86.

The McDonald and Siding Spring photometry found its main use in the derivation of photometric parameters given in the *Third Reference Catalogue of Bright Galaxies*[1]. Currently, the 'raw' data may be primarily of historical interest as few observers now attempt the sort of single-channel photometry that forms the basis of these observation sets. Even in that light, however, it may well be that some of the data are still useful, particularly for calibrating CCD (or other) imaging of the included galaxies, or for providing photometric zero points for small-field stellar photometry around or within the galaxies. Another potential drawback of the data here involves the *UBV(RI)$_C$* passbands. None of the current or envisioned optical sky surveys use the classical *UBV(RI)$_C$* system, so conversion to the survey band passes (or *vice versa*) would be a necessity. Are these transformations worth the potential loss of accuracy? While I feel that the answer is 'Unlikely!' I could well be surprised by the uses to which the data may eventually be put. There are some very resourceful and imaginative astronomers now working on various photometric aspects of objects in the night sky.

This paper is organized as follows: the first six sections discuss the McDonald observations, with a seventh covering Smyth's Siding Spring data, also *UBV(RI)$_C$*. For the McDonald observations, the second section describes the selection of observing targets; the third briefly covers the equipment and observing techniques, as well as Frueh and Gonzaga's *UBV* supernova-sequence work; the fourth, the establishment of a set of secondary standard stars around the equator; the fifth, the reductions and the reduced data; and the sixth, internal and external errors. The final sections have general conclusions and acknowledgments.

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Selection of galaxies, globular clusters, and stars

My initial goal of the observing programme was to provide data at relatively large apertures for galaxies larger than about five arcminutes at the 25·0 *B*-mag arcsec^{-2} isophote. By the 1970s, there were many observations of most of these objects available at small apertures. While adequate for calibration of surface photometry, the small-aperture photoelectric photometry needed the addition of the larger apertures to determine reliable total magnitudes (*e.g.*, for galaxies listed in the *Second Reference Catalogue*, RC2[2]). The galaxy list was based on RC2 diameters supplemented by large galaxies in Nilson's *Uppsala General Catalogue of Galaxies* (UGC)[3] in the north, as well as Lauberts's *ESO/Uppsala Survey of the ESO* (*B*) *Atlas* (ESO-B)[4] and our *Southern Galaxy Catalogue* (SGC)[5] in the south. The final list of large galaxies includes about 360 objects.

The Galactic globular clusters I observed were primarily northern objects, intended initially to expand on my own earlier *UBV* observations.[6] The publication of Hanes and Brodie's[7] extensive observations of Galactic globulars from Las Campanas while the present programme was in progress led to further observations of primarily northern globulars to complement their work in the south.

Stellar photometry initially focussed on establishing a network of secondary standards in the Selected Fields around the equator, but quickly expanded to supernova sequences at the request of James Bryan and his co-author Greg Thompson for their *Supernova Search Charts and Handbook*.[8] Marian Frueh and Shireen Gonzaga picked up this aspect of the observing, and their observations of stars suitable for sequences, including the *V* magnitudes published on the supernova *Charts*, are described here. Gerard de Vaucouleurs also requested data for several 'historical' supernova sequences. Work on sequences for, *e.g.*, M31/S Andromedae (SN 1885)[9], NGC 4753/SN 1983G[10,11], and M81/SN 1993J[12] also led to observations of several supernovae themselves. Jim Wray requested photometry for bright stars near galaxies included in his *Color Atlas of Galaxies*[13], and other McDonald colleagues from time to time also asked for photometry for stars relevant to their programmes. Finally, many stars subtracted from the galaxy observations are also suitable for inclusion in the sequences, so I list data for all of them as well.

Observing instruments and technique

Two EMI 9658R photomultiplier tubes were available at McDonald for general observing. These extended S-20 photomultipliers have sufficient response across the visual spectral range[14,15] to cover the standard Johnson *UBV* and Cousins $(RI)_C$ bands. While considerable *UBV* data for galaxies were generally available — albeit at small apertures — when the programme was conceived in the late 1970s, there were very little *RI* data available. The longer-wavelength data were desirable for, among other things, calibration of the red sky-survey plates being taken at Siding Spring, Palomar, and European Southern Observatories.

The dry-ice-cooled tubes were attached to filter boxes that included an aperture wheel with apertures that gave diameters of up to 4·0 arcminutes at the Cassegrain focus of the 76-cm telescope. In addition to the five standard photometric filters, a sixth space in the filter wheel was devoted to a carbon-14 'standard source' for monitoring the stability of the equipment. The filter wheel was driven by a computer-controlled stepping motor to give 10-second integrations through each filter in turn, with 1-second integrations on the standard source. The resulting data counts were output to magnetic tape cartridges as well as to a teletype printer with paper output.

On the advice of Tom Barnes and Tom Moffett, I used the photomultipliers at a lower than ‘normal’ voltage (+1200V rather than +1500V to +1600V), and had a ring magnet placed over the front of the photomultiplier. These steps had the advantage of lowering the dark count by a factor of about 16, while dropping the total counts by only a factor of 3·5.

The filters I used are listed in Table I (also see Bessell’s[14,15] discussions for more on the standard photometric systems).

TABLE I

Filters

U: 1mm UG2 + $CuSO_4$
B: 1mm BG12 + 1mm BG18 + 2mm GG385
V: 1mm BG18 + 2mm GG495
R: 2mm KG3 + 2mm OG 550 (Runs 1-12)
R: 2mm KG3 + 2mm OG 570 (Runs 13-24)
I: 2mm RG9

Through a misreading (*mea culpa*!), I used an incorrect blue-cutoff filter in the *R*-band for the first half of the programme. The transformation of these observations to the standard *R*-band system is still linear, though with a larger slope than for the remaining observations with the nominally correct filter. Table II lists the apertures I used with the equivalents in arcseconds and log aperture (1/10s of arcminutes as in the three *Reference Catalogues of Bright Galaxies*[1,2,16]) at each telescope.

TABLE II

Apertures

		76-cm telescope		*91-cm telescope*	
Nominal mm	*Measured* mm*	*Arcseconds (19·1″/mm)*	*logA (1/10s arcmin)*	*Arcseconds (16·8″/mm)*	*logA (1/10s arcmin)*
0·5	0·499	9·53	0·20	8·38	0·15
1·0	0·977	18·66	0·49	16·41	0·44
2·0	1·979	37·80	0·80	33·25	0·74
4·0	3·988	76·17	1·10	67·00	1·05
8·0	8·035	153·5	1·41	135·0	1·35
12·6	12·59	240·4	1·60	211·4	1·55

* Measured by W. Pence and B. Smith.

The observing technique was that of, *e.g.*, de Vaucouleurs and de Vaucouleurs[17]; de Vaucouleurs, de Vaucouleurs, and Corwin[18]; and Corwin[19]. Briefly, five observations of the target object were interspersed with four of the sky in the cardinal directions. The sky fields were selected by eye to be ‘blank’, or to have a background of faint stars similar to that found in the target object fields. The brighter standard stars were adequately covered with three observations of the star plus sky, with two of the sky north and south. A few faint galaxies required more counts to achieve an adequate signal, so I took nine galaxy-plus-sky readings for them, interspersed with eight of the sky alone. Stars superposed on the target galaxy or globular were observed with small apertures — with target object plus sky background taken on an approximately identical isophote within the object — and later subtracted. Stars with apparent companions usually had the companions measured separately with small apertures; these too were subtracted during reductions.

All the $UBV(RI)_C$ observing was done by me aside from two nights covered by Marian Frueh when I could not be present at McDonald. She used the same equipment and techniques that I have described above. The *UBV* sequences that she and Shireen Gonzaga observed were done with an uncooled 56-DVP photomultiplier, though with the same telescopes, filter boxes, and a similar observing technique. Frueh's contemporaneous *UBV* galaxy photometry is described by Frueh *et al.*[20] which has additional observing details. Robert Smyth's $UBV(RI)_C$ observations with the Siding Spring 41-cm and 61-cm telescopes were made in the same way as my McDonald observations, though he tied his observations directly to the Cousins E-region standard stars[21]. I will have more about Smyth's and the Frueh/Gonzaga observations below.

Standard stars

As no list of $(RI)_C$ standard stars existed that was accessible for northern hemisphere observers in the early 1980s, I — with the help of Robert Smyth and Michael Bessell — had to build one. Smyth and Bessell used the Siding Spring telescopes to transfer the Cousins[21] E-region $(RI)_C$ system to equatorial Selected Area stars already established as *UBV* standards by Landolt[22]. I also transformed the Moffett & Barnes[23,24] and Barnes & Moffett[25] Johnson $(RI)_J$ standards to the Cousins $(RI)_C$ system to strengthen the initial standard-star network and to help select standards of appropriate magnitude and colour during the early days of the programme. Another list of Johnson $(RI)_J$ equatorial standards by Kunkel & Rydgren[26] was also useful for this preliminary work. I did not, however, use any of the transformed Moffett/Barnes or Kunkel/Rydgren data in the final list of standard stars. Over the course of the 24 observing runs, I picked up not only many stars included in the previous lists but additional stars of various colours to extend the network in various equatorial Selected Areas. The final range of colour index for the 190 secondary standards is $B–V \sim –0·15$ to $B–V \sim 1·7$. These proved suitable not just for galaxies and globular clusters, but also for the stars of more extreme or unusual colours that I occasionally observed. I compared these secondary standard stars with the primary standards published later by Landolt[27] and Menzies *et al.*[28] (at the South African Astronomical Observatory, SAAO) and found the secondary standards to define a reasonably secure 'standard' system. Table III has the 'true' standard deviations for the three sources from triangular comparisons of the standard deviations of the mean differences. There were 110 stars are in common between Landolt's list and the McDonald observations, 90 stars between Landolt and SAAO, and 92 between SAAO and McDonald. Further details are given on my web pages.

TABLE III

Standard deviations (1-sigma errors) of a single observation for Landolt standards, SAAO standards, and McDonald secondary standards; units are magnitudes.

Mag/Colour	*Landolt*	*SAAO*	*McDonald*
V	0·0044	0·0038	0·0077
B–V	0·0040	0·0057	0·0066
U–B	0·0123	0·0113	0·0171
V–R	0·0050	0·0020	0·0065
V–I	0·0050	0·0025	0·0077

Reduction and data

Data reduction followed the classic approach as set out by Hardie[29,30] though with minor variations. I used nightly extinction and transformation coefficients (aside from three nights when weather interfered with observing standard stars; for those nights, I adopted mean extinction coefficients from other nights in the same runs), with the nightly zero-point being calculated in the extinction solution. This seemed prudent given the variations in the sky conditions, especially for the early runs affected by the eruption of El Chichon in 1982, and a strong El Niño-Southern Oscillation weather disturbance in 1983. Reductions for some nights had to be split into two or even three parts because of fairly rapid changes in the sky conditions.

The reductions were repeated at least twice for every observing night, and the data for the standard stars collected. A third reduction of all nights with the mean standard-star data gave the final values in the standard $UBV(RI)_C$ system. These are the data available on my web pages. As an example of the data, Table IV has the $UBV(RI)_C$ photometry for the 18 Galactic globulars that I observed. Again, the many details I've glossed over here are given at the web link cited above.

Internal and external errors

I discussed the errors in the standard-star photometry in the previous section. That discussion assumed that those errors are independent of magnitude, telescope aperture, night-sky brightness, *etc.* Errors in the galaxy and globular cluster photometry are certainly dependent on all these factors, but can be summarized as functions of signal-to-noise ratio (see *e.g.* Buta *et al.*[31]):

$$S/N = [(o+s)-s]/s,$$

where 'o+s' are the object-plus-sky counts and 's' are the sky-alone counts. Plots of the standard deviations in magnitude *versus* log(S/N) from repeated observations of the same object at the same apertures revealed the expected trend of greater scatter at low values of signal-to-noise. An example plot in the V-band is shown as Fig. 1. The exponential fit to the points is from the plotting

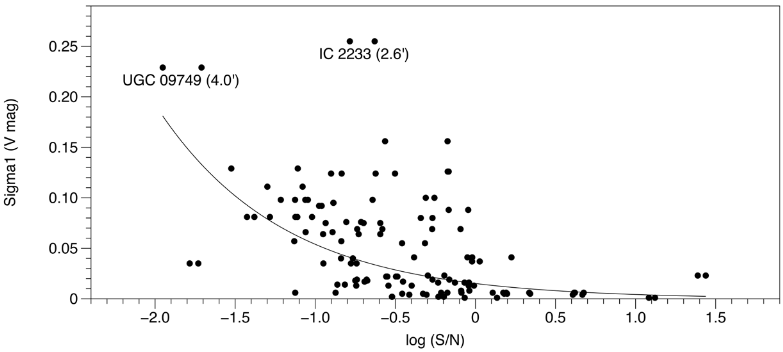

Fig. 1

σ_V *versus* log (S/N) from repeated observations for galaxies.

TABLE IV

McDonald $UBV(RI)_C$ for Galactic Globular Clusters

Cluster	*log A*	*V*	*B–V*	*U–B*	*V–R*	*V–I*	*Date (UT)*	*Note*
NGC 2419	1·41	10·890	0·652	0·053	0·451	0·939	86-10-27	
NGC 2419	1·60	10·780	0·642	0·050	0·460	0·921	86-10-28	*
NGC 2419	1·60	10·683	0·702	0·050	0·507	0·974	86-10-27	*
NGC 4147	1·41	10·537	0·572	0·035	0·401	0·797	87-03-31	
NGC 4147	1·60	10·471	0·567	0·034	0·408	0·843	87-03-31	*
NGC 4590	1·41	9·047	0·616	0·016	0·367	0·798	86-04-05	
NGC 4590	1·60	8·692	0·611	0·044	0·475	0·915	85-05-22	*
NGC 5024	1·41	8·351	0·629	0·045	0·434	0·874	87-03-31	
NGC 5024	1·60	8·086	0·635	0·053	0·439	0·884	87-03-31	
NGC 5272	1·41	7·143	0·683	0·103	0·459	0·916	87-03-05	
NGC 5272	1·60	6·871	0·679	0·098	0·457	0·917	87-03-05	
NGC 6205	1·41	6·887	0·674	0·055	0·452	0·890	86-04-04	
NGC 6205	1·60	6·477	0·670	0·043	0·450	0·890	86-04-04	
NGC 6229	1·41	9·549	0·697	0·104	0·459	0·926	87-04-01	
NGC 6229	1·60	9·456	0·707	0·107	0·466	0·939	87-04-01	
NGC 6341	1·41	7·125	0·623	0·003	0·436	0·866	86-04-04	
NGC 6341	1·60	6·903	0·611	-0·006	0·429	0·854	86-04-04	
NGC 6356	1·41	8·721	1·118	0·631	0·699	1·429	85-05-21	
NGC 6356	1·60	8·548	1·118	0·634	0·695	1·428	85-05-21	
NGC 6779	1·41	8·966	0·847	0·169	0·561	1·163	85-05-21	
NGC 6779	1·60	8·586	0·851	0·178	0·561	1·166	85-05-21	
NGC 6838	1·41	8·904	1·044	0·585	0·620	1·245	86-10-31	
NGC 6838	1·60	8·365	1·103	0·521	0·667	1·382	86-10-31	*
NGC 6934	1·41	9·105	0·752	0·160	0·494	1·011	86-10-28	
NGC 6934	1·60	8·930	0·761	0·186	0·500	1·025	86-10-28	*
NGC 6934 + star	1·60	8·302	0·905	0·392	0·532	1·054	86-10-28	
NGC 7006	1·10	11·033	0·728	0·127	0·490	0·984	86-10-27	
NGC 7006	1·41	10·774	0·745	0·120	0·493	1·015	86-10-27	*
NGC 7078	1·41	6·989	0·692	0·058	0·483	0·986	86-10-28	
NGC 7078	1·60	6·770	0·695	0·055	0·481	0·985	86-10-28	
NGC 7492	1·41	11·982	0·554	0·016	0·396	0·815	86-10-31	
NGC 7492	1·60	11·518	0·590	0·033	0·387	0·777	86-10-31	
GCl 107	1·10	12·318	2·114	2·409	1·277	2·576	86-10-31	*
GCl 107	1·41	11·376	2·148	1·827	1·287	2·567	86-10-31	*
GCl 107	1·41	11·407	2·122	1·392	1·272	2·558	88-10-14	*
GCl 107	1·60	11·068	2·291	1·326	1·330	2·642	88-10-14	*
GCl 107 + star A	1·41	11·232	1·736	0·897	1·201	2·446	86-10-31	
GCl 107 + star A	1·41	11·263	1·718	0·795	1·187	2·433	88-10-14	
GCl 107 + 3 stars	1·60	10·688	1·460	0·343	1·116	2·324	88-10-14	
Palomar 2	1·10	13·365	1·956	1·827	1·220	2·451	86-02-07	
Palomar 2	1·41	12·961	2·099	1·844	1·273	2·474	86-02-07	*
Palomar 15	1·60	13·764	1·072	0·605	0·704	1·368	83-04-16	*

Notes:

Cluster	*Date*	*log A*	*Note*
NGC 2419	86-10-27	1·60	6–7 field stars compensated in skies.
NGC 2419	86-10-28	1·60	Ditto.
NGC 4147	87-03-31	1·60	Several field stars compensated in skies.
NGC 4590	85-05-22	1·60	Two pretty bright stars west just out. Affected by clouds?
NGC 6838	86-10-31	1·60	Many field stars compensated in skies.
NGC 6934	86-10-28	1·60	Bright star subtracted.
NGC 7006	86-10-27	1·41	Three or four faint stars included, compensated in skies.
GCl 107	86-10-31	1·10	Not NGC 6749; that is an open cluster about 5 arcminutes south-southwest.
GCl 107	86-10-31	1·10	Two or three faint stars compensated in skies.
GCl 107	86-10-31	1·41	One star subtracted aperture slightly ex-centered to exclude others, remainder compensated in skies.
GCl 107	88-10-14	1·41	Star A subtracted
GCl 107	88-10-14	1·60	Stars A–C subtracted
Palomar 2	86-02-07	1·41	Nine globular cluster plus skies, eight skies.
Palomar 15	83-04-16	1·60	Several very faint stars in aperture, compensated in skies; slightly ex-centered to exclude a star. Nine globular cluster plus skies, eight skies.
Palomar 15	83-04-16	1·60	Centered at 16 59 48·7, –00 32 04.

program. While that would be an adequate representation of the errors, a more realistic fit for this particular example might be a simple step function with $\sigma_1(V) = 0·02$ for log (S/N) > 0, $\sigma_1(V) = 0·06$ for 0 > log (S/N) > –1·5, and $\sigma_1(V) = 0·12$ for log (S/N) < –1·5. I'll discuss this further below.

A curious aspect of the errors suggested by the plots like Fig. 1 is that these internal errors may actually be larger than the external errors found by Buta *et al.*[31,32]. Here is a possible explanation. Many of the galaxies with repeated observations were chosen because of known or suspected problems in the initial data, usually from the early runs in 1982 or 1983 (see above): marginal weather conditions, possible equipment problems, superposed stars in or out of the apertures, *etc.* Similarly, the repeated stars may have had similar problems. In the case of stars superposed on the galaxies, the galaxy background subtraction is crucial to obtaining accurate photometry. Because it proved difficult to match exactly the bright background of the galaxies on which the stars are superposed with the comparison areas without the stars, these stars are subject to relatively large errors. These problems suggest that the internal errors given below may be overestimated compared to 'clean' observations. Nevertheless, these errors are representative of the current observations given the observing conditions I dealt with.

With that in mind, I've treated galaxies and stars separately in the error analysis. Their luminosity profiles on the sky are also obviously different. The intrinsic profiles for galaxies are convolved with those imposed by the sky and observing equipment, while those for stars are assumed to be the result of the sky and the equipment alone. The difference can be demonstrated by plots of log(S/N) *versus* magnitude; an example, also in the *V*-band, is shown as Fig. 2. The two sequences seen there, labelled 'Stars' and 'Galaxies', confirm that different error functions will exist for point and extended sources on the sky.

Galaxies

Unfortunately, the raw counts needed for calculating the individual signal-to-noise ratios for the bulk of the observations are no longer available in my computer files. A reasonable substitute could be mean surface brightnesses, μ, of the object; Fig. 3 shows the *V*-band observations for the galaxies and stars

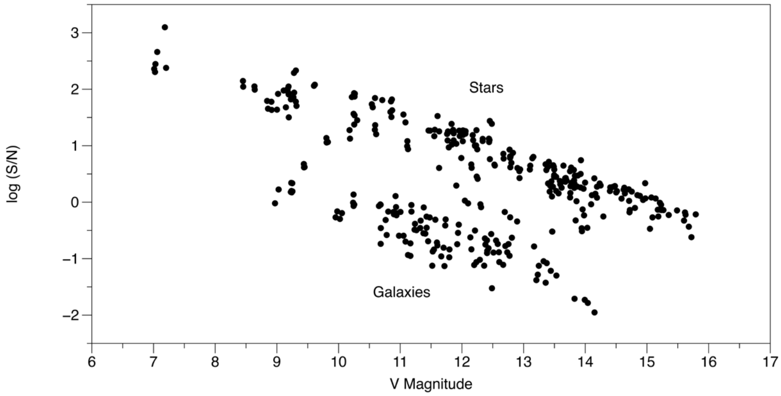

FIG. 2

log (S/N) *versus V* magnitude for stars as well as galaxies..

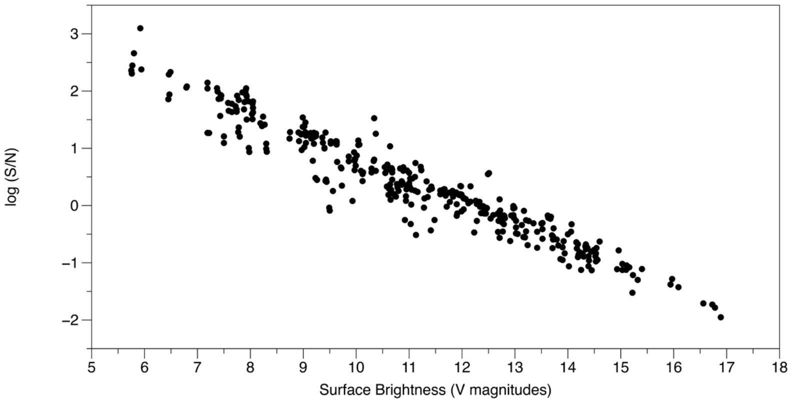

FIG. 3

log (S/N) *versus V*-magnitude surface brightness for galaxies

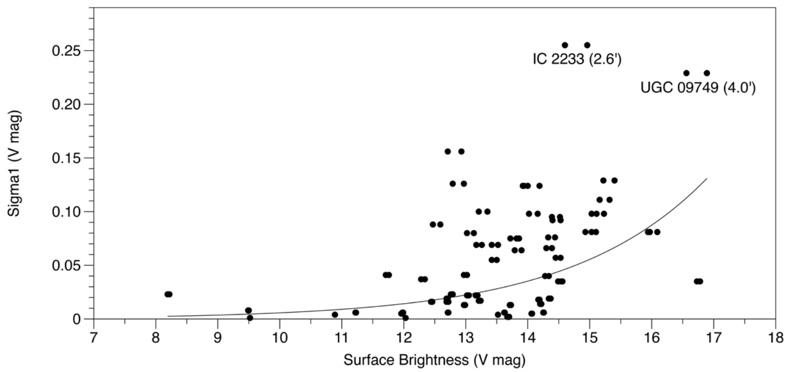

FIG. 4

σ_V from repeated observations of galaxies *versus V*-magnitude surface brightness.

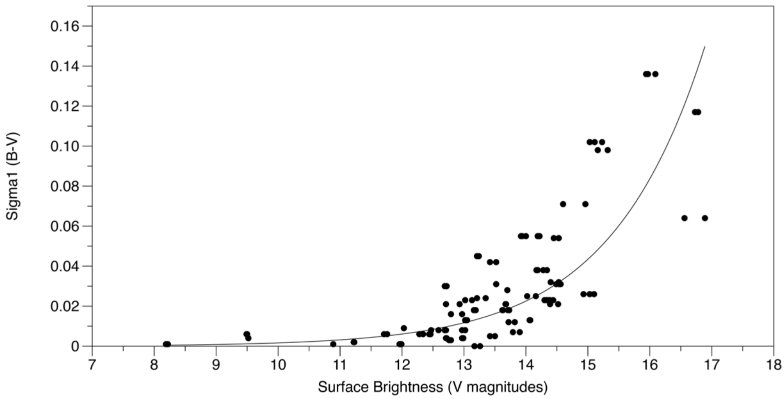

FIG. 5

σ_{B-V} from repeated observations of galaxies *versus* V-magnitude surface brightness.

with multiple observations. The strong correlation between surface brightness and mean S/N suggests that surface brightness, readily available for all the observations, is an adequate substitute for the individual S/N. (There is some evidence for subtle structure in these plots, but I have ignored it in the following error analyses.)

The plot of V-band standard deviation *versus* surface brightness is shown in Fig. 4. (As with the previous plots, the other filters show structure similar to the V-band plot. See my web site for those plots and other details.) This is essentially a mirror image of Fig. 1. A step function for $\sigma_1(V)$ with breaks at $\mu_V = 12{\cdot}0$ and 15·0 would do as well here as it did in Fig. 1. Colour-index errors follow the same general trends that the magnitudes do, though sometimes *without* the apparent step function seen in the V-magnitude plots (my web pages have all the plots); Fig. 5 shows an example. In what follows, swayed by my long-time prejudice for exponential error functions — and evidence for it in several of the plots here as well as the relatively small numbers of repeated observations — I've adopted the exponential fits.

For an *overall* assessment of the internal errors, I've pulled together Table V. This has representative errors at $V \sim 12{\cdot}5$ so as to be roughly compatible with the analysis in Buta *et al.*[31] The table also has the errors calculated with surface brightness at $\mu_V \sim 13{\cdot}5$ mag arcmin^{-2}. Details are on the web site.

Note, too, that these internal-error estimates apply only to my own $UBV(RI)_C$ galaxy observations at McDonald, not to Smyth's Siding Spring galaxy observations, nor to the supernova-sequence work by Frueh and Gonzaga. Statistical errors in their observations are discussed below.

TABLE V

Internal errors at for the McDonald galaxy photometry

$V \sim 12{\cdot}5$				$\mu_V \sim 13{\cdot}5$			
Magnitude	*m.e.*	*Colour Index*	*m.e.*	*Magnitude*	*m.e.*	*Colour Index*	*m.e.*
U	0·071	*U–B*	0·052	*U*	0·057	*U–B*	0·044
B	0·049	*B–V*	0·031	*B*	0·036	*B–V*	0·021
V	0·038	*V–R*	0·045	*V*	0·029	*V–R*	0·021
R	0·059	*V–I*	0·060	*R*	0·036	*V–I*	0·042
I	0·071			*I*	0·052		

Stars

In principle, stars can be easier to work with than extended objects because their luminosity profiles on the sky can be adequately modelled with the same point-spread function adjusted only to account for differing magnitudes. In practice, this means that, for the same star, smaller apertures will measure fainter magnitudes than larger apertures. I tested this during several of the 76-cm runs: observing stars at different apertures, I found that — in the mean — they are 0·01 magnitudes fainter with the 1-mm (18·7-arcsecond) aperture than the 2-mm (37·8-arcsecond) aperture I used for observing standard stars. The difference rises to 0·04 magnitudes for stars observed with the 0·5-mm (9·5-arcsecond) aperture. I made these corrections when necessary before proceeding with the following error analysis.

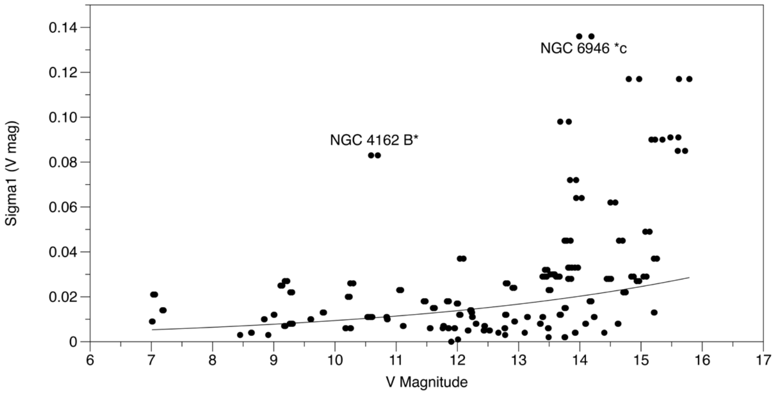

FIG. 6

σ_V from repeated observations of stars *versus* V magnitude.

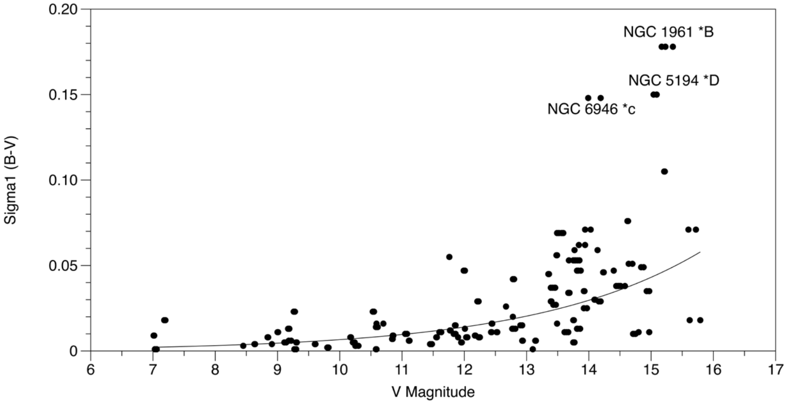

FIG. 7

σ_{B-V} from repeated observations of stars *versus* V magnitude.

Plotting the *V*-band standard deviation against *V* magnitude — Fig. 6 — again suggests a step function for the internal errors, this time with a single break point at $V \sim 13{\cdot}7$. (There are no standard stars in this plot, only 'programme' stars. Also, very discordant observations for two superposed stars are rejected from the *V*-band plot. See the web pages for details.) I have treated the errors for the colour indices for the stellar observations in the same way, plotting the standard deviation in colour index *versus* *V* magnitude. Fig. 7 shows that the results are, as expected, qualitatively much the same, this time with a break point at $V \sim 13{\cdot}5$.

As for the galaxies, Table VI has an overall assessment of the internal errors in the stellar photometry at $V \sim 12{\cdot}5$. Details, as always, are on the web site.

The errors in the Frueh/Gonzaga photometry for sequence stars around the galaxies are not rigorously derivable because of the very few repeated observations, and the lack of overlap with published photometry. But Buta *et al.*[31] have shown that Frueh's[20] galaxy photometry, made with the same equipment and often during the same runs, has external errors at $B \sim 13{\cdot}5$ of 0·033 in *B*, 0·021 in *B–V*, and 0·030 in *U–B*. Two factors will affect the relative errors between Frueh's galaxy photometry and the Frueh/Gonzaga stellar photometry: (*i*) the sequence stars are generally fainter than the galaxies behind them; but (*ii*) I assume that there is only a magnitude term in the stellar error function, not a surface-brightness term. These two may roughly cancel out, so I expect the external errors in the Frueh/Gonzaga stellar photometry to be of approximately the same size as those in Frueh's galaxy photometry.

External errors

Buta *et al.*[31] and Buta and Williams[32] have determined the *UBV* and *VRI* errors, respectively, for many different sources of photometry for galaxies including my McDonald photometry (sources COR-82, COR-84, COR-87, and COR-93 in their notation). Those two papers have the details of the error analysis, so the interested reader is referred to them. Briefly, the results for the McDonald photometry at $V \sim 12{\cdot}5$ are in Table VII.

TABLE VI

Internal errors at $V \sim 12{\cdot}5$ for the McDonald stellar photometry

Magnitude	*m.e.*	*Colour Index*	*m.e.*
U	0·043	*U–B*	0·038
B	0·021	*B–V*	0·012
V	0·017	*V–R*	0·011
R	0·020	*V–I*	0·022
I	0·028		

TABLE VII

External errors in the McDonald data at $V \sim 12{\cdot}5$

Magnitude	*m.e.*	*Colour Index*	*m.e.*
U	0·045	*U–B*	0·035
B	0·029	*B–V*	0·021
V	0·020	*V–R*	0·017
R	0·026	*V–I*	0·025
I	0·032		

While these are not directly comparable to the internal errors, the approximate agreement (compare with Fig. 4 for *V* magnitudes and Fig. 5 for *B–V* colour indices) is an indication of the general quality of the current data.

The reader must note, however, that the internal errors become much larger at fainter magnitudes (*c.f.* the 'step function' that I suggested in the previous section). So, while my overall judgement of the data is that they are 'acceptable', the data for the fainter galaxies, especially those with lower surface brightnesses, must be used with considerable care.

Siding Spring observations

During our time as post-graduate students at the University of Edinburgh in the late 1970s, Robert Smyth and I shared an interest in photometric properties of galaxies. Smyth was a post-doctoral fellow at Siding Spring Observatory, NSW, during 1980/81. He kindly agreed to observe the large southern galaxies not accessible from McDonald. He used the 41-cm and 61-cm reflectors with photometers and $UBV(RI)_C$ filters (including the correct OG 570 *R*-band blue cutoff filter) similar to those I used at McDonald. The apertures in the Siding Spring photometers also covered a range (38 arcseconds to 264 arcseconds) similar to those available at McDonald. As I mentioned above, Smyth used the Cousins[21] E-Region standard stars, so his results are strictly on the $UBV(RI)_C$ system.

Unfortunately, Smyth had to contend with unusually bad weather and, on the 61-cm telescope, occasional unstable equipment. Nevertheless, he was able to make 346 observations of 232 galaxies and two globular clusters (Palomar 15, as well as the Reticulum cluster now usually assigned to the LMC). His data have been available for some time in the Prugniel and Heraudeau[33] on-line database, as well as in the Longo and de Vaucouleurs[34,35,36] *UBV* and *VRI* collections, and on my own web site.

Errors in Smyth's photometry are larger than in the McDonald photometry because of the smaller telescopes he used, as well as the problems mentioned above. The error analyses by Buta *et al.*[31] and Buta and Williams[32] give the external errors at $V \sim 12{\cdot}5$ in Smyth's photometry shown in Table VIII.

Conclusions

The $UBV(RI)_C$ galaxy photometry that I've presented here may still be useful for calibration of surface photometry. Similarly, the stellar sequences may well be useful for determining at least preliminary magnitudes and colours for supernovae, bright variable stars, or other objects in or near the galaxies. Finally, the Galactic-globular-cluster photometry will help with determination of photometric profiles and magnitudes and diameters for those objects. The set of secondary standard stars, however, stands as an example of observational necessity given the lack of an accessible set of Cousins *R* and *I* standards in

TABLE VIII

External errors in the Siding Spring data at $V \sim 12{\cdot}5$

Magnitude	*m.e.*	*Colour Index*	*m.e.*
U	0·090	*U–B*	0·068
B	0·059	*B–V*	0·021
V	0·055	*V–R*	0·024
R	0·060	*V–I*	0·046
I	0·072		

the northern hemisphere when I began observing in 1982. While it served adequately for the present programme, and later to verify the high quality of the SAAO and Landolt standards, I do not recommend its use now that the accepted standards from SAAO and Landolt are generally available.

Acknowledgments

In addition to the observers and colleagues named in this paper, the many people who helped with this observational programme are listed on my web site. Here, I must especially thank McDonald Observatory for generous amounts of observing time, and the Astronomy Department of the University of Texas at Austin for access to computers and all the other professional facilities that I used throughout my time there.

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VLT, *GROND*, AND DANISH TELESCOPE OBSERVATIONS OF TRANSITS IN THE TRAPPIST-1 SYSTEM

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TRAPPIST-1 is an ultra-cool dwarf that hosts seven known transiting planets. We present photometry of the system obtained using three telescopes at ESO La Silla (the Danish 1·54-m telescope and the 2·2-m MPI telescope) and Paranal (Unit Telescope 1 of the *Very Large Telescope*). We obtained 18 light-curves from the Danish telescope, eight from the 2·2-m and four from the *VLT*. From these we measure 25 times of mid-transit for four of the planets (b, c, f, g). These light-curves and times of mid-transit will be useful in determining the masses and radii of the planets, which show variations in their transit times due to gravitational interactions.

Introduction

TRAPPIST-1 is an ultra-cool dwarf of mass 0·089 ± 0·006 $M_{\odot}$, radius 0·121 ± 0·003 $R_{\odot}$, and effective temperature 2516 ± 41 K[1]. Two transiting planets were found in this system by Gillon *et al.*[2], based on photometry from the 0·6-m *TRAPPIST* telescope[3]. A further five transiting planets were found by Gillon *et al.*[4] and Luger *et al.*[5] from observations with the *Spitzer* and *K2* satellites augmented by ground-based data.

Based on analysis of transit light-curves, the radii of the planets have been found to range from 0·76 $R_{\oplus}$ to 1·13 $R_{\oplus}$ and their orbital periods from 1·5 d to

18·8 d[6–8]. All seven planets are in orbital resonances with each other[7–9], causing dynamical interactions between the planets which depend on their masses and orbital characteristics. This has allowed measurement of their masses, which range from 0·33 $M_\oplus$ to 1·37 $M_\oplus$[7,8], from analysis of transit-timing variations (*e.g.*, refs. 10,11).

TRAPPIST-1 remains the lowest-mass stellar object known to host a transiting planet*, so the system is an important one for further study. Aside from mass and radius measurements, it is an important tracer of tidal effects[13–15], the formation and interior structure of rocky planets[16–19], and the characterization of atmospheres *via* transmission spectroscopy[20–23]. TRAPPIST-1 is a high-priority target for observations with the *James Webb Space Telescope*[24–28].

The faintness of the TRAPPIST-1 system ($V = 18{\cdot}8$, $I = 14{\cdot}0$) and the low planet masses means that it is difficult to measure the masses of the planets using high-precision spectroscopic radial velocities. Therefore measurements of the times of mid-transit for these planets are crucial for improving measurements of their masses, and thus densities and surface gravities. In this work we present extensive photometry of transits of TRAPPIST-1 obtained in the 2017 and 2018 observing seasons using three telescopes.

Observations with the Danish telescope

A total of 18 light-curves of TRAPPIST-1 were obtained in 2017 June–August using the 1·54-m Danish Telescope at ESO La Silla, Chile, equipped with the *DFOSC* imager. The data were obtained whilst the telescope was being operated by the MiNDSTEp Consortium[29] in the context of the transit project running as a side project in this consortium[30,31]. A Cousins *I* filter was used for all observations of TRAPPIST-1, which is an extremely red star. A total of 13 transits were detected, with others lost to poor weather or the shifting of the transit outside the observing interval due to dynamical effects.

Data reduction was performed using the DEFOT pipeline[30,32], which uses an IDL implementation of the DAOPHOT aperture-photometry routine[33]. The observations were taken in focus and were debiassed and flat-fielded. Differential photometry *versus* several comparison stars was obtained by optimizing the weights of the comparison stars simultaneously with a low-order polynomial to minimize the scatter around zero differential magnitude outside transit.

An observing log is given in Table I. The light-curves are shown in Fig. 1. The time-stamps have been placed on the BJD(TDB) time-scale using routines from Eastman *et al.*[34]. The times written into the FITS files were manually checked during the observation of the majority of the transits to confirm their reliability.

Observations with the MPI 2·2-m telescope

TRAPPIST-1 was observed on four nights using the MPI 2·2-m telescope at ESO La Silla. The *GROND* imager[35] was used to obtain observations simultaneously in seven passbands, approximating the Gunn *g*, *r*, *i*, and *z* and near-infrared *J*, *H*, and *K* filters. The *g* and *r* bands suffer from a high scatter due to the faintness of the target. Conversely, the *J*, *H*, and *K* bands do not yield good light-curves because the target is much brighter than the available comparison stars. We therefore present light-curves from only the *i* and *z* bands here.

*Based on data obtained from the *Transiting Extrasolar Planet Catalogue* (*TEPCat*[12] at https://www.astro.keele.ac.uk/jkt/tepcat/) on 2022/05/11.

TABLE I

Log of the observations from the Danish telescope. N_{obs} is the number of observations, T_{exp} is the exposure time, T_{dead} is the dead time between exposures, 'Moon illum.' is the fractional illumination of the Moon at the midpoint of the transit, and N_{poly} is the order of the polynomial fitted to normalize the light curve to zero differential magnitude. The aperture radii refer to the target aperture, inner sky and outer sky, respectively.

Telescope	*Planet(s)*	*Date of first obs*	*Start (UT)*	*End (UT)*	*Filter*	N_{obs}	T_{exp} *(s)*	T_{dead} *(s)*	*Airmass*	*Moon illum.*	*Aperture radii (px)*			N_{poly}	*Scatter (mmag)*
Danish	c	2017/06/10	08:13	10:30	*I*	74	100	12	1.32 → 1.10	0·876	9	14	30	1	2·9
Danish	b	2017/06/13	06:31	08:24	*I*	63	100	8	1.96 → 1.25	0·992	8	12	30	1	2·9
Danish	b	2017/06/19	07:02	09:15	*I*	72	100	11	1.50 → 1.12	0·301	8	13	30	1	1·9
Danish	e*	2017/06/30	08:00	10:09	*I*	67	100	16	1.15 → 1.10 → 1.13	0·432	9	13	30		2·8
Danish	f	2017/07/22	05:21	08:58	*I*	116	100	11	1.50 → 1.12	0·019	7	12	25	1	2·1
Danish	c	2017/07/26	08:25	10:28	*I*	67	100	12	1.13 → 1.51	0·117	8	12	25	1	1·8
Danish	g	2017/07/27	06:27	10:01	*I*	98	100	13	1.13 → 1.10 → 1.44	0·187	6	12	25	1	2·6
Danish	h*	2017/07/28	04:50	08:52	*I*	92	200–100	12	1.38 → 1.10 → 1.22	0·272	7	13	25		3·7
Danish	c, d*	2017/07/31	04:25	07:32	*I*	88	200–100	6	1.44 → 1.10	0·561	4	8	20		6·0
Danish	c, b	2017/07/17	03:51	08:27	*I*	103	100	25	1.49 → 1.10 → 1.17	0·258	8	12	25	1	2·2
Danish	e*	2017/08/18	02:36	04:50	*I*	69	100	25	1.72 → 1.14	0·170	6	10	20		3·1
Danish	b	2017/08/20	05:32	07:25	*I*	68	100	8	1.10 → 1.21	0·030	9	13	25	1	2·6
Danish	b*	2017/08/23	06:34	09:12	*I*	86	100	11	1.13 → 1.77	0·030	6	11	25		8·2
Danish	e*	2017/08/24	04:55	07:14	*I*	84	100	16	1.11 → 1.10 → 1.25	0·075	5	8	20		40·1
Danish	b	2017/08/26	05:59	09:05	*I*	98	100	13	1.11 → 1.80	0·224	9	13	25	1	2·4
Danish	c	2017/09/15	05:19	07:27	*I*	66	100	13	1.15 → 1.64	0·279	9	13	25	2	2·4
Danish	b	2017/09/20	23:29	01:17	*I*	51	100	11	2.42 → 1.37	0·008	8	13	25	1	2·5
Danish	b	2017/09/23	23:58	01:44	*I*	57	100	13	1.83 → 1.23	0·149	8	12	25	1	1·9

*transit not detected due to observing conditions or dynamical effects.

TABLE II

Log of the observations from the MPI 2·2-m telescope and the VLT. Other comments are as in Table I.

Telescope	*Planet(s)*	*Date of first obs*	*Start (UT)*	*End (UT)*	*Filter*	N_{obs}	T_{exp} (*s*)	T_{dead} (*s*)	*Airmass*	*Moon illum.*	*Aperture radii (px)*			N_{poly}	*Scatter (mmag)*
GROND	c	2017/06/10	07:49	10:37	*i*	80	90	25	1·40 → 1·10	0·876	15	22	40	2	2·4
GROND	c	2017/06/10	07:49	10:37	*z*	77	90	25	1·40 → 1·10	0·876	20	28	50	2	1·6
GROND	b	2017/08/02	03:01	04:49	*i*	54	90	25	2·17 → 1·31	0·747	27	35	60	2	8·6
GROND	b	2017/08/02	03:01	04:49	*z*	55	90	25	2·17 → 1·31	0·747	34	40	70	2	2·7
GROND	b	2017/10/06	01:17	04:30	*i*	105	60–80	27	1·19 → 1·10 → 1·21	0·997	14	23	50	2	3·1
GROND	b	2017/10/06	01:17	04:30	*z*	108	60–80	27	1·19 → 1·10 → 1·21	0·997	18	28	60	1	2·6
GROND	f	2017/10/13	01:41	05:45	*i*	119	80	31	1·11 → 1·10 → 1·70	0·429	16	25	50	2	3·1
GROND	f	2017/10/13	01:41	05:45	*z*	118	80	31	1·11 → 1·10 → 1·70	0·429	20	30	55	2	2·7
VLT	c	2017/11/05	02:23	04:29	$z_{special}$	192	12–8	26	1·18 → 1·77	0·980	10	15	35	1	3·1
VLT	c	2018/09/06	05:45	07:52	$z_{special}$	230	10–6	26	1·13 → 1·55	0·167	11	20	40	1	2·4
VLT	c	2018/09/11	02:13	04:17	815 / 13	145	25	26	1·31 → 1·09	0·028	12	20	40	1	2·3
VLT	b	2018/11/14	23:56	01:54	$z_{special}$	195	25–6	25	1·10 → 1·21	0·447	10	30	40	1	2·8

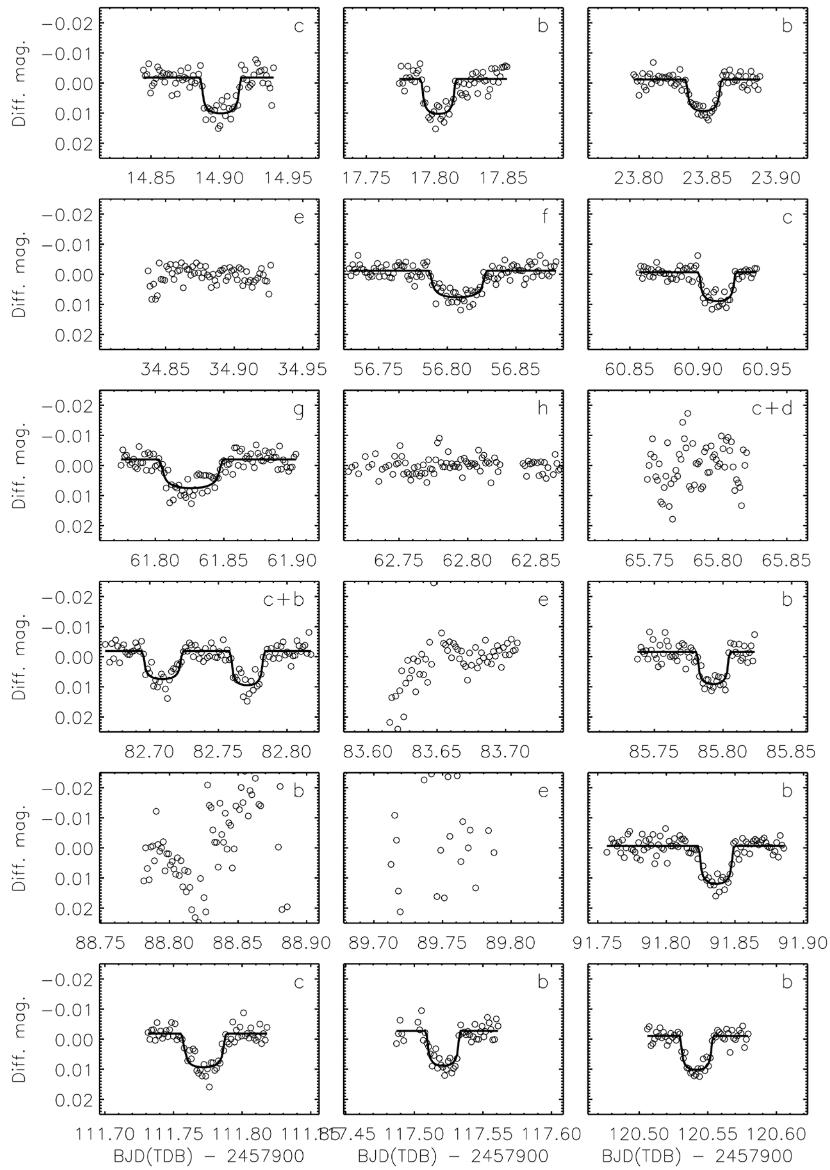

Fig. 1

Plot of the light-curves of TRAPPIST-1 from the Danish Telescope. Each panel shows one light-curve on the same scale (0·16 d and 0·05 mag). The data are shown using open circles and the JKTEBOP best fits using solid lines. For clarity, the error bars are not plotted. The designation(s) of the planet(s) transiting are shown at the top-right of each panel.

We encountered a problem with the presence of transient bad pixels in the *r* and *z* bands caused by a bug in the CCD-controller software. These bad pixels comprise approximately 0·5% of the pixels in an image and cause the pixel count rate to be either the bias level or unusually high. Left uncorrected, the bad pixels significantly increase the scatter in the light-curves. Fortunately, the bad pixels occurred randomly in each image. We were therefore able to find them by comparing each pixel value in two successive images to detect those that differed by more than a manually-chosen threshold. The count rates in the affected pixels were then replaced by the means of the count rates in the surrounding eight pixels.

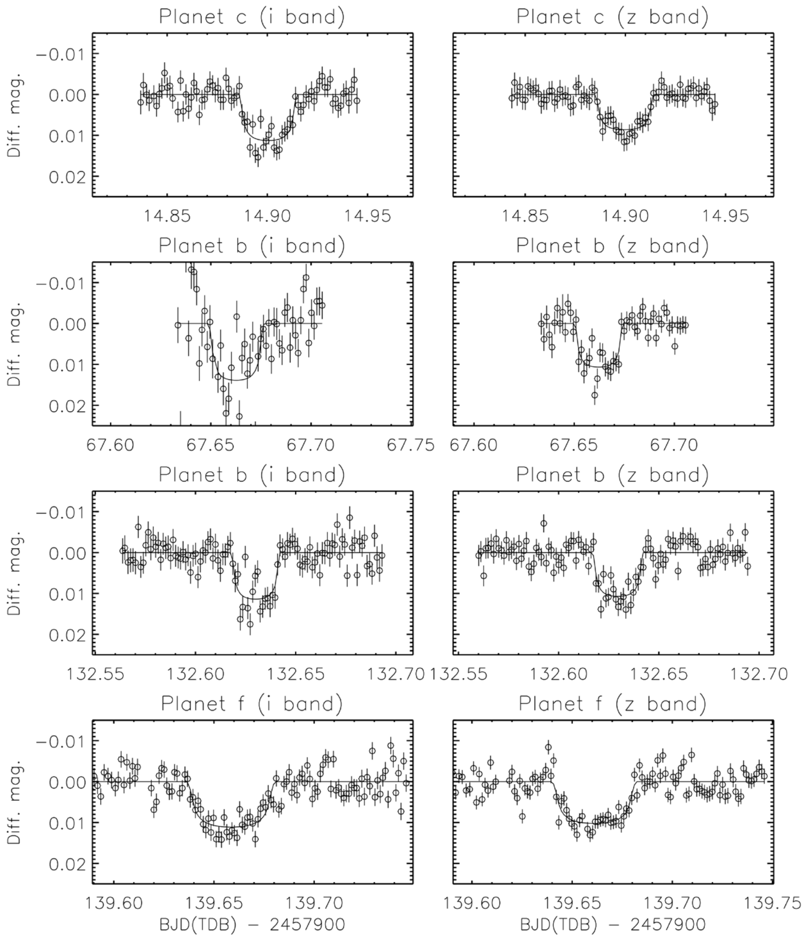

FIG. 2

Plot of the light-curves of TRAPPIST-1 from the MPI 2·2-m telescope. The data are shown using open circles and the JKTEBOP best fits using solid lines. Panels on the same row show data from the same transit.

Aside from the bad-pixel correction, the data were reduced using the DEFOT pipeline as described above. The observing log is given in Table II and the data are plotted in Fig. 2.

Observations with the VLT

One transits of TRAPPIST-1 b and three more of TRAPPIST-1 c were observed using the *Very Large Telescope* (*VLT*) Unit Telescope 1 (UT1) equipped with the *FORS2* imager[36]. The data were obtained through either a $z_{\rm special}$ filter with a central wavelength of 916 nm and a full-width at half maximum of 18 nm, or a night-sky suppression filter with a central wavelength of 813 nm and a full-width at half maximum of 13 nm. These observations were obtained in order to search for a variation in radius with wavelength indicative of the presence of a planetary atmosphere, as tentatively found for GJ 1132[37], but this test could not be performed due to the scatter of the observations plus complications with the scheduling of these time-critical observations in service mode.

The data were reduced using the DEFOT pipeline as described above. The observing log is given in Table II and the data are plotted in Fig. 3. These data have a relatively large scatter because all comparison stars had significantly lower count rates than the target star.

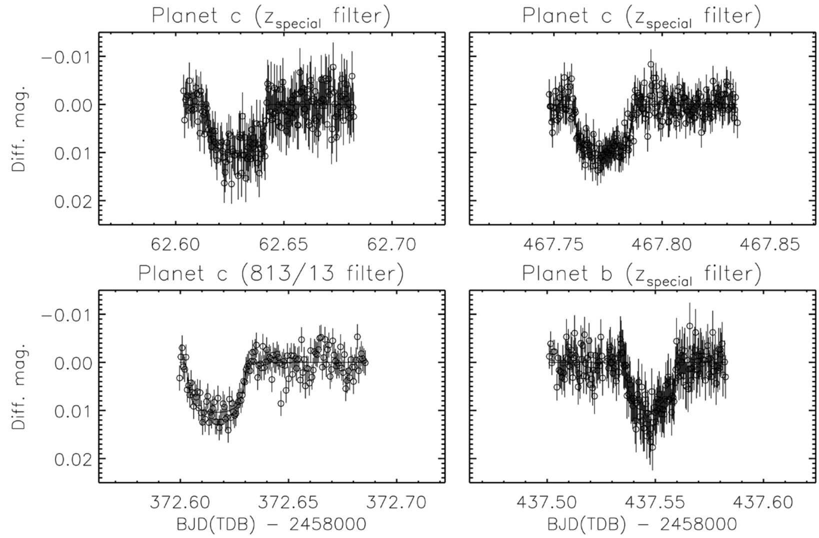

FIG. 3

Plot of the light-curves of TRAPPIST-1 from the *VLT*. The data are shown using open circles and the JKTEBOP best fits using solid lines.

Transit timing measurements

Each light-curve was modelled individually using version 38 of the JKTEBOP★ code[38,39]. We fitted for the sum of the fractional radii ($r_{\rm A} + r_{\rm b}$ where $r_{\rm A} = \frac{R_{\rm A}}{a}$, $r_{\rm b} = \frac{R_{\rm b}}{a}$, $R_{\rm A}$ is the radius of the star, $R_{\rm b}$ is the radius of the planet in question,

★ http://www.astro.keele.ac.uk/jkt/codes/jktebop.html and a is the semi-major axis of the relative orbit), their ratio ($k = \frac{r_b}{r_A}$), and the time of transit mid-point. We fixed the orbital periods and inclinations to the values measured by Gillon *et al.*[4]. Limb darkening was accounted for using the quadratic law with coefficients fixed at $u = 0{\cdot}25$ and $v = 0{\cdot}60$.

The light-curve from the Danish telescope on the night of 2017/08/17 contains two transits, the first by planet c and the second by planet b. These were modelled separately after removing the data for the other transit from the light-curve before fitting.

Four of our transit observations were obtained simultaneously in the i and z passbands using *GROND*. This provides an opportunity to check if the two light-curves from each night yield timings in mutual agreement. We calculated the level of agreement to be 1·5σ for the night of 2017/06/10, 0·3σ for 2017/08/02, 0·8σ for 2017/10/06, and 2·9σ for 2017/10/13. This agreement is acceptable but suggests that the error-bars of our timing measurements may be slightly too small.

The resulting transit times are given in Table III. The reduced light-curves will be made available at the Centre de Données astronomiques de Strasbourg*. Because all planets in the TRAPPIST-1 system show complex transit-timing variations caused by gravitational interactions, and because good ephemerides are available from elsewhere (refs. 4,6,8), we have not performed any analysis on the transit timings in the current work. They are instead presented here so they may be used in future studies of this system.

TABLE III

Times of mid-transit measured for the planets in the TRAPPIST-1 system.

Telescope	*Filter*	*Planet*	*Time of mid-transit (BJD/TDB)*
GROND	i	c	2457914·90035 ± 0·00039
GROND	z	c	2457914·89956 ± 0·00034
Danish	I	c	2457914·90084 ± 0·00047
Danish	I	b	2457917·80266 ± 0·00049
Danish	I	b	2457923·84702 ± 0·00042
Danish	I	f	2457956·80753 ± 0·00054
Danish	I	c	2457960·91366 ± 0·00036
Danish	I	g	2457961·82616 ± 0·00067
GROND	i	b	2457967·66265 ± 0·00098
GROND	z	b	2457967·66231 ± 0·00042
Danish	I	c	2457982·70928 ± 0·00051
Danish	I	b	2457982·77099 ± 0·00039
Danish	I	b	2457985·79287 ± 0·00042
Danish	I	b	2457991·83630 ± 0·00032
Danish	I	c	2458011·77209 ± 0·00046
Danish	I	b	2458017·52100 ± 0·00039
Danish	I	b	2458020·54178 ± 0·00030
GROND	i	b	2458032·63003 ± 0·00044
GROND	z	b	2458032·62955 ± 0·00038
GROND	i	f	2458039·65854 ± 0·00064
GROND	z	f	2458039·66100 ± 0·00057
VLT	$z_{\rm special}$	c	2458062·62830 ± 0·00031
VLT	$z_{\rm special}$	c	2458367·77302 ± 0·00023
VLT	815 / 13	c	2458372·61662 ± 0·00027
VLT	$z_{\rm special}$	b	2458437·54799 ± 0·00028

*http://cdsweb.u-strasbg.fr/

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This paper was based on data collected by MiNDSTEp with the Danish 1·54-m telescope at the ESO La Silla Observatory. This paper was also based on observations collected using the *Gamma Ray Burst Optical and Near-Infrared Detector* (*GROND*) instrument at the MPI 2·2-m telescope located at ESO La Silla, Chile, under programmes 099.A-9030(A) and 0100.A-9004(A). *GROND* was built by the high-energy group of MPE in collaboration with the LSW Tautenburg and ESO, and is operated as a PI-instrument at the MPI 2·2-m telescope. This paper was also based on observations collected at the European Southern Observatory under ESO programme 0100.C-0716(C). The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arχiv scientific paper preprint service operated by Cornell University. We thank Eric Agol for checking our planet identifications and alerting us to one incorrect one.

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CORRESPONDENCE

To the Editors of 'The Observatory'

Commemorating the Invention of the Printing Press

In his recent letter Mike Brain[1] notes the priority of Johannes Gutenberg as the inventor of printing with movable type. What is perhaps not widely known is that we could have ended up with a constellation commemorating Gutenberg's invention. In his magnificent and comprehensive star atlas called *Uranographia* published in 1801, Johann Elert Bode included a new constellation which he named *Officina Typographica*, the printing shop. It lay in what is now the northern part of Puppis, between Canis Major and the hind legs of Monoceros (see Fig. 1).

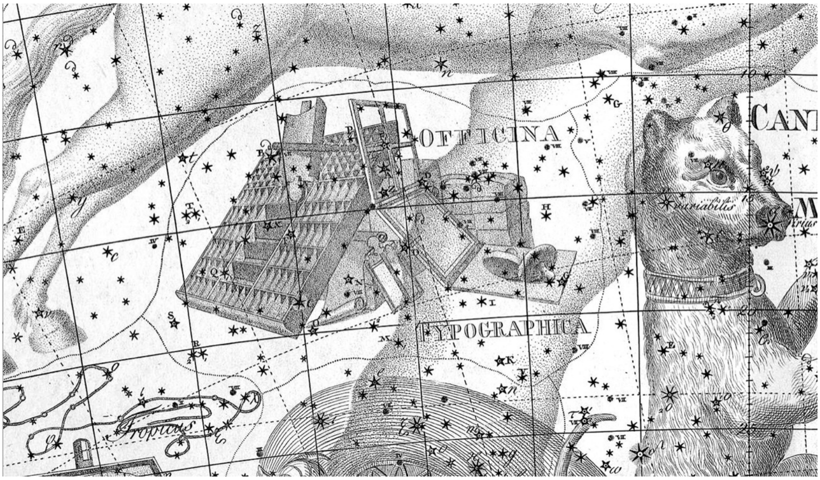

FIG. 1

Officina Typographica, commemorating Johannes Gutenberg's invention of movable type, seen on Chart 18 of Johann Bode's *Uranographia* (1801). As depicted by Bode, the constellation consisted of a case of movable type with composing stick; the frisket, a frame with four windows that folded over the printing paper; the tympan, on which the paper was placed; two inking pads to ink the type; and stacks of paper in the background. The printing press itself was not part of the constellation. The underside of Monoceros lies above it, and the head of Canis Major to the right.

The idea came about when he met the French astronomer Joseph Jérôme de Lalande at an international conference at Gotha, Germany, in 1798 August. At that time Bode had reached Chart 15 of his great atlas, out of an eventual total of 20. As Bode recounted it[2], "Lalande took this occasion to observe that room might still be found on some of the celestial charts for new constellations, and wished to see inserted among the stars an aerostat [*i.e.*, a hot-air balloon], as the invention of the French. I embraced this opportunity … to propose that a German discovery, made 350 years ago, *viz.* the art of printing, might be perpetuated in the heavens."

The Montgolfier balloon made its debut among the stars on Chart 16 of the *Uranographia* under the Latin name *Globus Aerostaticus*, squeezed in south of Capricornus next to the tail of Piscis Austrinus, while *Officina Typographica* appeared on Chart 18, thereby satisfying French and German sensibilities.

Both these new Franco–German figures were subsequently shown on many popular maps, but their stars were faint, they intruded on existing figures, and the motivation for their formation was overtly nationalistic, so it is not surprising that they were not adopted in the major catalogues such as the Harvard photometry which shaped the final IAU selection. Given the immense impact of Gutenberg's technological advance it surely deserved a permanent commemoration among the stars, but by Bode's time there was nowhere suitable to put it.

Yours faithfully,
IAN RIDPATH

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TW8 8PY

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REVIEWS

Sidney Coleman's Lectures on Relativity, edited by David Griffiths, David Derbes & Richard Sohn (Cambridge University Press), 2022. Pp. 259, 25 × 17·5 cm. Price £24·99/$34·99 (hardbound; ISBN 978 1 316 51172 5).

Coleman died in 2007, and the lectures presented here are from 1966–1969, so why a new book? That is due mainly to Coleman's reputation as a good lecturer, though he didn't like teaching[1]. The book is based on lecture notes by David Griffiths (also one of the editors), David Levin, and David Politzer (a student Coleman actually liked working with[1]). Coleman taught Physics 210 at Harvard three times, spring 1966, autumn 1967, and autumn 1969. The book is based on the notes from the first course by the first two students and from the third course by the third student. (Some of his lectures can be found on YouTube and, despite the low quality of the recordings, are worth watching.)

With respect to General Relativity (GR), I've mentioned in these pages the two main approaches, 'physics first' and 'maths first'. Although I generally prefer the former, which is better depends on the reader's preference but also on the goal. This book is very much in the 'maths first' category. While logically one could follow it step by step, which steps are taken and why can be understood only if one already has a good knowledge of Special Relativity (SR). Although the parts on SR and GR are about the same length and at about the same level, it is a fairly complete description of the former but just an introduction to the latter. To some extent, the maths-heavy description of SR makes the transition to GR somewhat more understandable. As such, with regard to SR it is not a beginner's book, but rather a resource for someone already knowledgeable of the topic (or for very bright students wanting to learn it from the ground up).

The introduction to GR is similar to many other such introductions, with the interesting exception that the connection between GR and the Friedmann models is clear and explicit. Another very good explanation of the connection between cosmology and GR is in a cosmology textbook by Heacox[2] (reviewed in these pages[3]), who seems never to have worked in cosmology. Also, Michael Berry's *Gravitation and Cosmology*[4] is good in that respect (though the level is lower). Do I see a trend there? Some cosmology textbooks assume a background in GR, so have no need to be explicit; others don't, so gloss over it. Interesting is that the ones which explain it in more detail are all by people known mainly for other things.

Despite the emphasis on maths, concepts are also stated clearly, though there are only a handful of diagrams. In particular, the difference in SR (due to the time taken by the signal to reach the observer) between observations (corrected for that time) and that which one sees (uncorrected) is clearly pointed out. The main text is interrupted by proofs, examples, problems (without solutions), the occasional 'box' of text, insightful footnotes, and, more informally, by questions with answers. Both the source material and the edited version are well done.

There are few typos or other mistakes in the text. An afterword by the editors points out one thing about which Coleman was mistaken, namely his belief that it wouldn't be worth it for students to do their thesis work in GR, referring to the essentially unproductive last thirty years of Einstein's life.* They then give lists of Nobel Prizes for work in GR, other important work in the field, and several notable textbooks. Appendix A is a useful compendium of formulae, and Appendix B contains the final exams from 1966 and 1969 (problems but no solutions). The book ends with a detailed 16-page small-print index.

This book is not for everyone, not even for everyone interested in relativity. But for the more mathematically inclined, both the detailed discussion of SR and the introduction to GR will prove useful. — Phillip Helbig.

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*That is an exaggeration, of course. While it is perhaps fair to say that Einstein's work on unified field theory led to nothing, and while he was much less productive after 1925 than before, he still published a few important works in the last thirty years of his life.

A Student's Guide to Special Relativity, by Norman Gray (Cambridge University Press), 2022. Pp. 229, 23 × 15 cm. Price £17·99/$23·99 (paperback; ISBN 978 1 108 99563 4).

Like another book[1] now reviewed[2] in these pages, this is a well-written, thorough account of Special Relativity (SR) with an introduction to General Relativity (GR). But there the similarity ends. Apart from being several decades more recent, this book concentrates very much on understanding the concepts and deriving results, rather than taking a "shut up and calculate" approach (a term coined[3] by N. David Mermin to describe the Copenhagen interpretation of quantum mechanics). While the first book is very mathematical, this one concentrates on detailed explanations. At the same time, "[i]t is also just about all of the Special Relativity that you will need in your future study of physics. It is also, possibly surprisingly, just about all the SR that there is ... . More advanced courses ... build on it but do not extend it." The Coleman lectures have somewhat more material on GR than on SR, even though the former is merely an introduction; that is because GR is much more complicated than SR. By contrast, in this book the 32-page overview of GR (one of four appendices) is very qualitative, but still useful, touching on various formulations of the equivalence principle, curvature, the weak-field approximation, the Schwarzschild solution, black holes, gravitational waves, and cosmology. (Gray has also written a similar book[4] on GR; I haven't read it but probably will.*)

Gray has taught courses on relativity for a couple of decades, and it shows. I think that this book is a very good description of SR. For my taste, most are too mathematical (useful for many things, but difficult to understand unless one already knows how it works) or too qualitative. It succeeds in its goal of being both comprehensive and accessible. It starts with two basic axioms (equivalence of all inertial frames and constancy of the speed of light in all such frames) and builds from there, introducing both mathematics and, even more so, concepts as needed. The standard topics are covered: space–time and geometry, the Lorentz transformation, vectors, kinematics, and dynamics. It is a description of the theory, though; applications (*e.g.*, from particle physics and astronomy) are mentioned as examples, but the treatment of them is not meant to be exhaustive. Gray mentions that his approach to SR is not the only one, nor even the only good one. Throughout the text, he occasionally refers to other treatments and how they differ from his own.

The only thing I missed was a bit more discussion on the nature of different effects: purely relative effects (A sees B's clock run slow and *vice versa*), real effects (B's clock is behind A's when the two are compared at rest after B travels away and returns, that depending only on the length and speed of the journey and not on the acceleration and is explicable within the context of Special Relativity), and effects, such as the appearance of moving objects, which depend on the finite velocity of light[5–7]. To be sure, most books on SR spend too little time discussing the effects in the third group; I miss them here only because the treatment is otherwise very comprehensive.

My recent reviews in this *Magazine* mention an improvement in quality with respect to typos, matters of style, *etc.* Fortunately, that trend continues here. The text is well organized: each chapter is introduced by a list of aims; more difficult and/or slightly off-topic passages (either entire sections or portions of a section

*There are several books in CUP's *A Student's Guide to* ... series. I haven't (yet) read any of the others. They are mostly about mathematical aspects of physics or even 'pure' maths. I'll probably read some of the others if they are as good as the one reviewed here. They seem to be ideal for someone like myself who wants to master the maths but prefers a 'physics-first' approach.

in small type) are marked with a 'dangerous bend' symbol; many discussions end with a reference to exercises (problems with no given solutions) at the end of each chapter. Explanatory notes are footnotes rather than endnotes, while literature citations (author/year) within the text refer to the list of references. There are a few black-and-white figures throughout the text. The main text is followed by four appendices (the GR introduction mentioned above, comparison of theory and experiment (with several pages on the famous 1919 eclipse expedition), maths revision, and a recipe for calculations) which provide necessary material without interrupting the main flow of the book. After those are five-and-one-half pages of references and a two-page small-print index.

I recommend the book to all interested in Special Relativity. Those new to it can learn it thoroughly from the ground up without being overloaded with maths. Those familiar with it might gain new insights and/or ideas for teaching the topic. — PHILLIP HELBIG.

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Gravitational Waves in Physics and Astrophysics. An Artisan's Guide, by M. Coleman Miller & Nicolás Yunes (IoP Publishing), 2022. Pp. 241, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 3049 7).

A relativist of my acquaintance once complained that a text by a different relativist began by telling the reader what a diffeomorphism is not. Let me therefore begin by telling you that this is not a General Relativity textbook. It is also not an astrophysics text book, or the reader would not be invited (page B-5) to consider "a massive galaxy with $\sigma_v = 200$ km s^{-1} and an average $\rho = 10^4\ M_\odot$ pc^{-3}". Rather it is intended as a tool to get a reader (student at the level of BSc $\pm$ 1 year, or other similarly prepared individual) ready to start research on gravitational waves as efficiently as possible, assuming prior knowledge of classical mechanics, quantum mechanics, and classical electrodynamics.

The authors also explain that they wish to encourage readers to develop the habit of doing a "Fermi-style" estimate of whatever they are looking for prior to carrying out a more detailed, rigorous calculation, if the approximate results seem to justify one. Estimating the yield of the Trinity atomic-bomb test by letting pieces of paper fly in the blast wave is given as an example, and the John Wheeler equivalent was the dictum not to do a calculation until you knew the answer. The exercises provided at the ends of each of the eight chapters and two of the three appendices are intended to promote that sort of analysis and so help to develop "physical intuition" in the serious reader.

Use of imaginary characters (perhaps based on contemporaries) in expository writing has a fine precedent in Galileo's *Dialogue Concerning the Two Chief World Systems*. Galileo's characters were Salviati (more or less himself), Sagredo (an interested and intelligent listener), and Simplicio (an obtuse Aristotelian). Miller and Yunes also make use of three such, each of whom is given a brief biography (on page *xviii*). They are Captain S. D. Obvious, Major I. M. Payne, and Dr. I. M. Wrong. Their names appear at the heads of many boxes through the text, coded as Payne in red, Wrong in green, and Obvious in blue. It is presumably not a coincidence that these are the primary colours of an additive colour system, so that if all three shine together, the result is clear, bright, informative white light. Capt. Obvious provides alternative explanations of things; Major Payne brings mathematical and theoretical rigour to the table; and Dr. Wrong is always getting confused, and from time to time thinks he has found some theory better than General Relativity.

The chapters address, roughly, overview, sources of gravitational radiation, modelling of binaries, detection and analysis of gravitational waves, astrophysics, cosmology, nuclear physics (meaning equations of state for neutron stars), and fundamental physics.

Each chapter (and the two appendices on Bayesian statistics and relativistic dynamics) ends with a list of "Useful Books". These range from classics like Weinberg (*Relativity and Cosmology*, 1972), Misner, Thorne & Wheeler (1973), and the DeWitt and Morette–DeWitt Les Houches proceedings (1973) to monographs as recent as the publication process permits. All these references are indeed books, not journal articles, and are intended to enable readers to penetrate further into the chapter subjects, find derivations of things assumed here, explore alternatives, and generally deepen their understanding.

Being relativists at heart, the authors use $c = G = 1$ units most of the time, thus all sorts of things, including masses and time-scales, are measured in metres, or m. But the total mass of a binary system is also m (probably italic, but almost indistinguishable). They describe themselves as agnostic on several issues, but meaning (I think) "preferring not to take a stand" rather than "persuaded that non-material things cannot be known".

The description of the discrepancy between "expected" and "measured" values of vacuum energy density is particularly succinct and clear. The "measured" is the one that is about 0·7 when the matter density (total) is about 0·3, that is, around 10^{-29} g cm^{-3}. And the "expected" is a Planck mass per Planck length cubed, or 10^{-5} g per 10^{-99} cm^3 or 10^{94} g cm^{-3}, and $94 + 29 = 122$ if we had kept better track of the π's and twiddles.

There is a merged index of people (Afshordi), concepts (Approximations), and entities (Apocenter), in which reviewers look first for their own names. Nope (but *Stellar Interiors* by Hansen, Kawaler & Trimble is among the 'Useful Books' of Chapter 5, 'Gravitational Wave Astrophysics'). A fellow geriatric faculty member who drifted past yesterday as I was starting to type this review, asked "What do they say about Joe?" No, Weber is not indexed, and the useful GR books do not go back quite as far as 1961 *General Relativity and Gravitational Waves* by J. Weber. But Captain Obvious says on p. 31, "Weber's announcements starting in the 1960s, of direct detection, which were later demonstrated to be artefacts of the noise and insufficiently detailed analysis of the data, did not help the LIGO case either." Have a go at parsing this to discover it actually says that the announcements were an artefact rather than that the appearances of two detectors above threshold at the same time were an artefact.

Some of the exercises are fun: how close can you get to a black hole before your bones break? Others begin "Let's play with ... " but require verifying derivations and other kinds of hard work.

A brave effort is made at "diversity and inclusion", with observers, experimenters, and theorists variously denoted as "she", "they", and "you", but the Bayesian offspring of a horse and donkey pairing is unambiguously said to be a mule (p. A-5). The protest march in the distance is the Union of English-Speaking Hinnies.

But let us give the authors the last word (this comes from page A-1 but could, does, and is meant to apply to many parts of the present volume): "This book is not going to be enough for you to master the subject, but at least it should give you a sense of the basics, so that you can study this in more detail by yourself in the future." An excellent overall description of *Gravitational Waves in Physics and Astrophysics: An Artisan's Guide*. And on balance an excellent stab at a difficult task! — VIRGINIA TRIMBLE.

An Infinity of Worlds. Cosmic Inflation and the Beginning of the Universe, by Will Kinney (MIT Press), 2022. Pp. 237, 21 × 14 cm. Price $24·95 (about £18) (hardbound; ISBN 978 0 262 04648 0).

This concise book is a very readable account of cosmic inflation, written by an expert who has written extensively on the wide variety of research topics that are touched on in the book. It is a nicely balanced story of the issues that inflation purports to solve, how it solves them, and the puzzles that remain. Anyone who is interested in how the Universe began will appreciate the insights that this book delivers. It is a non-technical account which first sets the scene with the standard cosmological model, and lay readers will get a broad understanding of why something like inflation is needed to account for observations such as isotropy and flatness, and get a good flavour of how inflation solves the issues. Experienced cosmologists who want to get a better understanding of inflation will find this an entertaining and informative read, and will particularly enjoy the last chapter on the state of play and the challenges that inflation theories still face. Finally, MIT Press have done a nice job of producing a very pleasing small-format book that helps to make the material accessible. — ALAN HEAVENS.

Active Galactic Nuclei. Fueling and Feedback, by Françoise Combes (IoP Publishing), 2021. Pp. 96, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 3033 6).

The field of active galactic nuclei (AGN) is rapidly evolving. Starting from the properties of the central engine in the 1960s, it now includes topics like the mutual interaction between black holes (BHs) and their host galaxies, the parallel evolution of BHs and galaxies, BH formation, and more. It is therefore justified to devote an entire five-chapter book to describe only one or two aspects of this large area of research. This is the intention of the new book by Françoise Combes, a well-known expert in the field, who chose to devote her book to fuelling and feedback in AGN. Chapters 2 and 3 of the new book, which are written like a review article, describe these issues and provide detailed and useful information that will certainly help researchers find their way in the field. The parts I find more convincing deal with local individual galaxies. The high-redshift and evolution parts are more questionable, reflecting perhaps observational limitations and biasses. Chapter 4 is devoted to the circumnuclear region and the two other chapters provide a general introduction and thoughts about the future of the field.

A weak point of the book is Chapter 1 which provides general information about the central BH, the accretion disc, the emitted spectrum, the radio properties, and more. This part contains incomplete information and explanations that do not do justice to new superb measurements and detailed current AGN modelling. Graduate students attempting to get familiar with AGN physics may get the wrong impression about some of these issues. It would have been useful to point such readers to more-detailed books on the subject, yet no information of this type is provided in the list of references. I also find the organization of Chapter 5 a bit unusual, with a first part that could have easily been absorbed into Chapter 4. Nevertheless, the feeding and feedback parts clearly justify the writing of the book. They are full of useful up-to-date information including many colour illustrations that help readers find their way in this complex and rather messy area of research.

What I am missing most in the book is more information, or at least some ideas, about feeding and feedback in the early Universe when galaxies had very different morphologies and active BHs were 3–4 orders of magnitude more luminous. — Hagai Netzer.

Large Scale Peculiar Motions: Matter in Motion, by Gary Wegner (World Scientific), 2022. Pp. 328, 23·5 × 16 cm. Price £100 (hardbound; ISBN 978 981 121 180 5).

As it says in the title, this university-level textbook is about motions. However, the title does not say that it means, largely, non-Hubble-flow motions of galaxies. This may be obvious to those working in the area — the author is an acknowledged expert, one of the so called 'Seven Samurai' (the silhouette of a Samurai warrior sneaks onto the front cover illustration of large-scale flows) — but perhaps not to the typical student perusing library bookshelves (if any still do!). Its origin in lecture courses is evident; many lecturers will probably have been tempted to spend half a course introducing enough astronomy so that the students can follow the second half, on the lecturer's own specific research topic. Here the first half of the book covers the history of observational and computational techniques, the distance scale, *etc.* The specific direction of the remainder is rather too niche for UK-undergraduate use, except by someone undertaking a final-year project on the subject. The large number of references might be valuable for the latter, or for a post-graduate student starting off in this area, though the student might not always be able to locate them, as mis-spelling of names is not infrequent (at one point we get Birkenshaw and Birkinshaw on successive lines). However, the main problems lie elsewhere.

To begin with, the subject matter, or at least its organization, is chaotic. Concepts are mentioned without discussion and then defined many chapters later. For instance, "TF" (with no further comment) is given as an example of a scaling relation on page 35 and the Tully–Fisher Relation finally turns up on page 141. There is a discussion in Chapter 9 on how important it is to make bias corrections to distances obtained from the D_n–σ relation, but we are not told what D_n is until Chapter 11. Apparently, our putative student should learn the formula for the Vainshtein radius of Galileon theories of modified gravity (something I seem to have survived without knowing) *before* the formula for distance modulus (which itself precedes the definition of a parsec by three chapters). There is a steady stream of errors throughout (*e.g.*, dark matter isn't 95% of the mass anymore; the 2C and 3C catalogues didn't use the Cambridge 1-mile telescope as it hadn't been built then; numbers of stars don't decrease below 1 solar mass, φ in Limber's formula isn't the luminosity function; the line-of-sight velocity isn't *equal* to the convolution of the galaxy and template spectra; the change of the cosmic star-formation density with redshift isn't the effect "known as 'downsizing'", *etc.*). Symbols pop up in equations without being defined (Ω and Λ, for starters) or change from equation to equation — the cosmic scale factor is usually S, but sometimes, when an equation is borrowed from elsewhere, it is a. Or try the sentence "… the spectrum of density fluctuations relative to $\bar{\rho}$ the mean cosmological density, $\delta = (\rho - \rho_0)/\rho_0$, where ρ_0 is the mean cosmological density, grows with time …". Or, worse, "Ω_0 is the matter density relative to ρ_0". In the section on gravitational lensing, in the description of the usual diagram, we are told "… β is the true direction to the lens. The angle ω is the direction of the lens as seen from Earth." In addition, regardless of the science, the publishers appear to have eschewed any proof reading. The text would certainly have benefitted from the services of a good proof-reader, as it suffers from numerous mangled or non-sentences, even in the specialist sections (*e.g.*, "… which is Peebles' (1980) approximation for the dimensionless growth rate, D linear growth function"). One lengthy sentence in the Foreword, that must have got away from the author, states that "Even before the times of Galileo and Newton, astronomical investigations … led to galactic dynamics, and discovery of the universe's expansion". The text also suffers from misplaced or missing commas ("Assuming a Gaussian function … as an illustrative approximation shows, that the higher frequency, k wiggles get progressively damped down.") leading to some "eats, shoots and leaves" moments — presumably "from studying matter in motion, science has unravelled, what we call the Laws of Nature" wasn't meant to isolate the central clause. Indeed, there are sufficient infelicities of sentence structure to bring to mind the instruction to examiners regarding the level of thesis corrections required "… if the errors, though trivial individually, are … so intrusive as to distract the reader's attention from the argument of the dissertation …". Maybe I have just spent too long reading dissertations. In summary, few UK readers are likely to want to purchase this for themselves, but some may wish to have their library buy it for reference. Even then, they should beware the errors and the confusing equations, which reduce its usefulness for a student. I can't say that I would recommend it. — Steve Phillipps.

Galaxy Morphology, by B. W. Holwerda (IoP Publishing), 2022. Pp. 209, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 3497 6).

Extragalactic astronomy in the 21st Century revolves in large measure around classifying galaxies. The reason for this is that modern instrumentation is capable of revealing details in very distant galaxies, which facilitates answering one of the most important questions in astronomy: how have galaxies evolved, from shortly after the Big Bang to the present? The need to examine galaxy morphology from low to high redshifts has spawned many studies involving classifying hundreds of thousands to millions of galaxies. In principle, this could be done visually using variants of the Hubble classification system, but with such large sample sizes, it quickly becomes impractical for one or a few galaxy morphology experts to do this. This led to the idea of crowd-sourcing visual classifications using the internet. But visual classification is only one way of categorizing galaxies. It has been known since the late 1970s that visual galaxy morphology correlates with quantitative measurements such as, for example, the integrated colours of galaxies. This led to a flurry of studies involving more quantitative approaches to galaxy structure.

B. W. Holwerda's *Galaxy Morphology* is an excellent introduction to the quantitative methods that have been used and is geared to the era of large image databases and the sophisticated programs needed to analyse them. These databases cover a wide range of redshifts and morphology, from X-rays to radio waves. To analyse properly such material, it is essential to have effective ways of quantifying characteristics such as angular size, integrated brightness, and other aspects of galaxy structure. Astronomers have long sought ways of replacing visual morphological classes with quantitative representations that can be used to determine scaling relations and to evaluate the accuracy of models of galaxy structure and evolution. Parameters such as the Sersic index and non-parametric approaches such as the CAS system can be effective for quantitative morphology but still have limitations. The interplay between visual and quantitative classifications led to the idea of using machine-learning methods to classify galaxies. Holwerda covers all of these topics and much more. The book is suitable for a course on galaxies and is written for extragalactic astronomy students "at any level". Each chapter is accompanied by a 'Jupyter notebook' assignment and has a useful list of articles for further reading. — Ron Buta.

Origins of Giant Planets. Disks, Dust, and Planetesimals, by Sarah Dodson-Robinson (IoP Publishing), 2022. Pp. 205, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 2134 1).

I expected this to be a collection of chapters by different authors assembled from papers presented at a conference, but I was wrong. Sarah Dodson-Robinson is not the editor, but is in fact the sole author. Her undertaking is all the more remarkable as a *tour de force* because this is only volume one of two. She follows giant-planet formation through the gas-dominated stages of cloud contraction into protoplanetary discs, condensation to dust and pebbles, and then into rubble-pile planetesimals. The effects of self-gravity, mutual gravitational interactions, and orbital migration are deferred until the second volume, although the final chapter steps across that threshold in discussing the Martian hafnium and tungsten isotopic record as tracers of the timing of embryo growth. Even though the theme is giant-planet origins, inevitably there is much of relevance to rocky planets, meteorites, and the Kuiper Belt too.

All chapters, after the entertaining introductory history-of-ideas chapter, abound in generally rather complicated equations. Dodson-Robinson writes well and engagingly, especially given the burden of all the equations. This is not a book for the mathematically faint of heart, but there are boxes that take the reader aside for a generally more 'friendly' chat. I particularly appreciated the four pages of Box 3.1 that describe and summarize the size progression of giant-planet fore-runners including the stages of planetesimal collisions and/or pebble accretion and then gas accretion that will feature in Volume 2.

Citations of peer-reviewed papers abound in the text, and each chapter concludes with several pages of references so that this book would provide a good entry into the field for new researchers. I would expect it to have a decade-long useful life in institutional libraries. It is well illustrated, mostly in colour. Frustratingly there is no index; maybe that will appear in the second volume, covering both books. — David Rothery.

Prebiotic Chemistry and the Origin of Life, edited by Anna Neubeck & Sean McMahon (Springer), 2021. Pp. 296, 24 × 16 cm. Price £109·99 (hardbound; ISBN 978 3 030 81038 2).

How exactly did life emerge from non-living chemical constituents on the early Earth? Anyone setting out to study the origin of life or astrobiology and attempting to answer this question, or who is interested in learning about the present state of the field, will find this book extremely informative. Taking the reader on a journey from geochemistry to biochemistry, many of the key prebiotic-chemistry prerequisites required to bring about the origin of life, as they are currently understood, are introduced. Neubeck & McMahon have gathered together a wealth of expertise from the field providing a detailed overview of each individual topic.

Each chapter can be read individually, although the book is laid out in such a way that reading sequentially highlights the interconnectedness of every step on the path to the first living organisms. Although not formally listed as such, there are essentially three main sections within the book. In the first three chapters we are introduced to geochemical topics which are sometimes under-appreciated in the field, but which of course play an essential role. Next we delve into prebiotic-chemistry concepts of increasing complexity from homochirality through molecular evolution, finally arriving at a discussion of the efforts to reconstruct the last universal common ancestor (LUCA). My own area of interest, the study of the first cell membranes, is expertly portrayed. A discussion of viruses relative to the origin of life is also a welcome addition. The concluding section comprises two chapters which are focussed on the search for the earliest traces of life in the rock record of the early Earth and how this relates to our understanding of the origin of life and also of the evolution of early life. Indeed, the final chapter introduces us to the origin and evolution of eukaryotes, arguably post-prebiotic chemistry but fascinating nonetheless.

The study of the origin of life is an often controversial arena with many different viewpoints. For that reason, those of us actively working in the field will undoubtedly have our opinions on other aspects that could have been included in this book. However, any compilation which aims to provide an overview of the subject is undertaking a very difficult task, particularly one that endeavours to include geochemical and palaeobiological insights which are often overlooked. In this regard, Neubeck and McMahon have achieved a good balance. The editors themselves state in the preface that they aimed to avoid some of the more traditional arguments and include novel viewpoints, which I think was a good decision. Although it is an impossible task to cover every facet of the increasingly exciting study of prebiotic chemistry, for those looking for an introduction to the current state of the field, this book is an excellent place to start. — Sean Jordan.

Planetary Habitability, by Stephen R. Kane (IoP Publishing), 2021. Pp. 122, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 2118 1).

This textbook offers a very accessible introduction to the topic of planetary habitability, both in the context of Solar System bodies and exoplanets. It focuses on the concept of the Habitable Zone (HZ), which it breaks down according to three broad influencing factors: the planet itself, the stellar host, and the planetary system. The different chapters and their sections are very well linked together, and often invite the reader to recall a concept previously explained. While this induces some repetitions, it highlights the essential cross-disciplinary nature of the field and the complex network of feedbacks and interactions it feeds upon. Despite the lack of data, the author suggests specific questions to answer in the near future, which gives a good idea of where the field is heading, especially for Solar System science.

Planetary habitability is a young and fast-evolving field and the author acknowledges the necessary incompleteness of his textbook, emphasizing that each approach "is likely case-specific in a way not yet obvious". In this context, Professor Kane chooses to remain very Earth- and Solar System-centric and approaches planetary habitability strictly through the lens of the Habitable Zone — for which he is extremely thorough and consistent. While this might reflect the current consensus among most scientists, it does not hint at a few promising directions that have recently emerged and triggered new considerations, separated from the conventional HZ concept. In addition, this textbook does not mention the recent evolution of the field towards adopting statistical and probabilistic frameworks to inform data interpretation consistently and weigh it against our assumptions and potential biasses, such as Bayesian methods. Finally, the extent to which Solar System science is and will remain the primary resource for advancing our understanding of habitable environments — including exoplanets — could have been more nuanced. The diversity of exoplanets (most of which find no analogue in our Solar System) already demands cautious extrapolation and an open mind constantly striving towards updating previous dogmas. — Estelle Janin.

Supernova, by Or Graur (MIT Press), 2022. Pp. 240, 18 × 13 cm. Price £13·99/$16·95 (paperback; ISBN 978 0 2625 4314 9).

Supernova is a recent addition to the MIT Press 'Essential Knowledge' series, announcing itself as a "concise illustrated introduction to the history and physics of supernovae". I guess that, rather like the OUP 'Very Short Introductions', it's primarily aimed at the curious educated layperson, which may explain the, for me, rather offputtingly cheesy cultural references that frame the Introduction to the book — Superman, Sherlock Holmes, Star Trek. I feared the worst, but was proven happily wrong (even if cats and Monty Python aren't entirely avoided subsequently…); after just a couple of pages the style pivots to an articulate exposition, of often quite technical material, in an engagingly non-technical narrative.

The book covers all the ground one might expect, clearly, and without equations: historical observations, modern searches, classification and physical processes, nucleosynthesis, relevant stellar evolution, cosmological applications. A nice aspect, perhaps reflecting the author's background as a research scientist, is that it's made clear where uncertainty or ignorance remains, and where future work may address this. Any necessary infrastructure, such as what a 'spectrum' is, is seamlessly integrated (though I'm not sure that it's still necessary or helpful for the reader to be told that a "CCD image is similar to a photograph captured on film" — what's film?). There are plenty of line diagrams and monochrome images scattered throughout, along with an insert of eight colour plates. Unobtrusive citations (numbered in the style of references in this *Magazine*) link to a 20-page section of detailed supplementary notes and primary sources. Further back-matter includes appendices on units and selected elementary particles, a glossary, suggested further reading, and an index.

The series is produced in a compact format, evidently tailored for affordability in terms of physical quality. With a bit of web searching, *Supernova* can be bought for under a tenner, which is a bargain for such an up-to-date, wide-ranging review. The odd quibble notwithstanding, I enjoyed this very readable summary of a wide range of 'supernova' topics, and would expect interested undergrads and amateur astronomers to benefit likewise. — Ian D. Howarth.

Saints and Sinners in the Sky: Astronomy, Religion and Art in Western Culture, by Michael Mendillo (Springer), 2022. Pp. 252, 24 × 16·5 cm. Price £24·99 (paperback; ISBN 978 3 030 84269 7).

Astronomy professor Michael Mendillo, of Boston University, USA, investigates how artistic depictions of the sky have not only developed over the centuries, but also how they have remained essentially pagan. The pivotal chapters of his book review the attempt by the German astronomer Julius

Schiller (*c.* 1580–1627) to expunge the old-fashioned array of celestial gods, instruments, and animals and replace them by good Christians. Out went the virgin, and in came St James the Lesser; the crab scuttles away to be replaced by St John; the centaur Sagittarius morphed into St Matthew. Astronomers, being a contrary bunch, ignored his efforts, and his reforms did not catch on. Astronomers stuck with the likes of Johannes Bayer and his *Uranometria Omnium Asterismorum*.

Mendillo then turns his attention to a gallimaufry of artists such as Giotto, Elsheimer, Rubens, Singer Sargent, Miró, van Gogh, Munch, O'Keeffe, and Dalí, and delights us with a well-chosen selection of masterpieces and an insightful discussion of motivation. We are presented with a most readable romp through astro-art history from the cave paintings at Lascaux to the ceiling of New York's Grand Central Terminal.

But I could not help but feel that something was missing. I kept wondering whether the artists, astronomers, and church-men were ever 'singing off the same hymn sheet'. All look up at the sky, but the astronomer sees something of scientific fascination, something that needs understanding, and accurate investigation. The artist concentrates on the beauty; here correctness is unimportant — if a few more stars near the horizon would improve the work, in they go; if the Moon is in the wrong place and of the wrong size, just expand it and move it. And the church-man, indifference maybe? I was not convinced that, when it comes to religion, the sky and its contents are anything more than an irrelevance.

This is a lovely book. The illustrations are superb, though being greedy, I would have been happier if they were larger. It is thought-provoking, highly readable, and well referenced. It is a book all astronomers will enjoy, and it should make our visits to art galleries both more frequent, and more beneficial. — David W. Hughes.

Stephen Hawking: Friendship and Physics, by Leonard Mlodinow (Penguin), 2020. Pp. 232, 20 × 13 cm. Price £14·49 (paperback; ISBN 978 0 141 99132 0).

This is a memoir about Stephen Hawking. It is neither a biography nor a (popular-)science book, though it contains elements of both. Mlodinow is Hawking's co-author on a couple of popular-science books; Hawking had contacted him because he liked his writing. He is not some sort of ghost writer with Hawking's name on the cover just for selling the book (though his name certainly helped sales); not only is Mlodinow a physicist but the books that he co-authored with Hawking — which, like his other books, I haven't read — were genuine collaborations. About a third of the book is about their writing collaboration on *The Grand Design*[1] (their second after *A Briefer History of Time*[2]), a third about Hawking's life up until then, and a third about Hawking's work, with the three threads interleaved. The book is well written, reflecting the fact that Mlodinow has alternated between being on the faculty of Caltech and working mainly as a writer, on a variety of scientific topics, though to some extent he also wrote while on the faculty and did research when mainly writing.

I've written above more about Mlodinow than about Hawking, as the latter is certainly better known than the former. He is so well known, and has been written about so much, that Mlodinow declined to write another biography when asked to do so just before and after Hawking's death. This book does fill a niche in that it offers an introduction to the man and his work *via* someone who knows both well, and is hence good for someone wanting to know the basics about one or the other without (yet) going into too much detail. (At the same time, for some, this book might reveal too much about Hawking.) The third strand, their collaboration, is perhaps the most interesting (in part because it is not as well-known as the other two), and the interleaved narrative actually works; that strand itself is about co-writing a book about the other co-author's work, which sounds more confusing than it reads.

Hawking's science is described in simple terms but without distorting it. The only mistake I noticed is the often repeated claim that John Wheeler came up with the term 'black hole' (though he did popularize it[3]). Apart from a black-and-white photograph of Mlodinow and Hawking, notes on sources, and acknowledgements, there is no additional material (nor is any needed).

I read *A Brief History of Time*[4] when it was new. I had already read many popular-science books and remember being somewhat let down. Of course, not all good scientists are good writers (and certainly not *vice versa*). The jointly authored books might be better written, but on the other hand an author of a popular-science book is not always the best source for information about his work, especially if it is the only source, which is certainly the case for Hawking with respect to most readers of his popular-science books. (Stephen Jay Gould comes to mind; he was a brilliant author, but, intentionally or not, the reader's perception of the field is coloured by the author's perception.) That is something to take into account when deciding whether to read the books co-authored by Hawking and Mlodinow. However, such reservations do not apply to this book, which was an enjoyable read and should appeal to those looking for an introduction to Hawking and/or his work. — Phillip Helbig.

References

(1) S. Hawking & L. Mlodinow, *The Grand Design* (Bantam), 2010.
(2) S. Hawking & L. Mlodinow, *A Briefer History of Time* (Bantam), 2006.
(3) M. Bartusiak, *Black Hole: How an Idea Abandoned by Newtonians, Hated by Einstein, and Gambled on by Hawking Became Loved* (Yale University Press), 2015.
(4) S. Hawking, *A Brief History of Time* (Bantam), 1988.

More From The Library

The System of the Stars, Second Edition, by Agnes M. Clerke (Adam & Charles Black), 1905. Pp. 403, 21 × 13·5 cm. Acquired by William Tyler Olcott of Norwich, Conn., on 1913 March 10, and at auction from AAVSO by V. Trimble. Price not given, but her other contemporary volumes were advertized at 15 and 20 shillings each.

"She wrote it! She wrote it! She really, truly wrote it!" (to be sung to the tune of *A Tisket, A Tasket, a Green and Yellow Basket*). What did she write? What you have almost certainly read in multiple debunkings of historical astronomy: here on page 349 at the beginning of Chapter XXVI, 'Status of the Nebulae', "The question of whether nebulae are external galaxies hardly any longer needs discussion. It has been answered by the progress of research. No competent thinker, with the whole of the available evidence before him, can now, it is safe to say, maintain any single nebula to be a star system of co-ordinate rank with the Milky Way."

Yes, but what was that evidence, and can the misleading path down which it drew her provide any guidance for our own decisions at forking branches of modern astrophysics? She divided the evidence into three categories, "the nature of the bodies themselves", "their individual stellar associations", and "their systematic arrangement as compared with the systematic arrangement of the stars". This third remains familiar, so let's deal with it first. Many of the nebulae, especially those with spiral form, avoid the plane of the Milky Way, where the stars are concentrated. We now attribute this 'zone of avoidance' to light absorption by interstellar dust, and Struve, Kapteyn, and others worried about something of the sort for decades before Trumpler settled the issue.

The first and second reasons are (mis)applications of Occam's razor, which (I think mistakenly) is again being stropped for various cosmological applications. Her point is that, because some nebulae show (in work by Huggins and others) just emission-line spectra, they must all be essentially gaseous in nature, with, in some cases, apparent continua being described as many closely-spaced lines. The middle point is that some nebulae, including Orion and the Pleiades, have gas around (from which the stars recently formed), and those must be within the Milky Way; then, again, all must be.

Supporting evidence comes, she writes, from the ridiculous consequences of assuming, for instance, M31 (Andromeda) to lie outside the Milky Way. This would, she opines (not quite showing the calculations), require its distance to be 25 times the diameter of the Milky Way and the brightness of the temporary star of 1885 (S And) to have been 16 million times as bright as the Sun. It is left as an exercise for the reader to plug in modern numbers and say to the first, "well, yes", and to the second, "actually a lot brighter than that!"

The line identifications in those gaseous blobs she has attempted to deal with earlier, in Chapter V. Yes, there is hydrogen nearly always; sometimes helium; and the definitive signature is the 5007 Ångstrom line of Nebulium. She does not like the idea of an emission feature that cannot be produced in the laboratory from any known element or mixture, with which I think we would all agree. She expected a rapid resolution of the problem through advances in spectroscopy. It took actually a bit more than 20 years and Ira S. Bowen's understanding of early quantum mechanics and atomic structure to replace Nebulium by forbidden transitions of ionized oxygen.

But let us turn to something more cheerful — the category of variable star she calls "temporary", though the name 'nova' was already in place for many of them. These number 27, the earlier ones having been compiled by Humboldt in Volume III of his *Cosmos*. Most of the fun comes in picking out which of the 27 one recognizes. Yes, the events of 1006, 1572 (Tycho), and 1604 (Kepler) are there, after which 1885 in Andromeda and 1895 in Centaurus, and a flock of actual novae in modern dress, including T Cor Bor in 1860, and Nova Persei in 1901. Summaries of the observations include, often, flickering (meaning stellar angular sizes, not planets), and something of the spectroscopy for the later events. What of the nine others before Tycho's star? None is either SN 1054 (the parent of the Crab Nebula) nor SN 1181. (These must lurk among "four or five questionable instances mentioned in the Chinese annals".) And none appear among D. A. Green and F. R. Stephenson's various compilations of possible historical supernovae. One would, I think, have to go back to Humboldt's list to make further progress. Clerke is not alone in mentioning that a surviving visual remnant of the Tycho event has been found (*MNRAS*, **34**, 168, 1874) by J. R. Hind, also the discoverer of the 1848 Nova Oph, which appears in Clerke's list.

Ah, but what did she make of these 27 temporary stars? Spectroscopy has not been a friend here! Indeed near maximum light some of the later events have shown a melange of continuum, emission, and absorption features. But so do some persistent stars, most notably P Cygni and Eta Carinae. As a result, the author concludes that novae cannot be the products of "fleeting effects of catastrophes", thus eliminating both "collision and stellar explosion theories of stellar outbursts".

Once again, Occam's razor has been used for throat-slitting, a warning again for modern astrophysics. — VIRGINIA TRIMBLE.

OBITUARY NOTICE

David Hughes (1941–2022)

I was shocked and saddened to learn of the sudden and unexpected death of Professor David Hughes on 2022 June 6. As one of the most prolific book reviewers for *The Observatory*, we were in almost constant contact and I could have regarded David as an important 'e-friend', although he was much more than that since we met often at RAS Council meetings back in the last century and I enjoyed the company of this larger-than-life, jovial, *bon viveur*.

His contribution to astronomy was enormous, especially in his passion for the small bodies of the Solar System, from meteorites up to planets, with a special fondness for Pluto (see one of his last reviews in the August issue, p. 187); he was rewarded with Mars-crossing asteroid 4205.

He was passionate about astronomy which made him a wonderful teacher, both in the university setting — he taught at Sheffield University from 1965 until retirement in 2007 — and in outreach. David was much in demand as a lecturer and broadcaster. Before retiring he gave about 20 'general public lectures' per year for four decades, and typically 20 interviews per year for radio and TV broadcasters. He continued after retirement and then also worked for the Smithsonian Institution, lecturing for them on cruise ships.

A more formal obituary of David has been prepared by Professor Mike Edmunds and will appear in *Astronomy & Geophysics*. The Editors of *The Observatory* offer their sincere condolences to his wife, Carole, and their children Ellen & Owen; we shall all miss him. — DAVID STICKLAND.

Here and There

THIS IS THE CRUX OF THE ERROR

... the north pole faces the same direction in space — towards Polaris — ... In the same way, the south pole keeps facing the Southern Cross. — *New Scientist*, 2022 April 23, p. 57.