THE
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A REVIEW OF ASTRONOMY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2024 February 9 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

MIKE EDMUNDS, *President*
in the Chair

The President. Welcome to the monthly A and G Highlights Meeting. This is a hybrid meeting and questions can be asked at the end of the lecture but you will be muted so please use the chat facility. Questions will be read out by the Assistant Editor of *Monthly Notices*, Dr. Pamela Rowden.

The Crafoord Prize in Astronomy has been won by three of our Fellows: congratulations to Douglas Gough (Cambridge), Jørgen Christensen-Dalsgaard (Aarhus), and Connie Aerts (Leuven). They have been awarded the Prize by the Swedish Academy of Sciences for their work on asteroseismology, so very well done to them.

On to today's programme. I'm very glad to welcome Dr. Laura Hayes to talk about 'The active Sun'. Dr Hayes is a solar physicist at the European Space Agency. Her research focusses on the high-energy processes in the solar atmosphere and the impact of solar flares on space weather. She completed her PhD at Trinity College, Dublin, in 2018 and furthered her postdoctoral work at NASA's Goddard Spaceflight Center in the USA until 2021 before joining ESA as a research fellow.

Dr. Laura Hayes. [*Solar Orbiter*, a mission launched in 2020 by the European Space Agency in collaboration with NASA, aims to study our complex and dynamic closest star, the Sun. Embarking on a unique trajectory, the mission approaches the Sun as close as 0·28 astronomical units (AU) during its perihelia, providing unprecedented observations of the solar atmosphere and its polar regions. This talk introduces the mission's objectives and design, presents the latest scientific results from *Solar Orbiter*, and highlights its contributions to understanding solar processes, including solar-wind origination and magnetic-field dynamics. Furthermore, the discussion will extend to how *Solar Orbiter*'s findings are being integrated with data from other missions and ground-based observatories across the heliosphere, such as the *Parker Solar Probe*, *SDO*, and *DKIST*, opening new avenues for comprehensive solar and space-weather research.]

The President. Thank you very much, indeed. *Solar Orbiter* has gone very near the Sun — has there been any deterioration in the spacecraft? Is it armour-plated sufficiently so that it doesn't degrade?

Dr. Hayes. This was one of the technological constraints of putting a mission close to the Sun. It is designed with the Solar Black material to protect it as it is going in close. To date we haven't seen any major degradation; of course there are little things but nothing unexpected.

The President. Any startling results? You've given us a general overview. Has it made a major contribution to understanding any of the processes?

Dr. Hayes. It has opened up more questions, which is always a good thing. In terms of discoveries, about finer-scale things we have seen which we call campfires — really small events in the solar atmosphere: the question is whether they contribute to the heating of the solar corona — we don't understand why it gets so hot. There have been some really nice results regarding the origin of the source of the solar wind.

Professor Mark Lester. I just wondered — those small fires: do you see them develop and grow into larger events, or do they always remain at roughly the same scale?

Dr. Hayes. From my understanding we don't see them grow into very large events, but it is a distribution so you have very few large events and the question is how far does that distribution go back. Is it the same physics that is going on in the smaller events and the larger ones? I think that the jury is still out on that, but there might be someone in the room who disagrees with me.

Ms. Ana Vitiello. Can you please tell us if there is a very strong wind, how fast can you act to prevent damage to the satellite?

Dr. Hayes. Usually when you have a large eruption like that there are two components. The solar flare, which is light, and which takes eight minutes to reach Earth, has a dramatic effect on telecommunications. The event we usually associate with that is a coronal mass ejection which really has an impact on our satellites and typically that reaches us within 1 to 2 days and we can mitigate that. The first thing we ought to do is to try and mitigate that. We haven't seen a very dramatic one in a long time. We want the solar flare to happen, but we don't want the consequences!

The President. Be careful what you wish for! Any further questions? If not, thank you very much [applause].

Our next talk is about 'The origin of metals and dust within galaxies in the first billion years of cosmic time' and it will be given by Dr. Joris Witstok. Joris is a Dutch astrophysicist who completed his undergraduate studies at Leiden; he moved to the University of Cambridge for his masters degree which he did on the numerical simulation of diffuse emission from the cosmic web; and undertook doctoral studies under the supervision of Renske Smit leading to research in the astrophysics of star formation within the first galaxies, using facilities such as *HST* and the *Atacama Large Millimeter Array*. He defended his thesis in 2022: 'Spectroscopic studies of star-forming galaxies and the intergalactic medium in the early Universe'. He is currently working as a PDRA at Sidney Sussex College and the Kavli Institute for Cosmology in Cambridge where he continues to explore the distant-galaxy frontier as a member of the *JWST NIRSpec*-spectrograph guaranteed-time-observation galaxy-assembly team. So, here to assemble some galaxies for us, please welcome Dr. Witstok.

Dr. Joris Witstok. What do we know about the early part of the evolution of the Universe? The epoch of re-ionization is the period in which I am most interested — the first billion years of cosmic time. The Dark Ages is the epoch when some of the dark matter (DM) begins to assemble into haloes which then host some of the first galaxies. This is where the cosmological model called ΛCDM has been hugely successful in allowing us to explain how we can get galaxies to form inside these DM halos. Cosmic dawn marks the formation of the first stars and galaxies and this is a huge milestone. Stars begin to emit lots of highly energetic ionizing photons — sufficiently energetic to ionize hydrogen which is largely neutral at this time. These first stars quickly explode as supernovae which then spread metals out into the Universe. I want to concentrate on this epoch and to show how the metals produced can be converted into dust — solid metal grains. What we wish to know is what does the metal and dust content of these first galaxies look like?

Just before the launch of *JWST* we thought that galaxies had blue stellar-continuum slopes and low stellar masses and that this points to minimal dust obscuration. These galaxies are also characterized by having metal-poor ionized gas. With the facilities such as *JWST* we can look anew at this. From the ground we could reach $z = 3{\cdot}5$ and were limited by atmospheric transmission, whilst if looking at the Ly-α line the limit was $z = 6$ or 7. Two of these facilities are *ALMA* and *JWST*. With *ALMA* we can see some metal transitions in the far IR whilst with *JWST* we can look at the UV and optical light of these galaxies. I want to talk about the project I have been working on. It is called the JADES survey and stands for *JWST* Advanced Deep Extragalactic Survey which is a joint effort between the teams running *NIRCam* and *NIRSpec* which are the main camera and spectrograph on *JWST*. Our website (http://jades-survey.github.io) has an interactive view of all the imaging we have done with *NIRCam*. Some of the target galaxies have exposure times of up to 30 hours on single targets, which gives us an unprecedented sensitivity limit. In 2017 our best data with ground-based facilities was on a $z = 8$ galaxy where a doublet of emission lines is just visible. Contrast this with a *NIRSpec* spectrum covering 1–5 microns and reaching $z = 10{\cdot}6$, and the spectrum is covered in features. It appears to have an AGN and therefore already houses a supermassive black hole in its centre. One galaxy appears to have formed just 300 million years after the Big Bang — we will follow this up by observations with *ALMA*.

What can we say about the metals inside these objects? Plotting O relative to H as a function of the galaxy mass, the local galaxies follow a tight relationship. The tighter this is the more metals are present, so the graph represents galactic evolution. With the new *JWST* data, the normalization decreases but we see the relation does extend to earlier times. Two galaxies at $z = 7$ appear very red and have high extinction which indicates a lot of dust. They have lots of stellar mass and high metallicity — all present within the first billion years. What do we know about how the galaxies bring up their metals and dust, since clearly they are able to do this rather efficiently?

Dust is a crucially important part of galaxy evolution in the sense that on the small scale it stimulates star formation by forming molecules and allowing gas clouds to fragment into smaller clouds, but for us observers it is annoying because it obscures our view of this process. It absorbs mostly in the UV and optical and re-emits thermally in the IR. We need to take this into account when doing our measurements.

If we look at the galaxy spectrum, in the UV the dust 'flattens' the spectrum there, and this is what *JWST* is able to see. Using *ALMA* we can directly detect the far-IR energy distribution, where the dust is thermally re-emitting. Features include emission from certain molecules, most importantly polycyclic aromatic hydrocarbons (PAHs) with a large peak indicating the cold-dust component. Even at $z = 8$ there are reservoirs of dust up to 10^8 solar masses surrounding these galaxies. This implies stars have to form and produce metals which condense into dust grains within a few hundred million years. What we also see, if we measure the temperature of the dust as a function of z or cosmic time, as we get to the early Universe, the dust temperature increases a little but not as much as previous models have predicted. The cooler the dust, the harder it is to observe. This is posing a challenge for current models. When we look at typical interstellar conditions, the density of the interstellar medium, the density at high redshift is forty times that at $z = 0$.

To explain the dust build-up, models invoke SNe and AGB stars whose winds create an environment for dust formation or even the direct growth of grains inside the interstellar medium. If we look at dust mass as a function of stellar mass we should be able to predict, given some amount of stars in a galaxy, what is the maximum amount of dust that a galaxy can produce. We also need to look more carefully at the properties of the dust grains. We measure the absorption and extinction in the optical and IR as a function of wavelength. Using stars in the Milky Way and the Magellanic Clouds of known spectral types we can determine how much light is obscured by dust, but obscuration and attenuation varies greatly in the Milky Way. There is a significant peak in the extinction curve at 2200 Å, known as the UV bump, thought to be due to carbonaceous dust. One promising candidate is PAHs — they are mainly formed by AGB stars. The most massive galaxies are very bright in the mid-IR and contain relatively many PAH molecules. In the UV those very same galaxies have a very strong absorption feature, so PAHs are very much correlated with this absorption feature. If these are formed in the most massive galaxies over a long time can we see this in the first generation of galaxies? — presumably not, but it provides a nice test case of SN and AGB-star dust production.

We can see this feature very early on and the galaxy in our press release from the JADES survey shows a strong absorption at 2175 Å. The data from *NIRSpec* allows spectra to be taken in the rest-frame UV and optical up to $z = 10$. One conclusion — either SNe or WR stars, both of which are potential dust sources, are able to produce dust on very short time-scales, as evidenced by a binary pair of WR stars which leave behind a multi-ring structure as they orbit. Recently a $z = 12{\cdot}5$ galaxy was observed by the *JWST* with 100-hours' exposure time. We finally managed to observe some of the emission lines which contain a lot of carbon and it is shining a light on what is happening in the very early Universe.

The President. Thank you very much. Can I invite questions?

Reverend Garth Barber. Could these very early advanced features be an indication of early dark energy, that the Universe is actually older than the present model?

Dr. Witstok. I think at this point we can't definitively prove or disprove any cosmological models. We first have to dig into the astrophysics and see if we can understand these sources responsible for the production of dust because there is a lot of uncertainty there. Even in local galaxies we are sometimes struggling to match the number of stars. With the amount of dust we see, I think there is some more work to be done on our side and then we can turn to the cosmologists and tell them that their model is wrong.

The President. There is a question on-line.

Dr. Rowden. This question comes from Gavin James. He asks "You suggest that dust has formed more quickly than might be expected. *JWST* observations also show that more galaxies are formed at higher redshifts than expected. What is your take on the accuracy of the current estimate of the age of the Universe?"

Dr. Witstok. It comes back to the same question. It is true that with *JWST* we have seen, for example, galaxies are around much earlier and are much more abundant than we might have expected before, but I think that first we have to see within the context of astrophysics there is a lot going on with how a galaxy forms, and how it builds up its stellar mass. There is definitely some room in the models there to try and explain how the galaxies are already in place quite early on. I think that at the moment this very much fits in with the ΛCDM models having an age of about 13 billion years.

The President. Don't panic!

Professor Ian Robson. In the 1980's there was a big bandwagon on polycyclic aromatic hydrocarbons (PAHs) explaining everything in terms of 2175 Å and spectral features in the infra-red, and yet Bruce Draine said in his review that this was inconsequential and that it was not conclusive, so what has happened now?

Dr. Witstok. I should say that I am not an expert in PAHs myself. I think that PAHs are the most important dust species in terms of the number of features and how they can explain some of the observations especially in the mid-IR. Most of the peaks in these spectra we are confident were produced by PAHs so they are definitely a very important component of dust as a whole. I think there are still a few details to be confirmed.

The President. What would worry me a little is that your very distant galaxy's spectrum did not look like a normal PAH feature. It was not a nice peak — in fact, it was rather messy. Should we begin to panic at that? Could it be something else?

Dr. Witstok. The feature that we are seeing is actually in the UV so the absorption by the same dust grains — these are the emission features.

Professor Richard Ellis. I don't understand this puzzle that dust forms so quickly. It is natural that if you go to the very early Universe there are probably lots of massive stars with low metallicity. They explode within five million years, and if we look at something like SN 1987A it produced half a solar mass of dust. Turning to this issue of why galaxies are so bright at this early time, one of the leading hypotheses is that they are sending out their dust that is already there. Is it a surprise that the Universe is dusty at such an early time?

Dr. Witstok. I would agree. It is not a surprise that it is dusty. The numbers that we see are starting to feel a little uncomfortable. On one of the plots I showed that we are starting to exceed even the most optimistic SN yields, so every SN would have to produce one solar mass of dust and not destroy any of it in the reverse shock.

Professor Ellis. But that is for some classic IMF.

Dr. Witstok. I agree — we definitely expect dust to be there.

Professor Steven Eales. Could you say a little more about the C/O ratio that you were talking about, because that is really interesting?

Dr. Witstok. There is recent work by Francesco D'Eugenio. As I mentioned, this is one of the deepest spectra we have taken so far and we can clearly see the C III doublet and also C IV is not detected significantly, but if we compare these abundances it points out the super-solar C/O ratio.

Professor Eales. Is that the opposite of what you would expect with normal stars?

Dr. Witstok. Yes.

Professor Eales. Do Population III models always predict a super-solar C/O?

Dr. Witstok. What I can say is that if you look at some of the most metal-poor stars in the Milky Way, they actually tend to be relatively carbon rich. This might be the direct enrichment of the Population III SNe.

The President. One last question on-line and then we must move on.

Dr. Rowden. This question comes from Sanjeev Kalita who asks "Can we explain high-z dust by shifting the Big Bang (alternative to ΛCDM), or can early Population III explain that?"

The President. That's the same question.

Our next talk is 'Our fragile space — protecting the near-space environment' and it is part of a photographic exhibition and engagement project. Our environment is a great concern for the RAS both for Earth observation and for satellites and for the implications for ground-based and space-based radio and optical observation. It is a very serious problem. We fire off letters, angrily, to lots of places and try to put pressure to get some kind of international regulation. It's a great pleasure to welcome Max Alexander who is a well-known friend of the RAS, whom I have known for many years. He is an international photographer and a creative strategist — I'm sure he'll tell us what that is, probably [laughter]. He specializes in science communication through visual storytelling. His passion for understanding the Universe and making it meaningful to others has motivated him to work in this arena. He has a diploma in astronomy from UCL and he is a Fellow of our Society. He freelances for numerous prestigious organizations around the world including the UK Space Agency, ESA, ESO, SKAO, book publishers, and magazines. He has photographed Nobel prize-winners, astronauts, and world leaders. He has had two science exhibitions at the Royal Albert Hall — 'Explorers of the Universe' and 'Illuminating Atoms'. His work for the UK Space Agency has involved photographing the ESA/British astronaut Tim Peake and includes documenting his Soyuz training, which must have been quite fun, and also providing him with photographic training for his work aboard the *ISS*. Max proposed an international asteroid day sanctioned by the UN, and he is also photographer-in-residence there. Please give a warm welcome to Max Alexander [applause].

Mr. Max Alexander. I want to talk about the exponential growth of satellites and mega-constellations, and the increasing amount of space debris. The starting point for me is astronomy. I have been working on these topics for three years including a year-long photography project. It's about three key things. How do we benefit from the use of space? What about the loss of the night sky and space sustainability — world projects and initiatives and regulation? I am doing reportage and portraits because it is important to tell the human story.

The photographic exhibition was hosted on the Underwriters Floor at Lloyds of London, because they are concerned about the risks, and it was opened by the astronaut Tim Peake.

Geostationary satellites are traditionally three Earth-diameters out but they are getting closer to Low Earth Orbit (LEO) and so thousands are needed to cover the Earth.

Three months after the end of the exhibition there was a round-table discussion at Lloyds. At the opening exhibition, standards for space sustainability were announced and amongst those attending were the Science Minister George Freeman, the CEO of Lloyds, and other senior personnel. Amongst the topics discussed were the benefit of space for telecommunications — the biggest provider of such services currently is SES of Switzerland. The conversation about mega-constellations was mainly about the internet, but financial services were thought to be just as important. Fifty per cent of arable farmers in the UK use satellite information and world-wide 18% of the economy is reliant on the use of space. This includes *Sentinel-5*, an instrument built by Airbus in Stevenage which is monitoring trace gases in the atmosphere. In addition, more than 50% of climate-change monitoring is done from space.

Turning to anthropogenic change — plastic in the ocean is a good analogue for what is going on in space since it has been dumped there for 65 years. It's now starting to happen in space — 47% of the material there is aluminium and this amounts to about 10 000 tons, but the velocity and momentum that it possesses is the danger factor. The UK Space Agency just commissioned a large report of the effect on the Earth's atmosphere of satellites de-orbiting. US Air Force studies of the upper atmosphere show traces of aluminium (10%?) which can only have come from satellites. A study in Iceland last week showed that in 10 to 30 years from now such events could affect the Earth's magnetic field. Another potential example of anthropogenic change is the appearance of noctilucent clouds 80-km high in the atmosphere which have been around since the industrial revolution — another example of the effect of human activity.

I have been to Chilbolton where they do satellite tracking — they are re-purposing some of their time and telescopes for tracking space debris and satellites. At Astrofest last weekend Robert Massey talked about work at Jodrell Bank and the substantial effect of satellites in radio wavelengths. The RAS is playing a leading role, in co-operation with Starlink and SpaceX.

The first recorded piece of space debris is in a Paris museum. It is a part of an Ariane 4 rocket which is three to four stories tall and ended up in Mongolia. Every time I was in a clean room, a space company, or a museum at ESTEC I cleaned out the cabinets and photographed examples of what is in space — solar panels, boom arms, fuel tanks, or the chassis of cubesats.

At the University of Kent they are doing ballistic tests, firing 3-mm plastic pellets at twice the muzzle velocity of a rifle into a piece of copper, but velocities in space are five to ten times the muzzle velocity of a rifle. A *Hubble Space Telescope* solar panel that was retrieved during a servicing mission was brought back to Earth to show the impacts sustained as a result of being in orbit. Donald Kessler has speculated on the possible domino effect if a satellite collided with another and the resulting fragments went on to impact other satellites.

I visited Vandenberg Air Force Base in California where I saw a Starlink launch with 40 or 50 small satellites on board. I flew overnight to Cape Canaveral where I observed two further launches. Last year more than 200 launches were approved and so the cost of satellites is coming down.

Increasingly, more military installations are being re-purposed for tracking space debris. In Madrid they have been tracking debris for 50 years and will continue to do so for years to come. On Tenerife, ESA can track satellites fitted with mirrors using lasers. Eventually they expect to be able to move satellites.

Professor Mini Rai on an all-party Parliamentary scientific committee has been given a £28M grant to develop robotic satellite catches. This is difficult to do as you have to match the rate of tumble. Another method is to use solar sails to de-orbit satellites. A Swiss company called Clear Space One has a £12M grant from the UK to develop this technology. Another line of development is the use of non-toxic materials in space instruments — Japan has, for instance, used wood in a satellite.

Reusing and refuelling satellites is also an idea that is being worked on. A Welsh company is looking at ways of de-orbiting satellites and recycling them.

A sub-committee in Vienna is working on the legal aspects of space. They are working on financial and economic incentives for companies to act responsibly. We need to get the Government on-board to incentivize the investors. The UK is playing a leading role here.

The President. Thank you, Max. Beautiful photographs. There is a very deep message that you are trying to get across. Questions and comments? I think that the important point you make is that there is so much money tied up in this internationally that unless you can get the money men involved, it is not going to happen.

Mr. Alexander. That is the key and getting the investors to invest only in those projects that reach these standards.

Professor Roger Davies. A lot of people model the Earth's atmosphere these days for obvious reasons — to study climate change. I don't know anybody working in this field who could make an estimate of the impact of thousands of tons of aluminium being dumped into the Earth's atmosphere. I don't know whether *you* do, but perhaps someone else here might have an idea of where that might be happening. That is such a high-profile problem, climate change, that adding that bit to it could have considerable impact.

Mr. Alexander. Certainly it's incredible — the different knock-on effects — they are everywhere you go. My personal view is everything in moderation. In November at the UK space conference on the effects of the orbiting satellites, it is a major UK research programme. I don't know where it is based. I would also say that the magnetosphere and the Earth's magnetic field will start to become of interest. I really do.

The President. A question on-line next.

Dr. Rowden. This question comes from Sanjeev Kalita: "Do we have space laws for exploring outer space such as colonization".

Mr. Alexander. I'm not a space lawyer. I don't know if the 1967 outer-space treaty covers colonization.

The President. Does anybody know?

A Fellow. It doesn't.

The President. Yet!

[*A City on Mars*, recently reviewed in these pages (**144**, 210), contains a very extensive discussion on the outer-space treaty and to what extent it covers present and planned activities in space. — Ed.]

Mr. Kevin McNulty. I'm just wondering with the satellites that were put up in the 60s and 70s — most of those can't do a controlled de-orbit, and if, in 10–20 years from now, the area around the Earth is packed with satellites, and if they all move out of the way to avoid a satellite coming through could that cause a Kessler effect?

Mr. Alexander. I don't know. Space is still very big and there is always the risk of collision. It takes only one collision to create thousands of pieces of space debris. In 2009 a Russian and an American satellite collided. China did a test with a satellite collision. There are about 40 000 pieces of debris being tracked at the moment, bigger than a mobile phone. Between 1 and 10 cm there are about a million pieces, and from 1 mm to 1 cm, about 128 million. It's just a matter of time and probability.

Dr. Quentin Stanley. I noticed that on the holding image as we came in here, there is a satellite on it. If you look at a Windows 11 build the first thing you get is an image of someone camping under the Milky Way and there are two satellites in it. Just to answer Kevin's question, Jonathan McDowell keeps a record of all the satellites, and you see these burns to move the objects out of satellite impacts and this goes on and on. You've done a brilliant job of highlighting these problems. Going back to Robert's presentation at Astrofest, this is something that concerned the RAS back in 1962 with radio astronomy. It's been going on for a long time and we need to put a bit more effort into it.

Professor Ofer Lahav. Given the situation at present with the amount of stuff that is out there, what is the forecast if nothing is done?

Mr. Alexander. I think it's an order of magnitude in the next ten years, by the end of the decade. Today there are about 10 000 satellites in space and there could be 100 000 in the next decade. There are currently licences for over a million.

The President. I'll just make a comment. For astronomical things that concern us a lot of mitigation can be done if the design of this craft is right and you have ways of shutting down a radio satellite with interference. A lot of work could be done on treaties if we could agree on the way the satellites are built, in reflectance, interference, and so on. That is one problem that can be dealt with. The debris problem is another matter but in a very serious way.

Professor Mike Cruise. Could I just suggest that people need to learn some lessons from what happened to the IPCC (Intergovernmental Panel on Climate Change)? What they found in their first ten years or so was that they had to be terribly careful about what they said, what graphs they produced, and so on. Not everybody who looks at your pictures or graphs will really understand what you are saying — some of the pictures, such as the re-use of the rubbish in space. I can see the front page of the *Sun* proclaiming "Boffins say a refuse park in space". The trouble is that you do not need a couple of hits like that to damage the case you are making. It's fantastic, but think carefully how pictures can be misconstrued by people, because the IPCC took a long time to learn how much damage was done by the public misunderstanding things they were saying.

Mr. Alexander. That's a fair point. There is a lot of aggressive lobbying but I think science communicators and policy makers felt they were walking on eggshells. We have an opportunity with space not to repeat that same behaviour and learn these lessons.

The President. I think that we are going to draw this to a close. Thank you, Max [applause]. Let me remind you that now, over in Burlington House, there is a drinks reception in the Council Room and you may like to continue some of these questions and comments over there. I give notice that the next open A&G Highlights meeting will be on Friday, March 8th.

THE STRUCTURE OF THE GALAXY AS DESCRIBED IN BRITISH PROFESSIONAL JOURNALS 1820–1920 PART 2: 1906–1920

By Steven Phillipps

Astrophysics Group, University of Bristol

Two previous articles considered early papers in British professional journals (primarily *Monthly Notices of the Royal Astronomical Society* and *The Observatory*) which turned out to be about external galaxies[1], and corresponding papers on the structure of our own Galaxy (up to 1905)[2]. Here we extend the latter until 1920 to cover papers up to the culmination of Harlow Shapley's series of papers[3,4] from Mount Wilson which demonstrated essentially the modern picture of the Galaxy, much larger than hitherto believed (in fact, too large), with surrounding globular clusters and the Sun significantly off centre in the disc.

Papers

Moving on to 1906, *The Observatory*[5] carried a Note on a paper by Arthur Hinks originally in the *Proceedings of the Cambridge Philosophical Society*. Hinks suggested that "stars and other bodies forming the Universe are distributed in independent clouds roughly in one plane. … The more distant star-clouds would make the Milky Way proper". The Small Magellanic Cloud was then a star-cloud away from the plane while the "Greater Cloud of Magellan may perhaps be more properly considered a nebula and star-cluster cloud".

From a monumental (715 page) *Memoir*[6] on double stars, as reviewed in *The Observatory*[7], T. E. Lewis deduced that "the [binary] stars around us form a universe very much in the shape of an egg, and that we are not in the centre". The long diameter was 600 light-years and the shorter 300. Unusually, the writer of the review was William Hussey of Detroit Observatory.

A review[8] of a contribution from a less-standard source, a lecture by Kapteyn presented to the British Association in Cape Town, discussed Kapteyn's latest work on proper motions which had led him to propose that most stars belonged to one of two 'star-streams' moving in opposite directions along a diameter of the Milky Way. The reviewer (Hinks) noted "the revolutionary character of this discovery". Arthur Eddington (then Chief Assistant at the Royal Observatory) made similar calculations — and came to the same conclusion[9] — based on Dyson and Thackeray's proper motions measured at Greenwich, also finding a tendency for stars of the same type to be in the same 'drift', but no evidence for them being at different distances[10]. Dyson and Thackeray's work was also reviewed in *The Observatory*[11] by Lewis Boss of the Dudley Observatory in New York, who produced his own catalogue of proper motions, which was in turn used by Eddington[12] in his study of the two drifts.

Eddington presented a similar paper in *Nature*[13], to which Alfred Russell Wallace, the famous naturalist, responded[14], proposing that if the stars were in orbits around some centre, the two streams were merely the consequence of "differential angular motions", in a similar way to the sometimes apparently retrograde motion of planets as seen from the Earth.

Another interesting contribution[15] in *Nature* was by E. H. L. Schwarz who, after suggesting that the 'double drift' was due to orbiting stars on the near side or far side of the Galaxy centre, speculated that the diffuse nature of the Galaxy (with no obvious core) was due to an interaction with the Andromeda Nebula, which he thought to be both external to and more massive than the Galaxy.

By counting stars in representative areas on Isaac Roberts' deepest photographs, J. E. Gore[16] estimated that over the sky the total number of visible stars (down to 17 mag.) should be around 64 million. More intriguing historically, though, was Winifred Gibson's 'Some Considerations regarding the Number of Stars', which is probably the first paper to attempt to apply a modern statistical approach to the stellar system[17]. She used Karl Pearson's new concept of 'correlation', finding no linear correlation between apparent magnitude and parallax and only weak correlation between proper motion and parallax. This suggested that "the system to which the lucid stars belong may possibly be a limited system of a definite and not random structure". (Pearson himself had nine papers in *MN*.)

An entirely different way of demonstrating the local arrangement of stars was presented to the RAS by Mr. T. E. Heath, who created stereographic images of star fields with which the user obtained a pseudo-3D view of the stars with known parallaxes. According to *The Observatory*'s review[18], the "result is most successful. Putting chart number 12 into a stereoscope, one sees Sirius and Procyon apparently hanging in space well in front of all the other stars". A few years[19] later he made a model showing the velocity vectors of stars, even colouring them by stellar type.

W. S. Franks, in a study of the colours and spectral types of stars[20], reiterated earlier results, noting "a curious affinity between Helium stars [B type] and bright line spectra [O type], with the Galaxy … and this becomes still more remarkable when we remember that all the "Wolf-Rayet" stars… all the temporary stars and the majority of short period variables are also in this region". He concluded that the "Galaxy seems to be the plane of origin of some of the most striking phenomena in the stellar universe … [which] must be the result of some grand physical law, at present undiscovered". (Recall that some authors used the term 'Galaxy' to mean the bright ring of the Milky Way, not the whole system of stars.)

Max Wolf[21] reported on photographs of a nebula in the Milky Way (NGC 7023) which he found to be an excellent example of a phenomenon he had observed before, that such nebulae were "encircled by a ring void of faint stars, and that this lacuna is the end of a long starless hole, apparently showing the direction of some unknown cosmic motion". (This work was described in detail when he won the RAS Gold Medal in 1914[22].)

Kapteyn presented his own work at the RAS in 1908 January[23], describing efforts to determine "the number of stars per square degree at any particular galactic latitude", but with no further interpretation. (In what follows we generally pass over papers presenting data on number counts or mean parallaxes as functions of apparent magnitude or Galactic latitude unless there is some significant interpretation in terms of Galactic structure.)

An 'Abstract of a discourse delivered at the Royal Institution' by Kapteyn also appeared in *The Observatory*[24] (produced by S. A. Saunder). Kapteyn had used his proper-motion studies to estimate the local star density as a function of intrinsic luminosity for stars between 0·01 and 100 000 solar luminosities. He suggested that the density was constant ("2000 stars … in a cubic light-century") out to 200 light-years from the Sun but decreased after that. From the "numbers of stars of different magnitudes down to the fourteenth", he deduced that "density-zero, or the limits of the universe" was reached at 30 000 light-years (about 9 kpc) from the Sun. (A longer version appeared in *Nature*[25].)

In addition to points already covered, Eddington's Report to the Council[26] on the 'Stellar Distribution' noted that Karl Schwarzschild in Göttingen had proposed a law of the distribution of velocities of stars which generalized the Maxwellian distribution to an anisotropic system with greater velocities along one axis, *i.e.*, a velocity ellipsoid. Eddington further noted[27] that this might come about through the gravitational contraction of an elongated initial distribution. The major axis would correspond to the direction of the two flows in the Kapteyn model.

H. H. Turner[28] demonstrated that interstellar scattering due to small particles (following Rayleigh's law) could account for the slope of stellar number counts not taking the canonical value 0·6 and being different for visual and photographic magnitudes. This would obviously also affect attempts to determine the density of stars as a function of distance.

In 1909 "Messrs. Hough and Halm" used radial velocities instead of proper motions to support the two-drifts hypothesis[29], with "the relative motion of the two streams … in the plane of the Galaxy, and directed towards its densest part". Eddington — despite them agreeing with his model — nevertheless disagreed[30] with some of their analysis. The following year Hough and Halm extended their analysis[31] to show that while the stars in one stream were consistent with a uniform distribution across the sky, "a chaotic assemblage of stars endowed with no other than chance motions, … in which our Sun is moving with uniform speed", those in the second stream were not, with the Sun evidently shifted off-centre of this drift in the direction towards the North Galactic Pole, the drift itself showing "strong evidence of a structural design", which they identified with 'the Galaxy'. Eddington was more positive about this later work[32], though he was unconvinced about the correspondence of drift 2 with the Milky Way.

Eddington[33] again reviewed associated work from the previous year, particularly Kapteyn's attempt to measure the reddening of more distant stars, from which he had estimated absorption of around 0·5 visual magnitudes per kpc. Pickering had suggested a different slope for the number counts of stars of different spectral types, which, he thought, would not be explained by extinction.

Continuing with 1910, G. J. Burns reviewed[34] his own and other attempts to measure the brightness of the night sky and the total amount of starlight, another proposed means of determining the extent of the Galaxy or Universe. The results suggested a total light equivalent to 1500 to 2000 1st-mag. stars and a surface brightness equivalent to 1–2 5th-mag. stars per square degree at the Galactic Pole. (At the end of the paper, he notes that his observations had been terminated in an unprecedented manner when a burglar made off with his specially built instrument, though "it hardly seems likely that a burglar … would make observations on the amount of "earthlight" in order to select a suitable night for the exercise of his profession".)

From a Note[35] on Barnard's description of his latest photographs of nebulae, it is evident that he now assigned dark areas to absorption, though he still found it "hard to believe in the existence of such [opaque] matter on such a tremendous scale".

In an intriguing battle of mathematical heavyweights, Arthur Eddington (not yet an FRS himself) reviewed[36] a paper by Karl Pearson in the *Proceedings of the Royal Society*, concerning the statistics of observed parallaxes and magnitudes as they related to the distribution of stars in space. For the magnitudes, at least, Eddington's withering assessment was that Pearson's "highly mathematical treatment adds nothing to our knowledge, and only serves to obscure what is a very simple and well known result" (*viz*., that star numbers did not increase with magnitude as they would for a uniform distribution in the absence of absorption).

Hinks[37] (who had also argued with Pearson) returned to the distribution of nebulae and clusters, reiterating that both planetary nebulae and other gaseous nebulae were concentrated in the Milky Way, as were loose star clusters. He then showed that globular clusters were "contained very nearly in one hemisphere of the sky, whose pole is on the galactic plane in galactic longitude about 300°", thus prefiguring Shapley's famous diagram. (The zero of Galactic longitude was then where the Milky Way intersects the equator, not the — then uncertain, of course — direction to the Galactic Centre.)

In 1911[38], Halm proposed a third drift delineated by 'Orion type' or 'helium' (O and B) stars. He also showed that 'average peculiar speed' increased from

B stars towards later types (this result had also been found by Boss and others[39]), consistent with ideas of equipartition of energy. (At the time, one theory was that later-type stars had cooled down further because they had lower masses.) As usual this was discussed by Eddington at the RAS[40].

Indeed, a summary of the whole question of the structure of the Galaxy, as it was understood in 1911 — at least, by Eddington — was provided in his address to the British Association, reproduced in *The Observatory*[41]. "It is believed that the great mass of the stars (excluding the Milky Way) are arranged in the form of a lens or bun-shaped system, our Sun occupying a nearly central position. Near the Sun, the stars are distributed in a fairly uniform manner, but in the remoter parts of the lens, or perhaps right beyond it, are coiled the great star-clouds which form the Milky Way". (It is intriguing how far the simple, and more or less correct, 18th-Century models of Thomas Wright or William Herschel had gone out of fashion.) Eddington also summarized the work on the two or three drifts. As to the origin of the increasing velocities of later-type (presumed older) stars, he deduced that it must be due to "the central attraction of the universe as a whole, and not the attraction of the immediate neighbours". Surprisingly, he seems not to have considered the possibility that the stellar system could be rotating. ("We might have expected … there would be more definite traces of a centre of gravity, and the velocities would be generally radial".) He did, though, discuss the revived notion that the Galaxy could be a spiral nebula, and that the other spirals "lie beyond the great mass of the stars".

With regards to the supposed third drift, Turner[42], in his 'From an Oxford Note-book', included a quote from W. W. Campbell at Lick, that "an error, of obscure source" was present in the B-star radial velocities, such that, in Turner's words, "the recognition of it is apparently fatal to the fascinating story of great stellar systems of B stars". On the other hand, H. C. Plummer[43] analysed, and confirmed, Campbell's suggestion that A stars had their velocities parallel to the plane of the Galaxy (as the radial velocities were lower in those seen at higher latitude). He later[44] repeated this for B stars. Again, no mention of rotation arises. There was also a Council Report to the RAS[45] covering these topics by H. F. Newall, who noted that Campbell found early-B types were on average 540 pc away but later-B types only 240 pc, while the preference for velocities in the plane was much less for F to K types and least for M stars.

Eddington[46] next produced a mathematical framework to determine simultaneously the distributions of linear motions, angular (proper) motions, and distances of the stars in a catalogue. He concluded that the two- (or three-) stream hypothesis was a better representation than Schwarzschild's ellipsoidal velocity distribution (as did Kapteyn and his assistant Weersma[47], when they presented their method).

Turner[48], though, worried about the apparent inconsistency of thinking of a single stellar system but two intermingled streams. If the system was even roughly a homogeneous sphere stars would be attracted towards the centre. He considered primarily stars falling along near-radial orbits, so that half were approaching the centre and half moving back out, creating the appearance of two streams. (He later[49] noted that stars moving slowly near apocentre could look like a third stream.) He did consider circular motions (for a uniform-density sphere rotation would be like a solid body), either all in the same direction or the "far more likely" case of stars moving in both directions, but largely he preferred near-radial orbits. These might also explain the variation of speed with type, as different-type stars could have originated at different distances from the centre of the primordial nebula and therefore reached different velocities when passing the centre (fairly near the Sun). In addition, Turner tried Plummer's law for the distribution of stars in a globular cluster as a model for the density distribution in the Galaxy but found that the slope of the number counts diminished too quickly with magnitude unless the position of the Sun relative to the centre was carefully adjusted. In passing, he introduced the ideas of dissipation of energy when material in the primordial nebula collapsed towards the centre and reached high density, perhaps leading to star formation, and of anisotropic collapse to a flattened shape. At the RAS, Rev. T. E. R. Phillips[50] queried how Turner's model fitted with the fact that "it is generally held that the Galaxy is not a mere perspective effect, but consists of a ring of clouds at more or less the same distance from us".

Turner[51] next attempted to determine the direction to the centre. Given that the two flows appeared to converge on positions at 6h and 18h RA, he had initially felt that the latter was the direction of the centre, but now (unfortunately) convinced himself that it was nearer the former, in the direction towards Taurus. In his model, intrinsically faint stars were constrained to a sphere near the centre of the system, with the Sun outside it. In response to a talk at the RAS by Plummer[52], the president, Dyson, noted that there now seemed to be three hypotheses, motions parallel to a plane, parallel to a line, or converging to a point.

Reverting to earlier methods, a rather strange paper read by (the equally strange[53]) T. J. J. See to the American Philosophical Society, and partly copied in *The Observatory*[54], used William Herschel's method of comparing the 'space-penetrating power' of telescopes to show that α Centauri should be visible with the 60-inch at Mount Wilson at a distance around 3 kpc. If the most luminous stars were 10 000 times brighter than 'solar stars', then they should be visible at 300 kpc. See also noted that Helium stars would be magnitude 21·1 (about the limit of photographic plates according to Pickering) at about 400 kpc. The reason for assuming that such distant stars really existed was stated to be "the well-known whiteness of the small stars of the Milky Way". By some further geometrical analysis he decided that the thickness of the Milky Way was twenty times the diameter of the ring of Campbell's Helium stars, or around 7 kpc.

Monck suggested[55] that in regions where stars were more thinly spread, mutual gravitational effects would lead to smaller peculiar velocities than where stars were more tightly packed, thus providing a test for a universe with diminishing density with distance from the Sun. The 1913 March RAS meeting[56] then saw both Dyson[57] and Eddington[58] report on their latest efforts to determine the radial distribution of stars based on the distribution of proper motions and an assumed normal distribution of space velocities.

Two interesting notes appeared in *The Observatory*[59]. The first was a review of a paper by Espin in *JRASC* on 'Dark Structures in the Milky Way' which "puts forward with much force the suggestion that there are masses of absorbing matter in space, which give rise to the appearance of dark spaces in the Milky Way" and that "the whole length of the great bifurcation is due to a vast absorption ring". The second was a summary of lectures given by Robert Thorburn Ayton Innes, director of the Union Observatory in Johannesburg, "though his conclusions are in many cases strikingly different from those commonly met with". Innes suggested that "the stellar system, of which the Sun is a member and the Milky Way the girdle, is distinctly limited, and that our telescopes penetrate far into space beyond its boundaries", but without revealing any external objects "such as the spiral nebulae have been suggested to be". He estimated the mass of the Universe to be 441 000 solar masses.

A review[60] of 'Some problems in Astronomy' included a discussion by F. J. M. Stratton of recent papers concerning 'Fixed Calcium Lines', *i.e.*, lines in stellar spectra that appeared not to be associated with the stars themselves. Stratton was inclined to agree with the proposal that they originated in interstellar clouds, since recognized as the first evidence for the interstellar medium.

The ubiquitous Eddington[61] (now Plumian Professor in Cambridge) next considered the dynamics of globular clusters under the assumption that effects between individual neighbours could be neglected and replaced by a smoothed-out density distribution. He estimated the local density to be 10 solar masses in a sphere of radius 5 pc and noted that if "the universe were a globular system of this density, each star would describe an elliptic orbit about the centre of the system in 300,000,000 years", independent of the size of the orbit. He then explored the possible radial and velocity distributions which would permit a steady state of the stellar system.

James Jeans, Eddington's frequent adversary, countered[62] with a study 'On the "Kinetic Theory" of Star-Clusters', considering the opposite extreme of binary interactions only. Assuming the important quantity to be the relative velocity of pairs of stars (taken to be 60 km/sec), he determined that the cumulative deflection of a star's path would only reach 1° after 3200 million years and that a single encounter giving rise to a deviation of 5° would happen only once in 5×10^{12} years. He therefore deduced that "there can be no question of a universe like ours coming to a final steady state such as we are familiar with in the theory of gases", with the relaxation time being of order 10^{14} years.

Plummer[63] returned to the distribution of B stars, finding additional evidence for them lying in, and moving parallel to, the plane of the Milky Way (and with a reasonably uniform density, rather than being in a ring). He favoured later-type stars (of lower luminosity) being in a more spherical distribution with random velocity vectors. After extending the analysis[64], though, he "found it difficult to retain the idea of distinct streams".

Eddington[65], while agreeing that earlier-type stars were steadily more concentrated towards the Galactic plane, consistent with them being more distant and more luminous, rejected this conclusion on the grounds that their 'mean parallactic motion' (motions towards the solar apex) and 'mean cross proper motion' (at right angles to the former) implied that F stars were the nearest and M stars more distant than A stars. He therefore deduced that A stars were genuinely concentrated in the plane while M stars were in a larger spherical distribution (because they were older and had developed larger random velocities). He squared this with the known low luminosities of nearby M stars by noting that Hertzsprung and Russell (the latter in a presentation[66] to the June RAS meeting) had recently suggested dividing M stars into 'dwarfs' and 'giants', so it was the latter which were very distant.

'Mr Jones', the future Astronomer Royal Sir Harold Spencer Jones, similarly found the largest proper motions to be for A5 to F9 stars (which also showed most evidence for streaming), with F and G stars the closest on average[67]. Radial velocities increased steadily for later types. In a separate contribution[68] he reviewed studies of interstellar extinction and reddening but was forced to conclude that the loss of light per unit distance was still largely indeterminate, though "undoubtably very small" (he suggested about 0·5 magnitudes per kpc). Notwithstanding the uncertainty, L. V. King took this a step further[69] and used Rayleigh's theory of scattering to deduce the required density of interstellar gas, assuming it to be composed of molecular hydrogen at standard temperature and pressure. He estimated a value around 10^5 molecules per cubic centimetre or 6300 solar masses per cubic parsec, exceeding the then estimated density in stars by a factor of 10^5.

Eddington produced his usual Report to the Council in 1914[70], noting in addition to the work above, Easton's latest "hypothetical representation of the Galaxy as a spiral" in *ApJ*. Eddington considered it "very instructive, showing how the spiral theory works out in detail". Eddington also reviewed[71] Campbell's book *Stellar Motions* which presented the latest work on radial velocities as a function of spectral type and apparent magnitude and on stars of very high velocity, amongst other topics. Eddington's own book *Stellar Movements and the Structure of the Universe* was reviewed by Dyson[72] and Plummer[73]. At the RAS, Dyson concurred that proper motions implied that M stars were distant and therefore of the giant variety. His star counts and derived parallaxes[74] gave a decline in number density of F and G stars by a factor 10 between 90 and 740 pc from the Sun.

Sydney Chapman and Royal Observatory colleague P. J. Melotte produced an extensive *Memoir*[75] on star counts down to magnitude 17 as a function of Galactic latitude, which Chapman summarized in 'On the Total Light of the Stars' in *MN*[76]. They found the same concentration towards the Galactic plane at all magnitudes. Further, from their (Gaussian) fit to the counts they estimated that they would need to reach a magnitude around 23 or 24 to see half of the inferred total of around 10^9 stars, while half the total light should be contributed by stars brighter than magnitude 10. The total light was estimated to be equivalent to 631 1st-mag. stars (which equated to "an ordinary 16 candle-power lamp at 47 yards distance"). Chapman later reviewed[77] corresponding work by van Rhijn in Groningen and Seares at Mount Wilson, who found instead greater concentration of faint stars in the Milky Way. He agreed with van Rhijn[78] that there had been an error in the Chapman and Melotte reduction (such that the extrapolated total number of stars increased to 3×10^9, half of them fainter than magnitude 25·5). R. J. Pocock[79] also supported the earlier southern-hemisphere result of Kapteyn, finding greater concentration for the fainter stars in the Perth Catalogue.

O. R. Walkey supplied two papers to *MN* in 1914[80], the first on defining the locus of the Galactic plane and the second on 'The Sun's Place within the Star-sphere' which used star counts as a function of Galactic latitude and longitude to find the height of the Sun above the plane (around 40 pc, though not explicitly stated) and distance from the centre (130 pc) of an oblate stellar distribution.

In 1915, Eddington updated his dynamical modelling[81] to show that there existed a density law such that a (spherical) stellar system in equilibrium could possess Schwarzschild's ellipsoidal distribution of velocities (and look like Turner's two or three streams), though the differential equation involved was insoluble. In an illustrative case with the central density seven times higher than near the Sun, the Sun's distance from the centre would be 500 pc and a star falling from near the Sun to the centre would gain a velocity of 36 km/sec. A further paper[82] extended the theory to oblate distributions of stars, the case where the potential was not necessarily just due to the stars themselves, and the addition of rotation.

With colleague W. E. Hartley, Eddington[83] considered tests of the model using radial velocities, finding that the prolateness of the velocity ellipsoid decreased for later-type stars, and the long axis (vertex) agreed with that found from proper motions. He also summarized (at the British Association[84]) the evidence, originally from Kapteyn and Adams (Mt. Wilson), for large-proper-motion stars (presumed nearby, low luminosity) having larger velocities than those of the same spectral type with small proper motion (assumed to be distant, high-luminosity stars), as he and Hartley also found. This allowed three possibilities; (*i*) average velocity decreased with distance from the Sun, (*ii*) velocities decreased with luminosity, (*iii*) there was a correlation between the line-of-sight and transverse components of the velocity. Kapteyn and Adams had suggested (*iii*), though it went against the theoretical preference for a Maxwellian distribution of velocities, but by including other evidence Eddington concluded that (*ii*) was the most likely.

Finally for 1915, Jeans[85] responded to the recent papers by Eddington and Turner with an extensive exercise in statistical mechanics which led him to the rather decisive conclusion, that "star-streaming is evidence that our universe has not yet reached a steady state. It is not, therefore, possible to derive any evidence as to the structure of the universe by combining our knowledge of star-streaming with the assumption that the universe is in a steady state". He did note a "special case", *viz*., "a universe which is rotating as a whole", in which case "the star-streaming must occur in circles round the axis of symmetry of the universe", but dismissed this as "the observed star-streaming is not of the form required". At the RAS, Eddington[86] added that the next question was then "how far it must be from a steady state: with a distribution of mass as found, can we get a Universe in an approximately steady state?".

Harlow Shapley's work made its first relevant appearances in the pages of UK journals in 1916 when Turner[87] reviewed his paper which found negligible reddening towards the stars of M13, Turner noting that this would solve the problem of the huge mass of interstellar matter found by King (above) based on other estimates. (This was not, in fact, the problem with King's calculation, his adopted value of 1·9 magnitudes per kpc not being unreasonable.)

The Observatory[88] reported the claim by Leopold Courvoisier (the chief observer at Babelsberg) in *AN* that stars at the 'front' of the Ursa Major cluster were heading in a slightly different direction to those at the 'back', inferring that they were in orbit around a point 930 pc away towards Cygnus, with a period of 180 million years.

Jeans and Eddington continued to trade papers in 1916. Jeans[89] considered the case where stars were initially in clusters, which then gradually disintegrated *via* interactions, the remnants of clusters appearing as star streams (anticipating, in some ways, the modern picture of the incorporation of satellite galaxies into the Milky Way). Under certain assumptions, he could also generate the law for star numbers and a velocity ellipsoid as observed, though the implication was that our "sub-universe" must have interacted with others. Unsurprisingly the paper generated considerable interest at the RAS[90].

Eddington[91], meanwhile, presented what appears to have been the second — and first generally useful — statement of the virial theorem in astronomy. (Poincaré had presented it earlier but in a not-easily-accessible 1911 monograph.) Eddington applied it to the case of the dissolution of a moving cluster, determining that even a small cluster should be stable for several hundred million years[92].

An idiosyncratic take on the size of the stellar system was supplied by C. V. L. Charlier[93]. By assuming that each sub-type of B stars had a well-defined absolute luminosity (estimated from their proper motions and radial velocities), he determined that 'The Galaxy of the B-stars' declined in density from the centre to zero after "some 150 to 200 siriometers". The siriometer was his own personal unit, a million AU or nearly 5 pc. The centre was supposedly 18·2 siriometers (88 pc) away in the direction of Carina. (In a later presentation to the RAS[94], he did correctly identify the minimum stellar density in the Milky Way towards Auriga, and the maximum in the opposite direction, Aquila/Sagittarius, as indicating the direction to the Galactic centre.)

Charlier was a supporter of the kinetic theory of stellar distributions, but nevertheless disputed[95] Jeans' conclusion (above) concerning the lack of a steady state. Charlier also considered that Turner's Ursa Major stream, for example, could be the remnant of a formerly large compact cluster. In the light of additional observations, in a subsequent paper[96] Jeans accepted some of Charlier's criticisms, suggesting that the Galaxy could have started as a rotating nebula and progressed through a spiral form, "the history of such a system of stars [consisting] of a gradual transition, or more precisely an asymptotic approach, to a state of steady motion of a system of independently moving stars".

Surprisingly, given the endpoint of his study just three years later, Shapley's first contribution in a British journal[97], a criticism of work on star distributions in globular clusters, ended with the statement that "one is naturally led to the hypothesis that the globular clusters are distinct systems, separate from and virtually independent of the galactic system, and some of them, perhaps, not greatly inferior to it in size". (He was at this point using other people's, rather small, estimates of the size of the Galaxy.)

Perrine noted[98] that the apparent centre of the distribution of globular clusters was in the same direction as the "very bright and suggestive region of the Milky Way in Sagittarius and Ophiuchus". He inferred that the clusters were "closely related to the galaxy" and were at "the same order of distance as the more remote portions" of it, though he did not explicitly suggest that they shared the same centre as the Galaxy. In letters to Eddington, summarized in *The Observatory*, Hertzsprung[99] had previously come to the same conclusion as Shapley on the size of globular clusters, but had now changed his mind[100], a measurement of the total light (as opposed to individual stars) implying much smaller and subordinate globular clusters as in Perrine's model.

On the other hand, further work on proper-motion distributions still led Dyson and Thackeray[101] to deduce a small Sun-centred Galaxy; in "the region nearest to us the density is a maximum, and diminishes as we proceed outwards, but much more rapidly in the direction of the galactic pole".

An important point was reached in 1917 November when *The Observatory*[102] carried a review by Eddington of Shapley's "remarkable series of papers", 'Studies of Magnitudes in Star Clusters, I.–VII.'. He discussed first the (lack of) extinction towards globular clusters, then their distances of order 10 kpc as found from the Cepheid period–luminosity relation or brightest-star magnitudes (Shapley gives 6·5 to 67 kpc, with the Sun 13 kpc from the centre of the distribution), and their dimensions and shapes. *The Observatory* had earlier reported on a BAA meeting[103] at which Maunder gave a shorter summary and the work (along with other papers noted above) was included in Eddington's next Council Note[104] on 'Stellar Distribution and Motions'.

This was updated in *Nature* in 1918 May, with a review by Crommelin[105] of Shapley's latest work, in *PASP*, on the distances. Crommelin reported that Shapley had distances for 69 globulars which formed a system with a longest diameter of 300 000 light years (around 90 kpc) and centred 65 000 light years (20 kpc) from the Sun.

A Note[106] in *The Observatory* reviewed work in *ApJ* by Gustaf Strömberg (Mt. Wilson) which suggested that stars at different distances were streaming in slightly different directions, consistent with orbital motion, though the reviewer

— probably Eddington or Spencer Jones, two of the editors — was perplexed by the lower radial velocities for stars nearer the supposed centre (in Carina, a long way from the actual centre).

Meanwhile, there were three 'home-grown' papers of relevance in 1918. Eddington[107] summarized the recent work concerning 'The Dynamical Problems of the Stellar System', specifically the equilibrium of oblate systems with star-streaming. He was sceptical that a suitable state could exist and therefore preferred a model which was still collapsing.

(In a wonderfully self-deprecating review of a booklet by T. E. Heath (see earlier) on 'The Distances, Absolute Magnitudes and Spectra of 734 stars', Eddington[108] had commented that "The general fate of these data is to fall into the hands of some mathematical astronomer, apparently actuated by an irresistible impulse to add things up and take the mean; then comes a sudden jump to mathematical formulae; integrals gather in formidable array, and the error-function makes its inevitable appearance; and so the riddle of the universe is slowly disentangled — or knots itself tighter — to the great satisfaction of those who have any notion what it is all about.")

Plummer[109] returned to star counts across the sky but analysed the density *via* spherical harmonics. He found that the second-order harmonics aligned with the Milky Way axis and with the direction of "greatest mobility" (*i.e.*, star streaming), which he interpreted as the system not being in equilibrium, with "a process of diffusion … tending to bring about a condition of greater uniformity in the galactic distribution". (He also calculated the light from all stars down to magnitude 16 but considered any attempt to extrapolate beyond this was impractical.)

On the other hand, at the end of a paper on orbits of binary stars, Jeans[110] concluded that the only hypothesis which could reconcile the facts of observational astronomy with dynamical theory was that "the present epoch in the history of our universe was preceded by one in which the stars were much more closely packed than they now are", so that more close interactions would have taken place. He supported this by noting that what we now call the Jeans mass would only be similar to the mass of typical stars if the density of the primordial nebula was much higher than the averaged-out density of the present Galaxy. (At the RAS[111], F. A. Lindemann noted that the present density could be suitably higher if there were numerous dark stars.) The dynamics of B stars and short-period binaries (usually early types) suggested to Jeans that these "were perhaps the last stars to be born out of the rotating nebula which we may suppose to have been the parent of our system of stars".

Eddington's 1919 review[112] of 'Stellar Distribution and Motions' included a paragraph on Shapley's determination of the distances of individual Cepheids which ranged up to 4000 parsecs or more on all sides of the Sun "so that they indicate a galactic system of far greater extent than any hitherto discussed". Despite this, Eddington in the following note[113] on 'The Distribution of Globular Clusters' reverted to assuming a local stellar system of diameter "not much more than 1 kiloparsec" which must "lie almost on the circumference of the greater system" outlined by Shapley's globular clusters. Shapley himself discussed the lack of globulars in the "equatorial region" of the Galaxy[114].

Returning to a topic mentioned earlier, John Evershed[115] noted the existence of calcium lines in the spectrum of Nova Aquilae (1918) which had zero radial velocity once the solar motion was accounted for, thus suggesting clouds at rest in the overall stellar system.

Anton Pannekoek[116] disputed Plummer's description of the distribution of stars (above), because of suggested inhomogeneity of the data, and gave a detailed description of the irregular stellar distribution which differed spatially from that of the brightness of the Milky Way. Allowing for the latitude dependence of the counts, he concluded that the dependence on longitude was due to two areas of deficiency, perhaps caused by extinction. Henri Nort[117], whose values Plummer had used, responded and pointed out that Pannekoek's result could also be interpreted *via* an elliptical, rather than circular distribution in the plane, *i.e.*, a tri-axial ellipsoid, as Nort had suggested.

Pannekoek[118] also disagreed with the view of a continuously declining stellar density with distance, returning instead to the model of the Milky Way as a ring of star clouds around the local stellar system. From changes in slope of the number counts towards bright star fields at around 12th magnitude, he deduced that the Milky Way clouds were in the distance range 40 to 60 kpc with a significantly off-centre position for the Sun.

Pannekoek and others generally used Kapteyn's 'luminosity law' (*i.e.*, what is now the stellar luminosity function), a gaussian with a fixed mean value. Halm[119], though, noted that in the general case both the density and the mean absolute magnitude could vary with distance (and direction). Considering the extreme cases of fixed luminosity law or fixed density, from a lengthy general exploration of the theory of star numbers and mean parallaxes as a function of magnitude, Halm concluded in favour of the latter, that is, the density of stars did not change with distance, but rather the variations were due to the luminosity law. (The following year, from a study of binary stars, Jackson and Furner[120] reached the modern conclusion that star numbers, in fact, increased continuously towards fainter absolute magnitudes.)

While Shapley presented the summary of the Mount Wilson work on the structure of the Galaxy in 1919 — a modern-looking disc of much greater extent than the 'local system' around the Sun, perhaps of radius 30 kpc or more with the Sun half-way to the edge, and the surrounding globular-cluster system with diameter of order 100 kpc — this was not actually a particularly defining moment. Indeed, the published version[121] of the 'Great Debate' of 1920 on 'The Distance Scale of the Universe', generally portrayed as concerning the existence of 'island universes', actually largely revolves, especially from Shapley's side, around Shapley's ten-times-greater size for the Galaxy than that still used by Curtis. As for the UK, with Eddington and Jeans now busy with relativity and the internal constitution of stars, there was no mention of Shapley's most recent work at all in 1920, and in fact there was only one paper linked to Galactic structure, Halm's[122] on his third-drift idea. Indeed, the first mention of Shapley's cumulative work came in a short historical piece by Hector MacPherson[123] in 1921, comparing Shapley's ideas with William Herschel's.

The Authors and Reviewers

Note that biographical notes are not included for contributors already included in recent articles[1,2,124].

Thomas Lewis had been an assistant at Greenwich since 1881. As well as observing binary stars he was in charge of the observatory chronometers as Superintendent of the Time Department. He was secretary of the RAS from 1905 to 1909.

Trained as an engineer, William Joseph Hussey was on the faculty at Stanford from 1892 and was Astronomer at Lick from 1896 to 1905 when he moved to Detroit. Like Lewis he spent many years observing a large sample of binary stars.

Lewis Boss was the long-serving director of the Dudley Observatory in New York who produced a notable catalogue of proper motions. He won the RAS Gold Medal for his work on the convergent point of the Hyades. His son Benjamin followed him as director of Dudley Observatory, working on similar topics to his father.

Charles Darwin's original correspondent on the theory of natural selection, Alfred Russell Wallace, had combined his interest in astronomy with his expertise in evolutionary biology in a 1904 book, *Man's Place in the Universe* (written when he was 82), which considered the possibility of life on other planets from a biological viewpoint.

Ernest H. L. Schwarz was a geology professor at Rhodes University in Grahamstown, Cape of Good Hope, and formerly a member of the Geological Survey of Cape Colony. He was particularly interested in the 'planetesimal theory' of the formation of the Earth.

Winifred Gibson was one of Pearson's graduate students at University College, London, and was later a university lecturer. She wrote several further papers related to star counts up to 1915.

Thomas Edward Heath ran the Star Patent Fuel Co. in Cardiff with his brothers and made a number of mechanical inventions allied to his business, also turning these skills to astronomy, for instance, building 'An Equatorial Driven by a Hydraulic Ram'.

Samuel Arthur Saunder was an RAS secretary, also a president of the BAA, and a leading lunar observer. A Wrangler when at Trinity (where he was a successful oarsman), by profession he was senior mathematics master at Wellington College.

Sydney Samuel Hough FRS, 3rd Wrangler and Fellow of St. John's, was appointed Chief Assistant at the Cape in 1898. He followed Gill as HM Astronomer in 1907 and completed two catalogues of fundamental stars and five volumes of the *Cape Astrographic Catalogue* before his early demise in 1923.

Jacob Karl Ernst Halm had a varied career, starting at Strasbourg Observatory in 1889. Six years later he was appointed first-class assistant at the new Royal Observatory, Edinburgh, and then went to the Cape as chief assistant when Hough was promoted, being mainly responsible for the spectroscopic work, though following the Great War he had problems as a German national. He is credited with being the first to suggest a mass–luminosity relation for stars.

Gavin James Burns had a degree from the University of London and worked as a civil servant in the buildings department of the War Office. He contributed papers to the *JBAA* on the distribution of stars and was one of the first to discuss airglow (then called 'Earthlight').

Henry Crozier Keating Plummer FRS had been an assistant at Oxford under Turner, but after a year at Lick in 1912 he became professor of astronomy at Trinity College, Dublin, and Royal Astronomer of Ireland. In 1921 he relinquished this to take a position as professor of mathematics at the Military College of Science at Woolwich. He is probably mainly remembered these days for the Plummer potential for globular clusters. He wrote several books, including the important *Dynamical Astronomy* in 1918. His father William Edward Plummer worked at the Oxford and Liverpool observatories for many years, being director of the latter.

Hugh Frank Newall was also the son of another astronomer, Robert Stirling Newall FRS, and was responsible for running his father's telescope after it was moved to Cambridge in 1890. (He had previously been an experimental physicist.) He was on the RAS council for 43 consecutive years from 1892 (president 1907–09) and wrote the ‘Stellar Spectroscopy’ report virtually every year from 1898 to 1920. He was awarded an honorary professorship at Cambridge in 1909 and subsequently was director of the new Solar Physics Observatory, continuing one of his main research interests.

Rev. Theodore Evelyn Reece Phillips obtained his MA at Oxford in 1894 and was a curate until appointed vicar of Headley, in Surrey, in 1916. He was an outstanding planetary observer and also worked on double stars. He was director of the BAA’s Jupiter section from 1900 to 1933 and president of the RAS 1927–29.

Thomas Jefferson Jackson See obtained a doctorate in Berlin, on binary stars, before returning to the US. Falling out with Hale while at Chicago, he next worked with Lowell — when suspicion over him fabricating results first surfaced — and at the USNO. He later claimed to detect planets around other stars and his “intemperate response” to criticism eventually led to him being banned from publishing in American professional journals (though this did not prevent him making 285 contributions in various places over a 47-year career).

Frederick John Marrion Stratton was 3rd Wrangler (behind Eddington) in 1904 and joined the university observatory in 1906. He was primarily interested in solar physics and stellar spectroscopy, becoming assistant director of the Solar Physics Observatory in 1913. In the Great War he rose to the rank of Lieutenant Colonel, then becoming Senior Tutor at Caius (the posts of Astronomer Royal, Astronomer Royal for Scotland, and HM Astronomer at the Cape were all later filled by his tutees). He returned to the SPO as its director and was RAS president 1933–35.

Harold Spencer Jones followed the standard route from Cambridge Wrangler to Greenwich Assistant, replacing Eddington when the latter returned to Cambridge in 1913. Working on optical design for the Ministry of Munitions during the Great War, he was later primarily interested in the rotation of the Earth. He was HM Astronomer at the Cape from 1923, working on numerous stellar programmes as well as his own Solar System research. Astronomer Royal from 1933, he had responsibility for the move to Herstmonceux after World War II and the planning for what became the *Isaac Newton Telescope*. He was knighted in 1943.

Louis Vessot King, an assistant professor at McGill University in Montreal, then only in his twenties, was considered to be the “foremost mathematical physicist in Canadian history” according to his Royal Society biographical memoir. His main research was in radiative transfer and electromagnetic shielding.

Sydney Chapman read engineering in Manchester before becoming a Wrangler in 1908, and Dyson subsequently appointed him as a Chief Assistant at Greenwich where he was mainly involved with magnetic observations, which led to his later career in geophysics. He became a lecturer in mathematics back at Cambridge in 1914 before professorships in Manchester, Imperial College, and, after World War II, Oxford. Elected an FRS in 1919, he was RAS president 1941–43 (winning their Gold Medal in 1949) and president of the International Union of Geodesy and Geophysics 1951–54.

Philibert Jacques Melotte entered the Royal Observatory as a ‘supernumerary computer’ in the astrographic department in 1895 when he was 15 years old. Developing expertise in celestial photography, he made his name by the discovery of Jupiter’s seventh satellite in 1908, but did not reach the grade of Assistant until 1934, subsequently working on the solar parallax under new AR Spencer Jones.

Pieter Johannes van Rhijn studied under Kapteyn, receiving his doctorate in 1915, and succeeded Kapteyn as professor of astronomy and director of the Astronomical Laboratory in Groningen in 1921. He worked mainly on star numbers and distributions.

Robert John Pocock graduated from Oxford and went on to work at the university observatory. In 1914 he was appointed director of the Nizamiah Observatory in Hyderabad. Much of his work was concerned with proper motions and he notably advanced the work on the astrographic zones which had been assigned to the observatory. Overall he had 16 papers in *MN*. He died of pneumonia after catching influenza in the 1918 Indian epidemic.

Herman Albertus Weersma obtained his PhD in Groningen in 1908 for a thesis on the solar apex, and continued to work with Kapteyn as his assistant after de Sitter moved on. He left in 1912 to become a secondary-school teacher.

Trained as a mechanical engineer at the University of London, before joining the ministry, Rev. Oliver Rowland Walkey was elected an FRAS in 1912 while a lecturer at UCL. By chance he was a fellow passenger of Eddington's (with whom he had corresponded) on voyage for the 1919 eclipse, though he was himself heading for the Amazon as a missionary. In 1940, while in India, he published *Concise General Astronomy* with Harihara Subramania Aiyar. He rejoined the RAS in 1943 and published a third *MN* paper in 1946.

Previously at Uppsala, Carl Vilhelm Ludvig Charlier became professor and director of the observatory at Lund in 1897. He was an Associate of the RAS from 1908 and a member of national academies around Europe. Working first in celestial mechanics and then statistical astronomy, he is now best remembered for his theory of an infinite hierarchical universe.

Trained in Copenhagen, Einar Hertzsprung first worked as a chemist before obtaining a position at Göttingen Observatory under Karl Schwarzschild in 1909. He was at Leiden from 1919 to 1946, becoming director of the observatory in 1937. He is, of course, most famous for his share in the development of the Hertzsprung–Russell diagram. He was the son-in law of Kapteyn.

A former student of H. N. Russell at Princeton, Harlow Shapley is best known for his work using Cepheids to determine distances to globular clusters, and hence demonstrate the large size of the Galaxy, as well as his part in the 'Great Debate' at the National Academy of Sciences, supporting the 'Metagalaxy' against the 'island universe' theory of spiral nebulae. Shapley moved from Mount Wilson to become Director of Harvard College Observatory in 1921 and, having accepted their existence, worked on external galaxies, especially in clusters. Indeed, he was one of the first to use the general term 'galaxy'. His independent political views led to him falling foul of the House Un-American Activities Committee in 1946. Some of his work was carried out with his wife Martha Betz Shapley, who published numerous papers on eclipsing binaries.

John Evershed FRS, RAS Gold Medallist in 1918, was a keen amateur observer and instrument builder before becoming director of the Kodaikanal Observatory in India in 1911. Primarily interested in the Sun, he is best known for the 'Evershed Effect' in sunspots. After returning to England in the 1920s he established a private observatory with a notable spectroheliograph where he continued to work until he was 86. Most of his work was carried out in partnership with his wife Mary.

Anton Pannekoek had been at Leiden Observatory in the early 1890s but after writing for socialist magazines was dismissed for leading a strike committee (he was later a major figure in 'council communism') and moved to Germany.

In Holland when World War I broke out, he worked as a secondary school teacher, being unable to take a position back at Leiden because of his Marxist views. However, he was appointed to a post in Amsterdam and founded their astronomical institute in 1921. Much of his career was involved with the Milky Way but he later switched to stellar astrophysics. He won the RAS Gold Medal in 1951, when he was 78.

Isidore Henri Nort was a PhD student at Utrecht and the work referred to was from his thesis, published as *The Harvard Map of the Sky and the Milky Way*. He joined the RAS in 1922 when working as a teacher in Gouda.

Herbert Henry Furner started at the Royal Observatory as a supernumerary computer in 1889 and joined the permanent staff in 1897. Making double-star observations, he took over the work with the 28-inch telescope when Lewis retired.

Conclusion

From the above it is clear that interest in the structure of the Galaxy was high in the fifteen years up to Shapley's key papers. In total there were 137 relevant contributions in *MN*, *Memoirs*, and *The Observatory* (also including a few in *Nature*) or more than nine per year. This compares to 96 contributions, or a touch over one per year on average before this[2]. Authors and reviewers since 1906 numbered 47, 30 of them from the UK (though not necessarily working there) more than 20 of whom can be counted as professionals. This is rather different to the case of papers on extragalactic systems, of which there were only 28 in the years considered here[1] with only five UK professionals contributing — stars were considered more valid subjects for study at the major observatories.

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 22: THE B-TYPE SYSTEM MU CASSIOPEIAE

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MU Cas is a detached eclipsing binary containing two B5 V stars in an orbit of period 9·653 d and eccentricity 0·192, which has been observed in seven sectors using the *Transiting Exoplanet Survey Satellite* (*TESS*). We use these new light-curves together with published spectroscopic results to measure the physical properties of the component stars, finding masses of 4·67 ± 0·09 $M_{\odot}$ and 4·59 ± 0·08 $M_{\odot}$, and radii of 4·12 ± 0·04 $R_{\odot}$ and 3·65 ± 0·05 $R_{\odot}$. These values agree with previous results save for a change in which of the two stars is designated the primary component. The measured distance to the system, 1814 ± 37 pc, is 1·8σ shorter than the distance from the *Gaia* DR3 parallax. A detailed spectroscopic analysis of the system is needed to obtain improved temperature and radial-velocity measurements

for the component stars; a precise spectroscopic light ratio is also required for better measurement of the stellar radii. MU Cas matches the predictions of theoretical stellar-evolutionary models for a solar chemical composition and an age of 87 ± 5 Myr. No evidence for pulsations was found in the light-curves.

Introduction

The study of detached eclipsing binaries (dEBs) allows the direct and high-precision measurement of the masses and radii of stars[1,2], which can be used to confirm and improve the predictions of theoretical models of stellar evolution[3–5]. The recent plethora of space-based telescopes has revolutionized this work[6] by providing light-curves of previously unattainable quality for a large number of dEBs. In the current series of papers[7] we are using this opportunity to improve and update measurements of known dEBs to increase the number with mass and radius measurements to 2% precision and accuracy[8].

In this work we study the system MU Cassiopeiae* an EB containing two B5 V stars on an eccentric orbit with a period of 9·653 d (Table I). Our analysis relies on new high-quality space-based photometry and on spectroscopic results available in the literature. Our decision to study this object was partly motivated by the recent acquisition of extensive light-curves using the *TESS* mission, and partly by the possibility of including it in an unrelated project (in preparation).

Table I

Basic information on MU Cassiopeiae. The BV magnitudes are each the mean of 122 individual measurements[12] *distributed approximately randomly in orbital phase, and agree well with the out-of-eclipse values from Lacy*[13]*. The* JHK_s *magnitudes are from 2MASS*[14] *and were obtained at orbital phase 0·268.*

Property	*Value*	*Reference*
Right ascension (J2000)	$00^h15^m51^s\cdot56$	15
Declination (J2000)	$+60°25'53''\cdot6$	15
Gaia DR3 designation	429158427924463872	16
Gaia DR3 parallax	0·5133 ± 0·0191 mas	16
TESS Input Catalog designation	TIC 83905462	17
B magnitude	11·12 ± 0·05	12
V magnitude	10·80 ± 0·06	12
J magnitude	10·127 ± 0·022	14
H magnitude	10·083 ± 0·021	14
K_s magnitude	10·021 ± 0·016	14
Spectral type	B5 V + B5 V	10

The variability of MU Cas was discovered by Hoffmeister[9], and subsequent work has been summarized by Lacy, Claret & Sabby[10] (hereafter LCS04). LCS04 were the first to determine the orbital period of the system correctly, and also measure the properties of the component stars from extensive *V*-band light-curves and a set of radial velocities (RVs) from high-resolution spectra.

*Note that entering "mu cas" into databases such as *Simbad* returns information for the bright star μ Cas. The results for the eclipsing binary can sometimes be obtained by searching for "MU Cas" (note capitalization), but in other cases "V* MU Cas" or alternative designations such as "HIP 1263" are more reliable.

Claret *et al.*[11] measured the apsidal motion of the system, which is slow, and did not use it as it lacked sufficient precision for their analysis. Aside from this work, MU Cas has been mentioned in a multitude of catalogue papers and lists of observed times of minimum brightness which need not be itemized here.

LCS04 deduced photometric spectral types of B5 V for both components of MU Cas based on *UBV* photometry. We define star A to be the star eclipsed at the primary (deeper) eclipse, and star B to be its companion. By this definition, star A turns out to be the larger and more massive of the two, but has evolved to a cooler effective temperature ($T_{\rm eff}$).

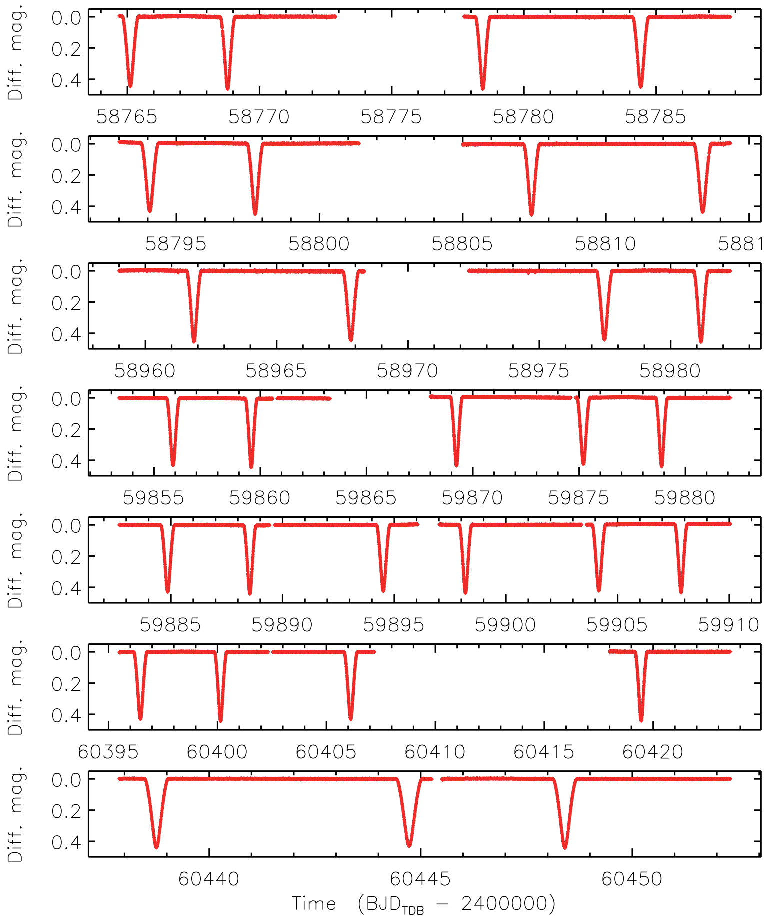

Fig. 1

TESS short-cadence SAP photometry of MU Cas from sectors 17, 18, 24, 57, 58, 77, and 78 (top to bottom panels). The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median.

Photometric observations

A profusion of photometric data exists for MU Cas, as it has been observed at 120-s cadence in sectors 17, 18, 24, 57, 58, 77, and 78 by *TESS*. We downloaded all these data from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[18] and the quality flag "hard". The simple aperture photometry (SAP) light-curves from the SPOC data-reduction[19] pipeline were used, converted into differential magnitudes and with the median magnitude subtracted for each sector.

The light-curves are shown in Fig. 1. Some gaps in coverage exist due to pauses in observation by the spacecraft, or where the quality threshold was not met, and a few instrumental jumps or trends are discernible. There is a total of 105 609 data points within these sectors. We trimmed a further set of data points where slow instrumental trends were clear, leaving behind 97 571 data points.

A query of the *Gaia* DR3 database† returns a total of 282 sources within 2 arcmin of MU Cas, as expected due to the faint limiting magnitude of *Gaia* and the proximity of our target to the Galactic plane. MU Cas is the brightest star within this sky region, the second-brightest is distant by 1·33 arcmin and fainter by 1·33 mag in the *Gaia* $G_{\rm RP}$ band, and the next-brightest is at 1·79 arcmin and fainter by 2·62 mag in the same band. As the pixel size and point-spread functions of *TESS* are large, at 21 arcsec and 84 arcsec (90% encircled energy) respectively, these nearby stars will contribute a small amount of contaminating light to the *TESS* observations of MU Cas.

Light-curve analysis

Our first approach was to isolate the data near eclipse. We extracted the data within 1·1 d of each eclipse midpoint, and renormalized them to zero differential magnitude by fitting a straight line or quadratic function to the data outside eclipse. On inspection of the results it was found that the eclipse depths change slightly between sectors — the primary eclipses vary from a depth of 0·463 mag (sector 17) to 0·440 mag (sector 58). We attribute this to varying amounts of contaminating light, as the sectors of data were obtained with different spacecraft orientations and pixel masks in the photometry pipeline. We therefore decided to model the sectors individually and combine the results afterwards.

The components of MU Cas are well-separated, so the system is suitable for analysis with the JKTEBOP‡ code[20,21] (version 43). We fitted the following parameters for each *TESS* sector: the fractional radii of the stars ($r_{\rm A}$ and $r_{\rm B}$), expressed as their sum ($r_{\rm A} + r_{\rm B}$) and ratio ($k = r_{\rm B}/r_{\rm A}$), the central-surface-brightness ratio ($\mathcal{J}$), third light (L_3), orbital inclination (i), orbital period (P), reference time of primary minimum (T_0), the orbital eccentricity (e), and the argument of periastron (ω) expressed as their Poincaré combinations ($e \cos \omega$ and $e \sin \omega$), one limb-darkening coefficient (see below), and a linear trend for the out-of-eclipse brightness for each *TESS* half-sector.

Limb darkening (LD) was included using the power-2 approximation[22–24] and the similarity of the stars allowed the use of the same LD coefficients for both stars. We fitted for the linear coefficient (c) but fixed the non-linear coefficient

*https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html

†https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=I/355/gaiadr3

‡http://www.astro.keele.ac.uk/jkt/codes/jktebop.html

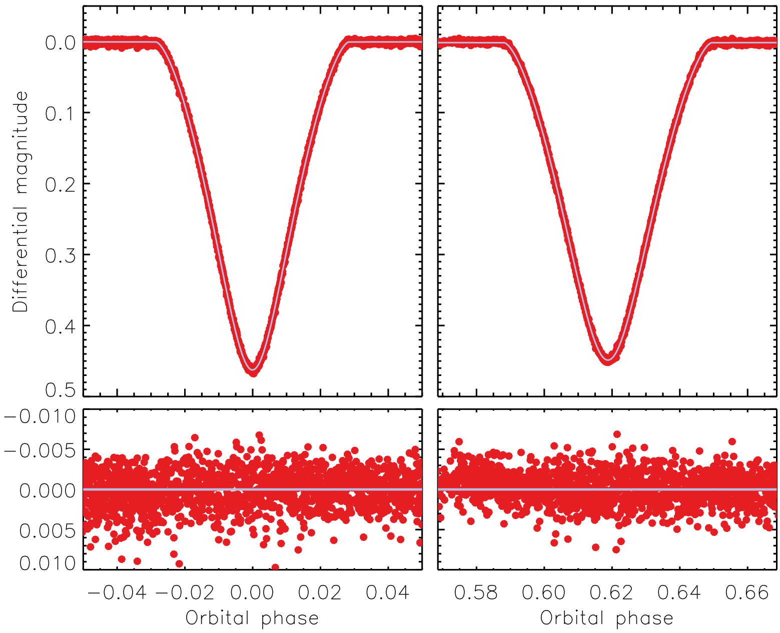

FIG. 2

JKTEBOP best fit to the 120-s cadence light-curves of MU Cas from *TESS* sector 17. The data are shown as filled red circles and the best fit as a light blue solid line. The residuals are shown on an enlarged scale in the lower panel.

(α) to a suitable theoretical value[25,26]. The strong correlation between c and α, and the inclusion of c in the list of fitted parameters, means our results are effectively independent of stellar theory.

The best fit to the data from sector 17 is good, is shown in Fig. 2, and is representative of the results for the other sectors. Once the fits to each of the sectors were established, we ran Monte Carlo and residual-permutation solutions[27] to obtain error bars for the measured parameters[28]. The immediate outcome of this process was that the results between sectors agree well with each other, but not within the uncertainties. For our final results we therefore provide the unweighted mean for each parameter, with uncertainties calculated by dividing the standard deviation of the values by the square-root of the number of sectors. These numbers are collected in Table II.

We find that some parameters are determined extremely well; these include the orbital inclination (±0°·03), the sum of the fractional radii (fractional uncertainty of 0·3%), the central-surface-brightness ratio (0·2%), and $e \cos \omega$. However, the ratio of the radii and the light ratio are relatively poorly determined and strongly correlated with other parameters. This effect is common in the analysis of the light-curves of dEBs with eclipses that are not total (*e.g.*, ref. 29) and is due to changes in the ratio of the radii having little effect on the shape of the light-curve.

TABLE II

Photometric parameters of MU Cas measured using JKTEBOP. The value for each parameter is the unweighted mean of the individual values per TESS sector, and its uncertainty is the standard deviation of the values divided by the square-root of the number of sectors.

Parameter	*Value*
Fitted parameters:	
Orbital inclination (°)	87·110 ± 0·033
Sum of the fractional radii	0·19395 ± 0·00027
Ratio of the radii	0·888 ± 0·016
Central-surface-brightness ratio	1·0178 ± 0·0008
Third light	0·0334 ± 0·0061
LD coefficient c	0·519 ± 0·027
LD coefficient α	0·3811 (fixed)
$e \cos \omega$	0·18728 ± 0·00008
$e \sin \omega$	0·04215 ± 0·00054
Derived parameters:	
Fractional radius of star A	0·10275 ± 0·00075
Fractional radius of star B	0·09119 ± 0·00099
Light ratio ℓ_B/ℓ_A	0·804 ± 0·029
Orbital eccentricity	0·19197 ± 0·00011
Argument of periastron (°)	12·68 ± 0·16

To visualize this we have constructed a set of correlation plots in Fig. 3. Panel (*a*) shows that the fractional radii of the stars are strongly anti-correlated, as expected when their sum is much better determined than their ratio. Panels (*b*) and (*c*) show that the surface-brightness ratio is well-constrained (by the relative depths of the eclipses) and thus the uncertainty in the ratio of the radii manifests as a large uncertainty in the light ratio. Panel (*d*) shows that the correlation is much weaker for the orbital inclination, and panels (*e*) and (*f*) that it has no significant effect on the Poincaré quantities.

Panel (*b*) shows that a direct measurement of the light ratio of the two stars, either from a composite spectrum or high-resolution imaging (*e.g.*, refs. 30 and 31), could solve this problem by specifying the allowed range of values of the ratio of the radii. To demonstrate this we reran the JKTEBOP fit of the sector-78 light-curve with the imposition of the spectroscopic light ratio of 0·79 ± 0·04 reported by LCS04. The uncertainties in the fractional radii were decreased by roughly a factor of 1·5 with respect to the solution without the light ratio, and application to all sectors results in a tighter clustering of parameter values.

Our results are in good agreement with the spectroscopic light ratio, but are independent of it; our tests show that a more precise light ratio than this is needed to measure the radii of the stars better.

Radial-velocity analysis

The *TESS* observations allow a more precise photometric model of the system, specifically for the orbital eccentricity and ephemeris. The eccentricity has been precisely measured above, but the ephemeris has not. We therefore fitted the light-curve containing each fully-observed eclipse (see above) with JKTEBOP to determine a precise ephemeris. We did not include published times of minimum because MU Cas experiences apsidal motion and analysis of that effect is outside the scope of the current work. The resulting ephemeris is

$$\text{Min I} = \text{BJD}_{\text{TDB}}\, 2459869{\cdot}229815(31) + 9{\cdot}65295307(29)E \qquad (1)$$

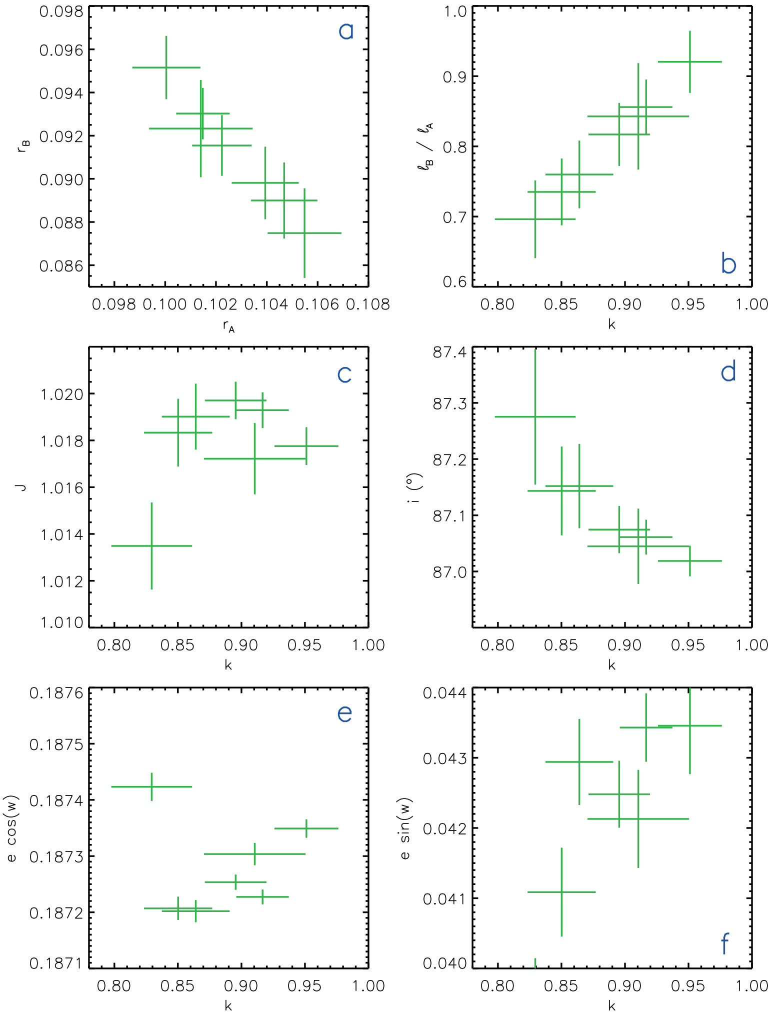

FIG. 3

Correlation plots from the JKTEBOP fits to the individual *TESS* sectors. The error bars in each case are the uncertainties obtained from Monte Carlo simulations.

where E is the number of cycles elapsed since the reference time.

Armed with this new information, it is worthwhile revisiting the spectroscopic orbit of the system. LCS04 obtained and presented 29 spectroscopic RV measurements for each star, which they fitted together with their photometric observations. We obtained the RVs from their table 2 and performed an independent fit with JKTEBOP. We fixed the parameters of the system except for the argument of periastron (to allow for possible apsidal motion), and the velocity amplitudes (K_A and K_B) and systemic velocities ($V_{\gamma,A}$ and $V_{\gamma,B}$) of the stars. We did not force $V_{\gamma,A}$ to equal $V_{\gamma,B}$ but their fitted values agree well. We also allowed for a phase offset *versus* the orbital ephemeris above, to account for shifts due to apsidal motion or time-conversion errors. The data were not provided with error bars so we adopted a single uncertainty for all RVs per star and adjusted it to force a reduced χ^2 of unity for each star.

The best fit to the LCS04 RVs is shown in Fig. 4 and is practically identical to that presented in fig. 1 of LCS04. We found K_A = 105·83 ± 0·85 km s^{-1}, K_B = 107·86 ± 0·95 km s^{-1}, $V_{\gamma,A}$ = −35·57 ± 0·55 km s^{-1} and $V_{\gamma,B}$ = −35·49 ± 0·66 km s^{-1}. The argument of periastron (ω = 10°·8 ± 1°·4) agrees with the photometric value in Table II, and the phase offset [$\Delta\phi$ = (8 ± 9) × 10^{-5}] is consistent with zero. The error bars quoted here were obtained from Monte Carlo simulations[32].

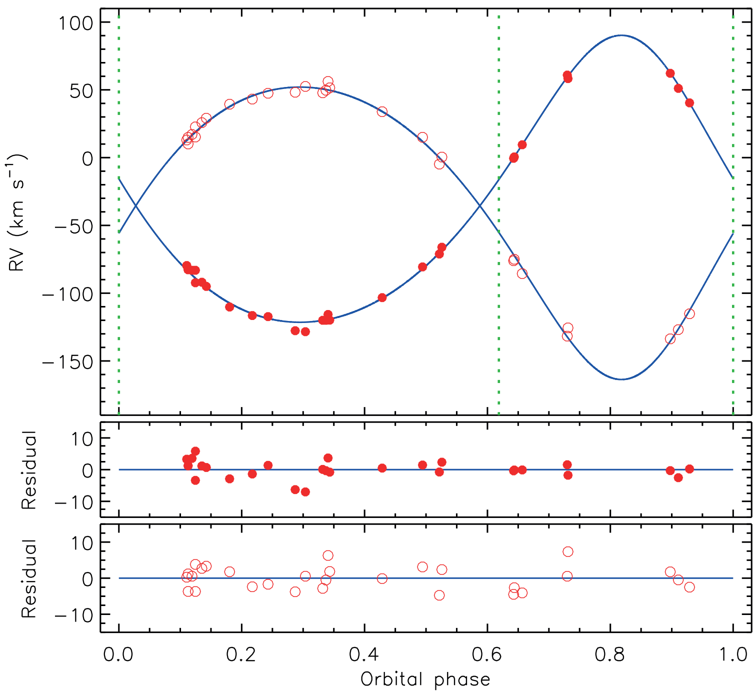

Fig. 4

RVs of MU Cas from LCS04 (filled red circles for star A and open red circles for star B), compared to the best fit from JKTEBOP (solid blue lines). The times of eclipse are given using vertical green dotted lines. The residuals are given in the lower panels separately for the two components.

Physical properties and distance to MU Cas

We determined the physical properties of MU Cas using the JKTABSDIM code[34] and the results from the light- and RV-curve analyses given above. The masses are measured to 1·9% precision and the radii to 0·9% (star A) and 1·2% (star B) precision. When comparing to LCS04 we find our results are in good agreement but with the identities of the two stars interchanged. The pseudo-synchronous rotational velocities of the stars are consistent with the values of 22 ± 2 km s^{-1} and 21 ± 2 km s^{-1} measured by LCS04.

The photometric analysis of LCS04 proceeded with the primary (deeper) eclipse being at phase zero; the secondary eclipse was at phase 0·62 in agreement with the current work. They then chose to swap the two stars to make the primary the hotter of the two; this also made it the smaller, less-massive, and less-luminous component. Our analysis proceeded in the same way but without the swap, so our star A is the larger, cooler, and more-massive object. The primary eclipse is deeper than the secondary eclipse, despite the inverted $T_{\rm eff}$ ratio, because a larger projected stellar area is eclipsed at primary than secondary. A good example of this situation can be found in our recent analysis of V454 Aur[35].

LCS04 settled on a mean $T_{\rm eff}$ for the system of 14 900 ± 500 K from a set of calibrations based on *UBV* and *uvby* photometry, which is consistent with but slightly below the expected value for B5 V stars[36,37]. Combining this value with the ratios of the surface brightnesses and radii from Table II, and equations 5 and 6 from Southworth[35], gives $T_{\rm eff}$ values of 14 870 ± 500 and 14 940 ± 500 K for stars A and B, respectively. These values are given in Table III and are much closer together than those measured by LCS04, as expected from the surface-brightness ratio being only slightly above unity.

We used the results in Table III, combined with the *BV* and JHK_s apparent magnitudes from Table I and the bolometric corrections from Girardi *et al.*[38], to determine the distance to MU Cas. The 2MASS JHK_s observations were taken at orbital phase 0·268 so correspond to the out-of-eclipse brightness of the system. An interstellar reddening value of $E(B-V)$ = 0·44 ± 0·05 mag is needed to align the *BV* and JHK_s distances, in good agreement with the $E(B-V)$ = 0·50 ± 0·08 mag suggested by the STILISM reddening maps*[39]. The most precise distance estimate from this work is in the K_s band and is 1814 ± 37 pc, slightly shorter than the *Gaia* DR3[16] value of 1948 ± 73 pc (a difference of 1·8σ). We are confident in our measurement of the radii of the stars — especially in their sum, which is more important than the ratio for distance measurement — so the discrepancy could indicate that the $T_{\rm eff}$ values of the stars are higher than inferred by LCS04. We experimented with adding a plausible 1000 K to the $T_{\rm eff}$ values, finding that this required an extra 0·01 mag of $E(B-V)$ and gave a distance larger by 54 pc. This partial solution to the issue could be checked by obtaining a spectroscopic estimate of the $T_{\rm eff}$ values of the stars.

TABLE III

Physical properties of MU Cas defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 33).

Parameter	*Star A*	*Star B*
Mass ratio $M_{\rm B}/M_{\rm A}$	0·981 ± 0·012	
Semi-major axis of relative orbit ($R^{\rm N}_{\odot}$)	40·06 ± 0·23	
Mass ($M^{\rm N}_{\odot}$)	4·674 ± 0·091	4·586 ± 0·084
Radius ($R^{\rm N}_{\odot}$)	4·117 ± 0·039	3·653 ± 0·045
Surface gravity (log[cgs])	3·879 ± 0·007	3·974 ± 0·010
Density ($\rho_{\odot}$)	0·0670 ± 0·0015	0·0940 ± 0·0031
Synchronous rotational velocity (km s^{-1})	21·57 ± 0·20	19·15 ± 0·24
Effective temperature (K)	14870 ± 500	14940 ± 500
Luminosity $\log(L/L^{\rm N}_{\odot})$	2·873 ± 0·059	2·778 ± 0·059
$M_{\rm bol}$ (mag)	−2·44 ± 0·15	−2·20 ± 0·15
Interstellar reddening $E(B-V)$ (mag)	0·44 ± 0·05	
Distance (pc)	1814 ± 37	

*https://stilism.obspm.fr/

Summary and conclusions

MU Cas is a dEB containing two B5 V stars in an orbit of period 9·653 d and eccentricity 0·192. We used light-curves from seven sectors of observations using *TESS*, combined with spectroscopic results from LCS04, to determine the physical properties of the system. Our results are in good agreement with those of LCS04 save for an interchange of the identities of the two stars: the primary star in the current work is the larger and more massive of the two, but has evolved to be the cooler component. That the primary (deeper) eclipse corresponds to the obscuration of the cooler star is a result of the orientation of the eccentric orbit, which causes a greater stellar area to be eclipsed during primary than secondary eclipse. The precision of our results is limited by the ratio of the radii, which is poorly measured from the deep but partial eclipses produced by the system, and the scatter in the available RVs.

We find a distance to the system of 1814 ± 37 pc, $1{\cdot}8\sigma$ shorter than the distance of 1948 ± 73 pc from the *Gaia* DR3 parallax. A possible solution to this difference is that the stars are hotter than given in Table III. The system deserves detailed spectroscopic study in order to check and confirm the $T_{\rm eff}$ values, measure more precise RVs to help the determination of the masses, and obtain a new spectroscopic light ratio to determine the radii of the stars better. We compared the measured properties of MU Cas to the predictions of the PARSEC theoretical stellar-evolutionary models[40] to check the level of agreement between observation and theory, and to infer the age of the system. A metal abundance of $Z = 0{\cdot}017$ and an age of 87 ± 5 Myr provides excellent agreement with the measured $T_{\rm eff}$ values and acceptable agreement with the measured radii.

The properties of both components are in the range where slowly-pulsating B-stars are found[41–43], prompting us to conduct a search for pulsations. The data from *TESS* sectors 57 and 58 were chosen as they provide the longest quasi-contiguous temporal coverage, a JKTEBOP fit was performed, and the residuals of the fit fed to the PERIOD04 code[44]. No significant periodicities were found, with 3σ limits of 0·2 mmag for frequencies from 0·4 d^{-1} to the Nyquist limit (359 d^{-1}) and 1 mmag for frequencies of 0·0–0·4 d^{-1}.

A final remark is that our work has failed to improve significantly the measurements of the properties of MU Cas from the previous analysis by LCS04. The huge advance in the quality of the available light-curves was not useful because the ratio of the stellar radii remains poorly determined due to degeneracies between fitted parameters. A detailed spectroscopic analysis is recommended instead, and the reader is reminded that it is good scientific practice to publish results even if they are uninteresting[45], especially if they act as independent confirmation of existing work[46] (see also the *Journal of Trial & Error**).

Acknowledgements

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*https://journal.trialanderror.org/

Space Agency (ESA) mission *Gaia*★, processed by the *Gaia* Data Processing and Analysis Consortium (DPAC†). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. 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.

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★https://www.cosmos.esa.int/gaia

†https://www.cosmos.esa.int/web/gaia/dpac/consortium

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CORRESPONDENCE

To the Editors of 'The Observatory'

Rosse versus Herschel: Rivalry among Great-Telescope Families.

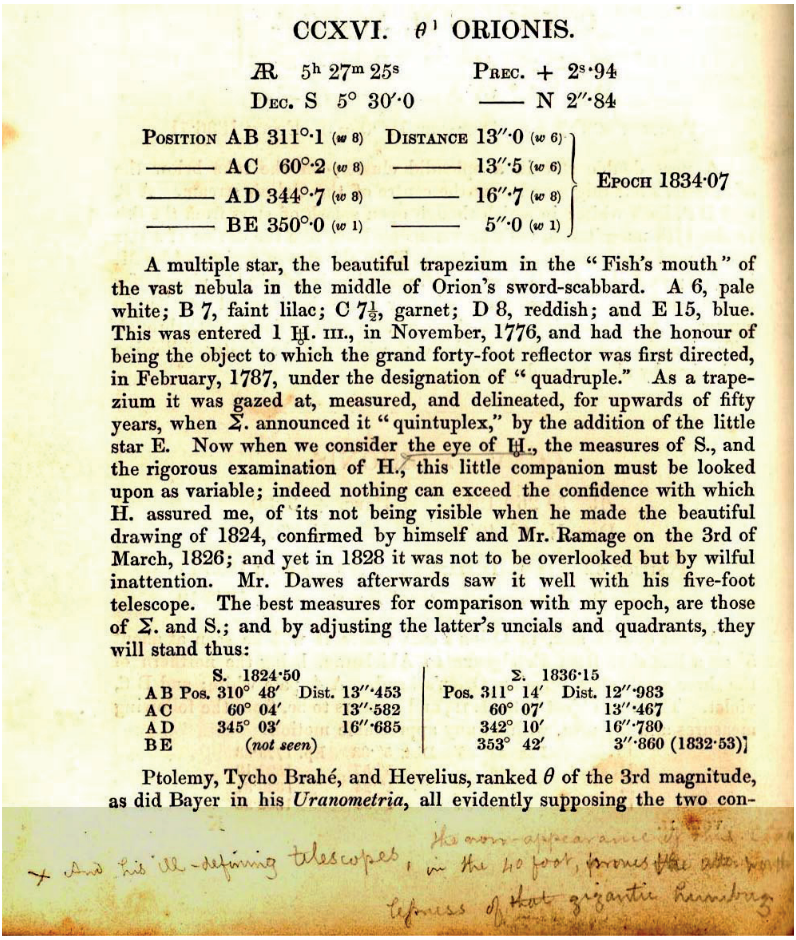
In 2023 the dispersal began through an Irish auction-house of part of the Birr Castle astronomical library of printed books. This will no doubt come as a surprise to some readers of this letter. The writer was thus fortunate to acquire two lots in the sale, including the Birr copy of Captain Smyth's *Cycle of Celestial Objects* 1844. The point of interest which prompts this letter is one of the marginal annotations in an evidently mid-19th Century hand* added by a previous owner, presumably the third Earl of Rosse, in Volume 2 of the *Bedford Catalogue*.

Appended to Smyth's entry for θ^1 Orionis on page 130 of that volume where Smyth remarks on the non-discovery of the fifth star 'E' by earlier observers in the words "Now when we consider the eye of Herschel,…" there is the following marginal comment in extremely faint pencil: "And his ill-defining telescopes, the non-appearance of this star in the 40 foot proves the utter worthlessness of that gigantic humbug" (Fig. 1). There may be some justice in this uncharitable assessment of the optical quality of Herschel's 40-foot, which was in any case never routinely used by its maker as a working instrument in his major observational programmes. The remark is, however, totally unfounded with respect to Herschel's smaller telescopes, as for instance amply proven by the astonishing performance of the '7-foot' of only 6·2-inches aperture† on close double stars: on that instrument the great binastrist not infrequently used magnifications of ×932 or even higher as standard working powers and discovered a number of binaries when at 1-arc-second separation or even less — ζ Cancri AB, *ω* Leonis, η Coronae, ξ Scorpii AB, *et al*…‡.

* For instance, using the archaic long 'S'. In fact, the style of hand bears a very close similarity to that of the caption on Rosse's original 1845 April sketch of M51 Canum Venaticorum as reproduced on page 233 of C. Mollan's *William Parsons, 3rd Earl of Rosse* (Manchester University Press), 2014.

†The 'Uranus' 7-foot telescope.

‡These were all discovered with the 7-foot in 1780–82 during Herschel's early single-handed 'Second Review' of the heavens, a specifically high-power examination of individual bright stars. Contrary to a widespread myth this work was not conducted jointly with Caroline at the much larger 20-foot, which instrument contributed negligibly to this systematic search for very close double stars. The famous 20-foot 'Sweeps' performed by the Caroline & William partnership were a completely separate research programme commenced in 1784 and using far lower powers.



CCXVI. θ^1 ORIONIS.

Æ 5h 27m 25s — Prec. + 2s·94
Dec. S 5° 30′·0 — —— N 2″·84

Position AB 311°·1 (w 8)	Distance 13″·0 (w 6)		Epoch 1834·07
——— AC 60°·2 (w 8)	——— 13″·5 (w 6)		
——— AD 344°·7 (w 8)	——— 16″·7 (w 8)		
——— BE 350°·0 (w 1)	——— 5″·0 (w 1)		

A multiple star, the beautiful trapezium in the "Fish's mouth" of the vast nebula in the middle of Orion's sword-scabbard. A 6, pale white; B 7, faint lilac; C 7½, garnet; D 8, reddish; and E 15, blue. This was entered 1 H. III., in November, 1776, and had the honour of being the object to which the grand forty-foot reflector was first directed, in February, 1787, under the designation of "quadruple." As a trapezium it was gazed at, measured, and delineated, for upwards of fifty years, when Σ. announced it "quintuplex," by the addition of the little star E. Now when we consider the eye of H., the measures of S., and the rigorous examination of H., this little companion must be looked upon as variable; indeed nothing can exceed the confidence with which H. assured me, of its not being visible when he made the beautiful drawing of 1824, confirmed by himself and Mr. Ramage on the 3rd of March, 1826; and yet in 1828 it was not to be overlooked but by wilful inattention. Mr. Dawes afterwards saw it well with his five-foot telescope. The best measures for comparison with my epoch, are those of Σ. and S.; and by adjusting the latter's uncials and quadrants, they will stand thus:

	S. 1824·50		Σ. 1836·15	
AB	Pos. 310° 48′	Dist. 13″·453	Pos. 311° 14′	Dist. 12″·983
AC	60° 04′	13″·582	60° 07′	13″·467
AD	345° 03′	16″·685	342° 10′	16″·780
BE	(*not seen*)		353° 42′	3″·860 (1832·53)]

Ptolemy, Tycho Brahé, and Hevelius, ranked θ of the 3rd magnitude, as did Bayer in his *Uranometria*, all evidently supposing the two con-

+ And his ill-defining telescopes, the non-appearance of this in the 40 foot, proves the utter worthlessness of that gigantic humbug

Fig. 1

A scan of the relevant page with the contrast of the lower margin stretched to make the marginal note legible.

Rosse's ill-disposed marginal remark just quoted — surely uncharacteristic of the Earl, a generous-spirited man by all account — reminds this writer, conversely, of that which he has seen reported somewhere as having been made by Caroline Herschel when told of Rosse's own construction of his great

Leviathan, to the effect that "some fool has claimed to build a telescope more powerful than my brother's 40-foot". There is nothing new, it would seem, about aperture-envy.*

Yours faithfully,
CHRISTOPHER TAYLOR[†]

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2024 September 11

[†]The Editors were dismayed to learn that Mr. Taylor passed away on 2024 December 18

REVIEWS

Supernova, by Or Graur (MIT Press), 2024. Pp. 212, 17·5 × 12·5 cm. Price $16·95 (about £13) (paperback: ISBN 978 0 262 54314 9).

MIT Press recently launched a set of small books in their Essential Knowledge series; their website currently lists 27 titles on a wide variety of topics, from Astronomy to Whiteness. The astronomy category comprises two quite separate volumes, although on related topics, *Galaxies* and *Supernova*, both by Or Graur. They are pocket-sized volumes, and (if the book under review is typical) avoid mathematics but have copious references (by endnotes) to more technical material, all gathered at the end by chapter.

The style makes for easy reading, but a lot of information is included, from the earliest observations by the Chinese and the Romans (that surprised me — I don't think of the Romans as observers of the sky) to the present day. Apart from the historical introduction, the seven other chapters generally take a theme and develop it. The book is well illustrated, with a mixture of diagrams, graphs, tables, black-and-white photos, and eight colour plates. There is a useful glossary and a couple of pages of definitions. I am not an expert on supernovae, but I believe that he covers all the necessary topics at a level suitable for the layman. An unusual feature is a series of pages with a key quotation (usually a single sentence) from his text, printed in large font in white on a black background. Reading only these pages would give readers a reminder of key points and probably tempt them to read more.

The price is very reasonable, and I can recommend this book unreservedly. — Robert CONNON SMITH.

*Rosse's own 72-inch, as is well-known, came in for its own fair share of this quite apart from Caroline's sour remark, as, for instance, the comment of a visiting French astronomer who said that he was shown something "they told me was Saturn"! Anyone familiar with the use of large reflectors at low-altitude sites knows full well how temperamental they can be and how hyper-sensitive to the effects of seeing, so it is absurd to attribute this unbelievably poor performance to the optical quality of an instrument which had easily split γ^2 Andromedae when at 0·6 arc seconds separation.

Galaxies, by Or Graur (MIT Press), 2024. Pp. 195, 17·5 × 12·5 cm. Price $17·95 (about £14) (paperback; ISBN 978 0 262 54875 5).

According to the Foreword, books in MIT's *Essential Knowledge* series supply "foundational knowledge that informs a principled understanding of the world", which sounds a rather esoteric aim. Fortunately, the present book is much more interesting and informal than that introduction might suggest. The level would be suitable for, say, A-level school students or anyone with a general interest in science. The topics covered are wide-ranging, some history of the subject, galaxy types, structure of the Galaxy, star formation, supermassive black holes, clusters and the cosmic web, dark matter and energy, a spot of cosmology, galaxy formation, evolution, and mergers. Some colleagues may be a bit aggrieved at the shortage of mentions of X-rays, but largely the contents are as you might hope. There are a few things you could quibble about slightly, but (as the author quotes from *The Hitchhikers Guide to the Galaxy*), I think we can judge them "mostly harmless". Large numbers of references to original papers are included in the Notes, which is unusual for a book of this type, though I can't help thinking that going straight from reading an introductory text to, for instance, Binney & Tremaine's *Galactic Dynamics* could be somewhat ambitious, not to mention Einstein's *Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie*. The book ends with things the reader can do besides reading, such as joining Galaxy Zoo or finding a dark-skies site. All in all, an excellent, short, non-mathematical introduction. Recommended. — Steve Phillipps.

The History of Our Universe in 21 Stars (That You Can Spot in the Night Sky), by Giles Sparrow (Welbeck), 2023. Pp. 351, 20 × 13 cm. Price £9·99 (paperback; ISBN 978 1 80279 505 9).

Having read another book[1] by the same author (positively reviewed in these pages[2]), I expected an enjoyable, well written, informative, and non-technical popular-science book; I was not disappointed. As the title indicates, twenty-one stars (and three 'impostors') are used as jumping-off points to illustrate aspects of stellar structure and evolution (and a bit more *via* the impostors) as well as basic astronomical knowledge such as distance determination and the main points of the history of astronomy. Each object has a finding chart and description of how to find it, also indicating its magnitude and what type of instrument, if any, is needed. The impostors are the globular cluster Omega Centauri, the Andromeda Galaxy, and the quasar 3C 273. As in the recent review[3] of another book[4], the only real mistake I noticed was towards the end of the book in the discussion of cosmology (jumping off from supernova 1994D to the magnitude–redshift relation for type-Ia supernovae and to observational cosmology in general): while it is a matter of taste whether one describes the cosmological constant as getting stronger over time (by definition, it is constant, though its effects dominate more and more over those of matter as the latter is thinned out by the expansion of the Universe), the 'Big Rip' scenario, in which even (gravitationally or otherwise) bound objects will be disrupted, will not happen if dark energy is just the cosmological constant, but rather involves a more exotic form of dark energy. (It is also probably not the case that the Michelson–Morley experiment influenced Einstein's thinking on Special Relativity, but any mistake here is more than made up for by the mention, in the same footnote, that Michelson appears as a character in an episode of the US Western television series *Bonanza*[5,6]. Interestingly, Lorne Greene, who played one of the main characters, Ben Cartwright, in *Bonanza*, later moved to the stars, playing Commander Adama in the science-fiction television series *Battlestar Galactica* in the late 1970s.)

Although essentially no readers will be able to connect their own observations of the objects mentioned in the book with their scientific descriptions, the format nonetheless thus bridges the gap between amateur astronomy on the one hand and astrophysics on the other; the latter is presented non-technically but clearly and without loss of accuracy. The book also contains many footnotes providing tangential information. Somewhat odd is the reference format (for the handful of citations per chapter): title, author, year (*i.e.*, no journal or other information). While that is probably enough to track them down, full references and/or DOIs would have taken up negligible additional space.

Apart from the twenty-four chapters and the reference list, the book contains essentially only a page of acknowledgements and an introduction. In addition to the finding charts (with the figures represented by the constellations as grey backgrounds), there are a few other black-and-white diagrams and photos spread throughout the book as well as occasional 'boxes' with additional information. As usual, the editing could have been somewhat better, though there are only a few actual typos.

Using specific celestial objects as jumping-off points to discuss various astrophysical topics in more general terms is also the strategy used in another book[7] reviewed in this *Magazine*[8], although that book, fitting for one on galaxies, contains many large, high-resolution colour photos. That doesn't make sense for a book mostly about stars, though the idea of moving from what one sees in the sky to the physics behind it is the same. This could be a good first book on (mainly stellar) astrophysics for someone interested in astronomy. — PHILLIP HELBIG.

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(8) C. Potter, *The Observatory*, **138**, 338, 2018.

An Introduction to Mathematical Astrophysics, by Neil R. Taylor (Observatoire Solaire), 2024. Pp. 317, 27 × 19 cm. Price £37 (on Amazon), £35 (directly) (hardbound; ISBN 978 1 9999044 2 5).

This book is intended for students with A-Level mathematics and physics, first- and second-year undergraduates in physics and astronomy, and amateur astronomers. In a little over 300 pages, it covers a vast amount of material, from history, through Solar System and dynamical astronomy, stellar astrophysics, the Galaxy, galaxies, cosmology, Special and General Relativity, and just about everything you want to know about astronomy. The author obviously has a huge comprehensive knowledge of the subject — but how successful is he in putting it over for the intended readership?

Unfortunately, it appears to have been privately published and printed, and has doubtless never been through the hands of a copy editor. While, like the curate's egg, it may be good in parts, I think I can safely say that I have never seen a book so riddled with mistakes on page after page from start to finish. These include mistakes in science, in mathematics, grammar, spelling, punctuation, and sentence structure, as well as the appallingly poor typesetting of mathematical symbols and equations to such an extent that I cannot honestly say that I recommend the book to anyone who is trying to learn from it.

To list all the mistakes would probably take up an entire issue of *The Observatory,* so I'll just choose a random few. Among the more amusing spelling mistakes are Harlow Shapely and discreet energy levels. As for punctuation, Lynne Truss (of *Eats, Shoots and Leaves* fame) would have a field day, with a vast mine of mistakes to choose from. Suffice it to say that the author seems to have no idea whatever of the use of apostrophes, commas, or hyphens. Among the many scientific mistakes, we are told that hadrons are mesons and muons, that a pion is the lightest of the muons, protons and neutrons are bosons, and electrons are baryons. We are also told that a black body absorbs no radiation. Cool objects don't emit any radiation below a threshold (a falsity obviously caused by a misinterpretation of the Planck curves illustrated just below it). In the Sun's spectrum, the atomic hydrogen emissions are a very distinct case and "shine-out" as bright lines against the backdrop of the continuum spectra. Type Ia supernovae emit silica lines. Faraday showed that magnets move within an electrical conductor. The pressure of a gas is not a scalar nor a vector, but a tensor. (Spectroscopy shows that) the coma of a comet consists predominately [*sic*] of (atomic) hydrogen. In neutron stars, electrons are accelerated by magnetic fields. You may remember from school physics that blue light is refracted less that red light. (Gosh — I'd forgotten. I thought my teacher said "more than" — did he get it wrong?). This is why our sky is blue. The atomic mass of helium is 2. (The author also confuses atomic weight with mass number, and tells us that the atomic weight must be written to the lower right of an element's symbol.) A globular cluster has lots of high-metallicity stars. Fe^{13+} is atomic iron with 13 of its 16 electrons missing. Methane, water, and carbon dioxide are diatomic elements. And so it goes on and on.

I'll give an example of just one mathematical derivation. We'll calculate the angular momentum of a solid rotating star. (I'm not sure what a solid star is.) The angular momentum of a closed system is *Smvr*. (We are not told what a closed system is or what the symbols stand for.) If we consider the scenario of a solid rotating star, we can integrate over the whole star and arrive at the angular momentum of the star as *MRv*, where *M* is the mass of the star, *R* its radius, and *v* the speed of rotation. Such is the quality of the mathematical derivation — and, of course, the wrong result. For a solid sphere of uniform density, the angular momentum would be only 40 percent of this. For a real, gaseous star, its angular momentum is nothing at all like this.

I think I have written enough. A brief summary, I'm afraid, is that I cannot recommend this one to those trying to learn mathematical astrophysics. — Jeremy B. Tatum.

The Enchantement of Urania: 25 Centuries of Exploration of the Sky, by Massimo Capaccioli (World Scientific), 2024. Pp. 573, 23·7 × 15·7 cm. Price £135 (hardbound; ISBN 978 981 124 777 4).

Massimo Capaccioli climbed five rungs of the academic ladder at the University of Padua from 1969 until 1990, becoming full professor, then moved to the University of Naples as full professor in 1995 (where he was also director of the observatory 1993–2005), becoming an emeritus towards the end of 2014. He was also a visiting professor at the University of Texas and counts Gérard de Vaucouleurs as a mentor. He has (co-)authored more than a dozen books, mostly in Italian (some of which have been translated to other languages). This book is his own translation of the 2020 Italian version, the latter of which he had been working on since 2011.

This is a history of astronomy, but different from others which I have read, for several reasons. Although the topics covered in the 19 chapters are more or less what one might expect (with a slight preference for observation and instrumentation over theory), the fact that the chapters are the only division (no parts, sub-chapters, sections, *etc.*) reinforces the similarity of the narrative to myth (in a positive sense). Apart from the subject matter, the style reminds me of a bard recounting an oft-told tale, with a clear narrative peppered with asides and allusions which keep the narrative interesting without detracting from it. There are 1213 footnotes providing additional commentary, citations to the literature (including some to this *Magazine*), or both, and the main text often follows separate strands which are braided together.* (The citations, while accurate, are sometimes to surprising sources, perhaps reflecting the author's personal source of the corresponding information, rather than some standard citation.) While none of the main points were new to me, I encountered several details for the first time (some similar to the biographical details presented by Steven Phillipps in his recent historical series in these pages). While it is a history of (mostly Western) astronomy, political and other details of the corresponding times are also mentioned to provide context.

There are no equations, making the book accessible to a wide readership, though without too much simplifying of concepts. Perhaps unexpected for such a book, there are no illustrations whatsoever, apart from the cover featuring a painting of the muse Urania superimposed on a wide-field image containing stars and galaxies. Not surprisingly for an historical, as opposed to systematic, presentation, astronomers play as much a role as does astronomy. The nineteen-page index contains only names. One of those is Archbishop Isidore of Seville (560–636), quoted explaining the difference between astronomy ("the study of the stars") and astrology ("the superstitious line of thought"); many books on astronomy claim that there was essentially no difference between astronomy and astrology until much later (though to be sure some did both); a reference to the original Latin text is provided. Other titbits new to me were how Ptolemy measured the magnitudes of stars (based on their time of appearance at sunset) and that γ Draconis will be the brightest star in our sky in 1·5 million years (one of many interesting facts revealed in a long footnote when the star is mentioned in the main text because it culminates over Greenwich). The book is full of such delightful excursions. Although most topics one would expect are covered, the level of detail varies. Some are mentioned in only one sentence (perhaps with a footnote citing an entire book on the topic), others get a paragraph or two, and still others, such as the construction of the 200-inch *Hale* telescope, get several pages. (There is an entire chapter 'The Eighth Wonder', but it also includes many pages about Walter Baade and Bernhard Schmidt in Hamburg, Baade and Zwicky in California, and the history of the Schmidt cameras in Hamburg, at Palomar, and elsewhere, and the surveys made with them.)

*The range of knowledge of the author, indicated not just by the main text but especially by the footnotes, is vast. Both the main text and the footnotes refer to the main topic of the book, interesting additions, and broader historical and literary contexts, often in interesting superpositions, somewhat like adding a footnote about the Maxwell equations to Walt Whitman's "I sing the body electric".

Of course, in a book of this length, it would be a surprise if there were no mistakes at all, but they are mostly harmless: in addition to typos and linguistic errors typical of Italian speakers — though the translation is on the whole good — sometimes unimportant (for this narrative) details are wrong, *e.g.*, Max Born emigrated to the UK, not as stated to the USA, the ESO headquarters were first briefly in Hamburg before Geneva and then Garching (only the last two are mentioned), and sometimes relatively common myths are repeated, *e.g.*, that Einstein was led to Special Relativity *via* the Michelson–Morley experiment. Some matters of style and so on could have benefitted from better proof-reading, but other things, such as mis-spelled names, would need a proof reader familiar with the well-over-one-thousand names mentioned in the book (though different spellings of the same name should have been easy enough to spot). The author seems to be very well informed, so I was surprised that he thinks that there is more than just a shadow of a doubt on Eddington's interpretation of the famous 1919 eclipse-expedition results, as that long-standing myth has been convincingly debunked[1,2]. The back-cover description states that "[a] rich bibliography has also been added in the appendix", but there is no appendix at all. (The citations, though, contain full bibliographic information, including titles, issue numbers, and first and last page numbers.*)

However, in comparison to the treasure-trove of information contained in this tome, my complaints are minor. It is both a good introduction to the history of astronomy for someone who knows little or nothing about that field, but also an enjoyable read for those who know considerably more. Probably everyone would learn many new interesting things, and it is also valuable for its many citations to the primary literature, including the sources of quotations, of topics mentioned in the text. — PHILLIP HELBIG.

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(1) D. Kennefick, *No Shadow of a Doubt: The 1919 Eclipse that Confirmed Einstein's Theory of Relativity* (Princeton University Press), 2019.
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Here and There

DANGEROUSLY OUT OF FOCUS

The Cassegrain focus — effectively the lens — of the Subaru telescope atop the Mauna Kea volcano in Hawaii — *New Scientist*, 2023 January 23, p. 31.

*As a reference to Hubble's enormous ego, Capaccioli cites the definitive biography[3] (reviewed by our long-standing Editor[4]) and explicitly "pp. 1–420" (*i.e.*, the entire book).

Advice to Contributors

The Observatory magazine is an independent, on-line only, journal, owned and managed by its Editors (although the views expressed in published contributions are not necessarily shared by them). The Editors are therefore free to accept, at their discretion, original material of general interest to astronomers which might be difficult to accommodate within the more restricted remit of most other journals. Published contributions usually take one of the following forms: summaries of meetings; papers and short contributions (sometimes printed as *Notes from Observatories*); correspondence; reviews; or thesis abstracts.

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and for books:

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where the items in square brackets are required only when citing an article in a book. Authors are listed with initials followed by surname; where there are four or more authors only the first author '*et al.*' is listed. For example:

(1) G. H. Darwin, *The Observatory*, **1**, 13, 1877.
(2) D. Mihalas, *Stellar Atmospheres (2nd Edn.)* (Freeman, San Francisco), 1978.
(3) R. Kudritzki *et al.*, in C. Leitherer *et al.* (eds.), *Massive Stars in Starbursts* (Cambridge University Press), 1991, p. 59.

Journals are identified with the system of terse abbreviations used (with minor modifications) in this *Magazine* for many years, and adopted in the other major journals by 1993 (see recent issues or, *e.g.*, *MNRAS*, **206**, 1, 1993; *ApJ*, **402**, i, 1993; *A&A*, **267**, A5, 1993; *A&A Abstracts*, §**001**).

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