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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2023 November 10 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

Mark Lester, *Senior Secretary*
in the Chair

The Chair. Firstly, I have apologies from the President who is unavoidably delayed by floods somewhere between here and the Principality, so unfortunately you have myself, the Senior Secretary, to chair the evening session. This is a hybrid meeting; questions can be asked at the end of the lecture, but you will be muted, so please use the chat facility. Your questions will be read out by Dr. Pamela Rowden, RAS Editorial Assistant.

The first talk will be given by Dr. Beatriz Sanchez Cano from the University of Leicester who was the recipient of the Fowler Award for 2021. Dr. Sanchez Cano is an STFC/Ernest Rutherford Fellow and Lecturer at the University of Leicester working mainly on planetary–solar-wind interactions. Beatriz did her PhD in Spain at the Universidad Complutense in Madrid. She has spent several long research stays at the European Research and Technical Centre (ESTEC) of ESA in the Netherlands and at the Abdus Salam Centre for Theoretical Physics in Italy. She moved to Leicester in 2014 as a PDRA where she became an academic member in 2021. The title of her talk is 'Mars' ionosphere — from our current knowledge to the future of Mars exploration'.

Dr. Beatriz Sanchez Cano. The Martian space environment is a complex system in which strong couplings occur between the solar wind, magnetosphere, ionosphere, and atmosphere. For planets such as Mars without a global intrinsic magnetic field, the ionosphere is the conducting layer embedded within the thermosphere and exosphere that is mostly the result of solar extreme-ultraviolet (EUV) photoionization. Furthermore, it is also the layer that connects the neutral atmosphere with space and acts as the main obstacle to the solar wind. The solar wind interaction with the ionosphere is, therefore, a critical factor for understanding atmospheric evolution of unmagnetized or nearly unmagnetized planets.

This talk focusses on our current knowledge of the Martian ionosphere, how it is affected by space-weather activity, and how it compares to other planets. Mars is special in the sense that it has interaction with the solar wind because it possesses crustal magnetization in its surface that directly interacts with the solar wind. Moreover, orbital eccentricity, together with the 11-year solar cycle, are the dominant long-term factors that model the behaviour of the system, which is strongly affected by sudden inputs of energy from solar transient events, such as coronal mass ejections, which are known to affect space. Some of the most obvious effects are displayed in the form of Martian aurorae, of which four different types are currently known: a discrete aurora over crustal-field regions, a sinuous aurora, which is similar to the discrete aurora but often far away from crustal fields, a diffuse aurora that occurs after space-weather activity, and a proton aurora in the day-side produced by solar-proton impacts in the atmosphere. However, other phenomena also occur during space-weather activity that are allowing us to advance in the understanding of the ionospheric reaction to different space-weather events during different phases of the solar cycle, both from the data analysis and ionospheric-modelling perspectives. This is the case of radio blackouts observed at Mars by the current two radars in operation, which stop receiving signals from the surface of Mars during those events. These are direct space-weather effects, which are produced by radio-signal absorption in the lower ionosphere of Mars (~ 70 km) and are the result of new ions found there (where typically there are not many) produced by the space-weather event. This is key research at the moment since it has strong implications for planetary exploration as it affects current technology deployed on the planet.

Our knowledge of Mars as a coupled system comes from near three decades of continuous exploration, which has opened the door to the understanding of the Martian space environment as never before for any other planet than Earth. However, this knowledge is very limited as it comes from isolated observations of different parts of the system taken with different instrumentation. The future of Mars exploration needs to have a full scientific characterization of the plasma environment, which is essential to understand the radiation reaching the surface of Mars, and that can only be done with simultaneous and co-ordinated observations of the different regions of the planet. This is why the community, led by myself, is proposing a mission to Mars named *M-MATISSE* (*Mars Magnetosphere ATmosphere Ionosphere and Space weather SciencE*) to the European Space Agency in its so-called Medium class (M7), which is currently in Phase-A of the competition.

Understanding the fate of the ionosphere, as a natural sink of both internal (*i.e.*, atmospheric cycles) and external (*i.e.*, solar wind) energy inputs, is the key for a successful future systematic exploration of Mars.

The Chair. Speaking as someone who is directly interested in this mission, you can't bring it forward, can you?

Professor Marina Galand. Thank you very much for a very interesting talk. Can you say more about the mission, what kind of plasma and particle instruments you have? Is there also any instrument covering the UV, for example?

Dr. Sanchez Cano. It is a full plasma mission. It is actually based on experience from NASA's *Mars Atmosphere and Volatile EvolutioN* (*MAVEN*) mission but the problem with *MAVEN* is that it is just one satellite. At the moment it is not sampling the solar wind so it is extremely difficult to do the science that we wanted to do. That is the motivation for our mission. We start out with exactly the same instrumentation; we have six instruments and two of them actually have sub-instruments. They cover the neutral atmosphere from the surface up to space and also cover the ionized part of the atmosphere from the lower part of the ionosphere at about 70 km up towards space. For the first time we have an electric-field sensor, and it will be amazing to understand the currents at the planet which we couldn't have done before. Unfortunately there is not an IERS instrument, but there is an all-round camera in visible light and there are also instruments for all energies of ions and electrons. I believe we have covered all of the energies for the key types of particles as well as the fields and also we have a camera for dust. This will allow us to do meteorological studies in the future if people are interested in that.

The Chair. Any other questions in the room?

Mr. Horace Regnart. If anyone were foolish enough to suggest that tax cuts were a better option than funding your research, would you point out to them the costs and benefits of understanding the risk to telecommunications that follow from not understanding the sort of work that you and your colleagues are doing.

Dr. Sanchez Cano. This is a question which comes up quite often. It may sound like a lot of money to invest but it is not when considering the amount of benefit that we get. In the technology sector, the medical sector, even in the human sector, we can learn a lot about the human body by trying to protect cells in an environment such as this one. For me it is a full benefit for society, and I hope that everyone can see that.

Professor Kathy Whaler. I wonder if there are lessons for the terrestrial environment as the field strength here is weakening, particularly over the South Atlantic; does the fact that we have such a dense atmosphere compared to that of Mars make the comparisons not so useful?

Dr. Sanchez Cano. Venus has a similar interaction to that of Mars but the atmosphere of Venus is much, much denser than that of Earth. It has the same interactions as Mars, the same atmospheric escape, even if it is not as dense. The magnetic field of Earth is getting weaker because it is in the process of inversion so there will be a point when the magnetic field will reach a point similar to that of Mars. We know that in the past Mars had a field like Earth — we see the magnetization at the surface which came from a dipole which formed thousands of years ago, but something happened to the planet possibly as the result of a meteorite impact which stopped the dynamo inside the planet. We don't know what will happen to Earth but it is good to learn how the bodies close to Earth have evolved in the inner Solar System so we can apply the lessons to Earth. If the magnetic-field strength reduces to the level of that of Mars, at least we know what we are going to find. We have an excellent laboratory in the Solar System and we should do all we can to exploit it.

The Chair. Nothing online? In that case can we thank Beatriz again? [Applause.]

Our next presentation is to be given by Dr. Elizabeth Watkins from the University of Manchester. She received her PhD in astronomy at Cardiff studying the impact of stellar feedback in the star-forming molecular clouds in the Milky Way. She continued studying stellar feedback during her first postdoctoral position at the University of Heidelberg. While there she moved on to studying feedback on much larger scales in nearby galaxies, focussing on observing and identifying super-bubble regions of hot gas. She currently works at the University of Manchester where she is comparing simulations of stellar feedback with observations, to understand better how feedback benefits molecular clouds and the star formation within galaxies. The title of her talk is 'Characterizing (super) bubbles in nearby galaxies'.

Dr. Elizabeth Watkins. Without the light that stars produce, we are unable to understand the Universe around us. Therefore investigating how stars form from the interstellar medium (ISM) within galaxies, and the processes that regulate this star formation, is an important field of astronomical research. Super-bubbles are hot, expanding regions of ionized gas that sweep up the surrounding ISM into a shell and are driven by the winds and supernovae (*i.e.*, stellar feedback) from young stars. Studying these bubbles is therefore one way we can chart the interaction between stellar feedback and the ISM, and the larger galactic flows needed to regulate star-formation processes globally. The first *JWST* observations of nearby galaxies (<30 Mpc) unveiled a brand new (and breathtaking) view of galactic structures rich with bubbles in exquisite detail. These bubbles finally showed the extent to which young stars shape their galaxies. *JWST* and *ALMA* are providing novel constraints on bubble populations and stellar-feedback physics, which has an impact on the clouds and molecular gas from which stars form.

Using *JWST* data observed for a *JWST*-Cycle-1 Treasury Programme, I presented the first extensive extragalactic catalogue of these bubbles in NGC 628 at high resolution (12 pc) and statistically evaluated their characteristics. The catalogue contains 1694 bubbles with radii between 6–550 pc. Of these, 31% contain at least one smaller bubble at their edge, indicating that previous generations of star formation have a local impact on where new stars form. With 1694 bubbles found in a single galaxy, we can expect to find up to 500 000 bubbles in total from *JWST*-Cycle-1 and now Cycle-2 Treasury Programmes that will cover 90 galaxies. To find these bubbles, future plans include the development of automated algorithms, machine-learning techniques, and citizen-science projects. This work has been published in the *Astrophysical Journal Letters* as part of a *JWST* special edition in 2023.

To quantify the feedback energetics on the star-forming gas, we have created the largest molecular super-bubble catalogue found to date within nearby galaxies using ^{12}CO (2–1) observations. Since stars form from molecular gas, using it to find super-bubbles allows us to trace the exact impact stellar feedback has on star formation. However, molecular gas, such as ^{12}CO, is quickly destroyed by young stars, and so molecular super-bubbles do not get very big before they are no longer detectable in ^{12}CO. This means we need high resolutions and large mapping areas to investigate a statistically significant sample of molecular super-bubbles. With 90 galaxies observed in ^{12}CO at about 100-pc resolution as part of the 'Physics at High Angular resolution in Nearby Galaxies' (PHANGS)-*ALMA* large programme, we finally have the means to undertake such a study. Focussing on 18 *ALMA* galaxies with co-spatial *HST* and *MUSE-VLT* observations, I catalogued 325 super-bubbles with radii between 30–330 pc and expansion velocities of about 10 km s^{-1}. By focussing on a subset of these that have clear super-bubble signatures (unbroken shells, *etc.*), we can leverage the kinematic information available with ^{12}CO along with the stellar information available with *HST* to constrain the feedback processes driving the super-bubbles. The two datasets together show that most molecular super-bubbles are driven by the kinetic push from supernovae, and rather than dispersing and destroying molecular gas, I find that the gas is swept up into a shell that grows over time. Therefore, molecular super-bubbles can potentially form stars in their shells rather than inhibiting star formation, matching what I observed in the higher-resolution *JWST* observations for the NGC 628 bubble catalogue. This work has been published in *Astronomy and Astrophysics* in 2023.

The Chair. Any questions from the audience?

Dr. Quentin Stanley. It must be very exciting to see all those images, as you say. Can you say how you manage to spot those bubbles manually — there still seem to be a lot of areas that are still dark?

Dr. Watkins. I use a combination of three wavebands. It is basically an *RGB* image. I use red from *JWST*, and it needs to be co-spatial with H-alpha which shows that ionized gas is powering the bubble. I also have to check if there is any blue light which is tracing the young stars in the centre. If I had all three of these co-spatial — that is how I found the bubbles. They tend to be quite round and obvious to the eye. It is subjective, but we did get other people to do this and we found that even if we had slightly different bubbles, we got the same results.

Professor Steven Searjeant. Really nice talk. Finding all of those bubbles is an heroic effort.

Dr. Watkins. No, it wasn't really. I enjoyed it — I love monotony! [Laughter]. It was so much more relaxing than writing applications for telescope time.

Professor Searjeant. There are numerical simulations of spiral discs. I guess they are of similar quality to this, so have you eyeballed simulated data to see if this overlap of bubbles is what is going on?

Dr. Watkins. It's funny that you should ask that. We are trying to do citizen-science projects like Zooniverse to find bubbles. We do have some simulated galaxies and some of them do look quite similar to NGC 628, the Phantom Galaxy, and we are going to put a couple of them in to test. The problem with simulations is how the energy is injected — it's totally different. They inject it at different scales and if they do it like a single super-bubble they model it with those different models that I was talking about, but not all of them follow that model. They are simulations, but how they work is a bit different.

Dr. Pamela Rowden. This question comes from Ki-sha Kwok. "May I ask how the public can find these data too?"

Dr. Watkins. You have to go to the Mikulski Archive for Space Telescopes (MAST); typically they have their own reduction. The reduction we have done is much better and we will be making our reduction public. I know that you can definitely get the raw data from MAST at the Space Telescope Science Institute (STScI). If you can't find it please feel free to e-mail me or people in PHANGS — you can even e-mail the STScI and they will help you.

Dr. Rowden. This is a question from Julian Sylvester-Summer. "Would machine learning be a promising approach to finding bubbles in galaxies, instead of eyeballing?"

Dr. Wilkins. There are a few things being done right now. One team wants to get the citizens involved, another team has been writing algorithms to find bubbles automatically. Machine learning is great but what I did is not scaleable to 90 galaxies, but because this is a new field, it had to be done by a human first. To do machine learning we would have to find more bubbles than this to get a good sample so that when we have more galaxy data we can feed that in. Machine learning is one of those things that we will use because there are potentially 500 000 bubbles.

A Fellow. I have to ask the physics-uncertainty question which is how sure are you that there are not 1695 bubbles?

Dr. Watkins. I could have kept going. When we got other people to do this work we had to get them to check that what I did is not based on human bias, so two other people bravely volunteered and they each found only 800 bubbles. They did not go to such small scales as me. Below 30 pc they are not complete. For all the large bubbles, we all found the same bubbles. There will be bubbles that I perhaps got wrong or missed, but it doesn't matter as we have enough statistically.

The Fellow. It would be interesting to see what AI did.

The Chair. I know that this is a very interesting topic but I'm afraid that we are going to have to call it a day on the questions. One more on-line. I'm glad that *Hubble* is still involved. All I would say is that it gives a whole new meaning to the term 'Hubble bubble' [laughter].

Dr. Watkins. HST is still being used and is still oversubscribed. It has been vital for the work that we do.

Dr. Rowden. John Alderson is asking how does bubble size and number correlate with star formation in terms of mass per year?

Dr. Watkins. The size of the bubble is a mixture of the pressure pushing out to the galaxy pressure holding it in. The pressure pushing it out is related to the star-forming (SF) rate. A higher SF rate leads to more bubbles and those bubbles can have a different size distribution. How we find the theoretical number of bubbles is a mixture of how long we can physically see the bubble, the average mass of the cluster, and then the SF rate. All of that gives you the prediction, so SF is a key number when working out how many bubbles to expect.

The Chair. Thank you, Elizabeth [applause].

Now we have the James Dungey Lecture and I'm delighted to say that here to present it is Marina Galand, Professor in Planetary Science at Imperial College London. Her principal research interest is the study of planetary atmospheres and cometary comae. She has investigated the deposition of solar and auroral energy in atmospheres throughout the Solar System and beyond, using sophisticated, state-of-the-art kinetic and fluid models that she has developed and adapted to new environments. She has undertaken this modelling activity in close links with space missions such as *Cassini*, *Rosetta*, *Ariel*, and *JUICE* and is leading the magnetometer on probe *B2* in the *Comet Interceptor* mission. She has been awarded the Ferdinand Holweck Medal and Prize of the Institute of Physics (IoP) and the Société Française de Physique (SFP) for her research and is actively involved in outreach to stimulate the public's interest in space science and to inspire the next generation.

Professor Marina Galand. I would like to thank the RAS very much. I was extremely grateful to have been awarded the James Dungey Lecture. The first one was ten years ago to celebrate Jim's 90th birthday. He is no longer with us, but this year we celebrate his centenary.

Jim Dungey was an amazing scientist. He pioneered many fundamental concepts in space physics, and more especially in the solar-terrestrial coupling, and he had the idea of the open magnetosphere to describe the interaction of the solar wind with the Earth, with reconnection on the day-side and night-side of the Earth — the so-called Dungey cycle. He was first to recognize that the Earth's radiation belt has an external source. He was a modeller and followed space missions closely. He also highlighted the importance of the ionosphere about which I am going to talk today.

Today I will be focussing on the energy deposition yielding the formation of the ionosphere. Consider a neutral species in the atmosphere — say N_2; then solar extreme UV (EUV) photons and energetic electrons can ionize the atmosphere leading to the formation of ions and electrons, hence a plasma that we call the ionosphere. This layer is critical in linking the atmosphere to the space environment of the Solar System body considered. This plasma can interact with dust or macroparticles and in the case of Titan it can lead to a complex organic factory. This ultimately leads to prebiotic chemistry on the surface of Saturn's moon.

To probe the ionosphere we can send rockets (100–1000-km altitude) and planetary probes but it can also be probed remotely. The energy sources which lead to the creation of the ionosphere can also excite the neutral species. Eventually there has to be de-excitation which can occur through radiation decay which leads to the production of a photon. The emitted radiation can be analyzed spectroscopically in order to learn about the source process and these atmospheric regions. I have been developing and applying models throughout the Solar System to assess how the energy is deposited and redistributed in the atmosphere and how the ionosphere is formed, transported, and lost, using a kinetic and fluid approach. I have combined data from different types of instrument from a given space mission with physics-based models in order to enhance the science return.

I would first like to concentrate on the magnetosphere–ionosphere coupling, as Jim Dungey was the first to highlight its importance in solar/terrestrial coupling. One of the consequences of this coupling is auroral emission by which Jim Dungey was fascinated.

The ionosphere is a layer of plasma in the atmosphere. How does magnetospheric/ionospheric coupling at Earth compare to the one at Ganymede? Ganymede, one of the Jovian moons discovered by Galileo, is the largest moon in the Solar System, larger than Mercury. It has an icy crust — on the day-side the atmosphere is formed from thermal sublimation and in the polar regions there are bombardments by energetic particles which lead to sputtering of the moon's surface. The sputtering leads to the release of water, O_2, and H_2. Solar radiation can then ionize the neutral species in the thin atmosphere which leads to the formation of the ionosphere. How does this differ from Earth? Compare the profile of the electron density with altitude: at Earth the ionosphere is typically above 80 km, whilst at Ganymede it extends down to the surface because the underlying neutral atmosphere is very thin. A similarity is the presence of an internal magnetic field — Ganymede is the only known satellite in the Solar System to generate one. It seems that the core is liquid metal which is producing the field through dynamo action. Whilst the ionosphere on Earth is the inward boundary of the magnetosphere, at Ganymede the ionosphere is produced within the magnetosphere and these two regions are intrinsically coupled. Whilst Earth is immersed in a super-magnetosonic solar wind, Ganymede is located in the magnetosphere of Jupiter which is sub-magnetosonic. At Earth the super-magnetosonic flow leads to a bow shock whilst at Ganymede the interaction of a subsonic magnetospheric flow with magnetic-field lines leads to Alfvén wings. A surprise on Ganymede is that most likely 100 km below the icy crust there is an ocean. This ocean experiences a changing of Jupiter's magnetic field; this produces a current which in turn gives rise to a magnetic field and it is this induced magnetic field that the magnetometer onboard *JUICE* will try and detect in order to characterize the subsurface ocean.

To summarize, the magnetosphere around Ganymede is quite complex. There are closed magnetic-field lines going from footprint to footprint on Ganymede whilst at high latitude you have open magnetic-field lines with a footprint on Ganymede and the other end at Jupiter. The co-rotating plasma with Jupiter goes much faster than the moon; the magnetospheric tail is in front of the moon.

There are only two close fly-bys of Ganymede by the *Galileo* spacecraft to provide data on the ionized layer below 2000-km altitude. Recently *Juno* did two fly-bys of Ganymede, one of which was close, but *Juno* will not be able to return to Ganymede. To study Ganymede's plasma layer we need to use modelling, so one of my PhD students, Gianluca Carnielli, developed the first 3-D model of

Ganymede's ionosphere. Solar EUV and energetic electrons ionize the neutrals leading to the production of electrons and ions. The modelling simulates the transport of ions through the electric and magnetic fields once the ions are produced by ionization. The ions can also undergo charge exchange with atmospheric neutrals. Inside the magnetosphere of Ganymede, the ionospheric plasma dominates over the Jovian plasma. How realistic is the modelled atmosphere?

We compared the simulation with the observations using the few data we had, particularly from *Galileo*. Among others, we looked at the total electron density *versus* time along the trajectory of *Galileo* which flew by Ganymede. We needed to increase the neutral-density factor by ten to have agreement between the observed and simulated electron densities. The number density of neutrals at Ganymede is not very well known. More recently a new model to explain some recent *HST* observations was published which includes the fact that more water and H_2 needs to be added to explain those observations. A closer agreement in terms of electron density is reached when the simulation is using this updated background neutral atmosphere.

What we learn from the modelling is that not only are the Jovian particles penetrating the polar regions and sputtering the surface but now, having actually modelled the ionospheric ions, they are accelerated with enough energy to sputter the surface themselves and to contribute to the production of the neutral atmosphere. If you are interested, there is a book on Ganymede which is due in 2024 May from CUP.

One of the consequences of magnetosphere/ionosphere coupling is auroral emission. To produce an aurora we need energetic electrons or ions originating from outside the atmosphere. An aurora is the photo-manifestation of the interaction of energetic extra-atmospheric particles with an atmosphere; the key thing is that the source of energy comes from outside the atmosphere.

On Earth we have aurorae, including one in the UK last Sunday. The green glow is produced by oxygen emission and it forms an oval around the magnetic poles. These ovals are also present at Ganymede and have been observed with *HST*. Atomic oxygen lines at 1304Å and 1356Å observed at Ganymede are the same lines that have been observed at Comet 67P.

At Ganymede the source of the O I emission lines is energetic electrons which dissociate O_2 and excite one of the produced oxygen atoms. At Comet 67P, is dissociative excitation of neutral species (H_2O, O_2) by energetic electrons the only process that generates the far ultraviolet (FUV) O I lines? If so, what is the source of these energetic electrons? To address the first question, we focus on FUV emissions observed at nadir (*Rosetta*–comet radial direction) [*Rosetta* escorted 67P for over two years] on a part of the surface which was in shadow to minimize scattered sunlight. Using measurements of energetic electrons and of the neutrals from *Rosetta* we simulated the brightness and compared with the observations from the UV spectrograph on-board *Rosetta*. Not only is there very good agreement between observations and the simulations but also, when the model predicts no emission, the spectrograph detected no emission either, showing that the dissociative excitation by energetic electrons is the main process of generating aurorae at Comet 67P. Now that we have confirmed the process yielding the auroral emissions, what is the source of the energetic electrons — are they coming from solar radiation or elsewhere? This time we used FUV observations from limb viewing (direction 'above' the cometary nucleus). We used the measured electron flux at *Rosetta* and the observed the column of atmosphere along the line of sight to estimate the brightness and then we compared this estimation with the observation of the emission which was produced far from *Rosetta*. This time we used hydrogen Lyman-β data produced through the same process as O I lines. Not only is there very good agreement in brightness, between observations and calculations, but there were also sharp changes which were captured in both. The electrons responsible for the emissions are not local; they were solar-wind electrons accelerated in the environment of the comet which then dissociate H_2O molecules. Through the observation of the O I 1356-Å line we can assess the variability of solar-wind electrons, so it has space-weather implications.

After this tour at Ganymede and Comet 67P, what is next? Ganymede is the main target of the *Jupiter Icy Moons Explorer* (*JUICE*). I was fortunate enough to be present at the launch from French Guyana on 2023 Apr 14. *JUICE* is now on its way, ultimately reaching Jupiter. It will make three fly-bys of the Earth–Moon system for gravitational assist and another past Venus. The magnetometer was built at Imperial College London, led by Professor Michele Dougherty. I am also associated with the radio plasma-wave instrument and the UV spectrograph. Four out of five of the stated aims of *JUICE* are concerned with Ganymede: why is Ganymede unique, what are water worlds like, what is the nature of the complex relationship of Ganymede with Jupiter, and is there life in the Jupiter system? In 2031 *JUICE* will be orbiting Jupiter with some fly-bys of the moons, and ultimately it will enter orbit around Ganymede with closest circular orbits of 200-km altitude.

What is happening on the cometary front? After *Giotto* and *Rosetta*, the next ESA mission to visit a comet is the *Comet Interceptor* mission originally proposed by Geraint Jones, the lead, from UCL, and Colin Snodgrass, the deputy lead from the University of Edinburgh. I joined the proposal at the start. The goal is to target a dynamically-new comet — a comet which reaches the inner Solar System for the first time, as we would like to study a body which is as pristine as possible. Comets were formed at the same time as the Solar System but unlike planets and moons they do not evolve for most of their lives until they reach the inner Solar System. They are time capsules. Another originality of *Comet Interceptor* is that it offers a multi-point capability.

In 1966 Jim Dungey already proposed a cluster mission to ESA. This ultimately led to *Cluster* with four spacecraft which was launched in 2000 and is still orbiting the Earth. *Comet Interceptor* is composed of three spacecraft, the mother spacecraft *A* and two probes *B1* (from JAXA) and *B2*. It was selected by ESA in 2019 and adopted in 2022 which means that we can go ahead with building the instrument. We have to deliver the instruments by the end of October 2025/early 2026 with launch in 2029. When the dynamically-new comet is detected we need to be ready to reach it. The spacecraft will be waiting at the Lagrange point L2. I am interested in the interaction between the solar wind and cometary plasma, especially plasma and field boundaries and regions.

We have engagement events for the public every month at Imperial College London. For December the topic was 'Space'. It is important to share our passion for space physics and science in general and inspire future generations. All the work I have described has been possible thanks to collaborations with colleagues in the UK, Europe, and the USA, and above all, with my team at Imperial College London.

Dr. Sanchez Cano. I have a question on the last slide that you showed of the cometary environment where the solar wind was accelerated. Can you explain the process at play?

Professor Galand. What happens is that the solar radiation ionizes the cometary neutral gas which leads to the set-up of an ambipolar electric field and a potential well. The solar-wind electrons fall into the potential well, are accelerated, and are able to ionize and excite the neutral gas. You have the energy of a solar-wind electron which is colour-coded in energy on the figure with blue as low energy and red as higher energy; as the electrons fall into the potential well they are accelerated. If they don't undergo collision then they get out of the potential well. If not they will deposit energy by ionizing and exciting the cometary gas; that is the source of the cometary aurora.

Mr. Steven Cockcroft. I love the idea of picking up a pristine comet. How do you know that it is pristine, and that it didn't pass 100 years ago and we just didn't spot it?

Professor Galand. Modelling the dynamical history we can look back at the evolution of comet orbits. Nearby stars, or massive planets such as Jupiter, can alter the cometary trajectory. For 67P, in the 19th Century and also in the 1920s and late 1950s, its orbit was perturbed which brought it ultimately into the inner Solar System where it has outgassed more significantly. There is an hemispherical asymmetry in the composition of the neutral gas in 67P and that may be due to evolutionary changes. For *Comet Interceptor*, we really want to have as pristine a comet as possible. When new candidates are detected, the dynamical history has to be modelled.

The Chair. A quick question about *Comet Interceptor*. You are at L2 waiting for your pristine comet to appear. How long can you wait and will you be operating your instruments there?

Professor Galand. *Comet Interceptor* can wait up to four years at the Lagrange point L2. It's a function of the amount of propellant. Currently ESA is not planning to allow science operation for L2 but let's see. There is already a Target Identification Working Group as part of *Comet Interceptor* and we have already started to look at candidates, in order to assess how many dynamically-new comets per year we could discover and are suitable candidates. We also have back-up candidates just in case. It will take between six months to three years to reach the comet; if you wait longer at L2 it will not be possible to go as far. Let's hope to find a very good target fast enough not to have to wait at L2 too long.

The Chair. Can I thank you again, Marina? [Applause.]

I'd like to remind you about the drinks reception after this meeting in the RAS Council Room and I give notice that the next A & G Highlights meeting will be on Friday, December 8th.

LATE-VICTORIAN LANCASHIRE ASTRONOMERS AND THE RAS 1871–1901

By Steven Phillipps

Astrophysics Group, University of Bristol

A previous paper[1] outlined the contribution of Lancashire astronomers to the Royal Astronomical Society in the fifty years to 1870. For most of this time the RAS and its journals were essentially the only specific vehicles through which serious participants could share their astronomical interests. As the century progressed, though, various developments spread the astronomical base more widely, in what Allan Chapman[2] has called "the rise of the leisured enthusiast". A new 'popular' journal, the *Astronomical Register*, appeared in 1863 and local astronomical societies began to establish themselves, notably in Liverpool in 1881, while the British Astronomical Society, later Association (BAA), followed in 1890, with a North-West Branch centred on Manchester. This article explores how these factors affected the involvement (or otherwise) of Lancashire astronomers in the RAS. As in the previous paper, 'Lancastrian' is taken to mean a resident of the traditional (pre-1974) county, counting only persons who became involved, or at least interested, in astronomy while living there (though a few born in Lancashire but living elsewhere rate a mention).

1871–1880

We should actually first note an extra pre-1870 FRAS inadvertently omitted from the previous paper[1]. Born in 1817, Rev. John Edwards trained at St Aidan's College in Birkenhead and was appointed rector in Bradford-cum-Beswick in Manchester in 1859, becoming expert in ecclesiastical history. Also interested in the history of astronomy, he was elected an FRAS in 1869[3].

Even though the RAS president was the Lancashire-born William Lassell[1,2] (by then resident in Kent), only one Lancastrian was elected a Fellow in 1871. This was Samuel Cottam of Wightwick House, Higher Broughton near Manchester, born in 1828, the son of the earlier Fellow, Samuel Elsworth Cottam[1]. Cottam Jnr. was a chartered accountant, becoming the head of the family firm, and was also a painter, a musician, and a photographer[4], but did not publish any astronomical results.

There was, though, a brief note in *Monthly Notices* (*MN*) in 1871 on the Zodiacal Light[5] from a non-member, Rev. W. A. Jevons of Liverpool. William Jevons was a Unitarian minister, born in Worcestershire in 1794 but brought up in Liverpool. He was educated at Manchester New College, a non-conformist academy (actually then sited in York), but left the ministry due to differences of views. He wrote a book for schools: *Elements of Astronomy illustrated by the more useful Problems on the Globes and adapted for the Use of Young Persons and those unversed in mathematics*. His nephew, W. Stanley Jevons, is generally considered to have been the first mathematical economist.

Also in 1871, *Nature* reported a paper[6] read at the Manchester Literary and Philosophical Society by Prof. Osborne Reynolds in which he suggested that the tails of comets, the solar corona, and the aurora were all electrical effects in the ether which filled space, specifically "comet's tails are an effect due to the medium through which it passes being heated and illuminated by the comet". Reynolds, born in Belfast in 1842, had been appointed professor of engineering at Owens College, the forerunner of the Victoria University of Manchester, in 1868. He subsequently became famous for his studies of fluid mechanics, particularly turbulent flow (the Reynolds number, *etc.*). He became an FRS in 1877 and won their Royal Medal in 1888[7]. However, despite writing on the structure of the Universe, he appears never to have joined or communicated with the RAS.

Returning to actual RAS members, John Alexander Bennion (born in Manchester in 1849) evidently developed his interests in astronomy while studying at Manchester Mechanics' Institute and Owens College in the late 1860s, obtaining certificates in both natural philosophy and engineering, and was elected an FRAS at an early age in 1872. Trained as an engineer, in 1869 he had won 1st prize of £5 for his performance on Principles of Mechanics in the final examinations of the Royal Society of Arts, Manufactures and Commerce. Matriculating at Cambridge in 1875[8] he was called to the bar in 1884 and described himself as barrister-at-law when voted vice-chairman of the Mathematical and Physical section of Manchester 'Lit and Phil' in 1888. He was later director of technical education for Lancashire County Council and lived in Blackpool.

Rev. Samuel Jenkins Johnson[9] also became an FRAS in 1872. Though by then a vicar in Devon, he was born in Atherton in Lancashire in 1845 and after obtaining his degree was a curate in nearby West Houghton. He sent observations of Mercury that he had made from Lancashire in the 1850s and 1860s to the *Astronomical Register*[10] in 1872 and had earlier[11] communicated observations of the aurora *via* W. F. Denning, founder (in 1869) and secretary of the fairly short-lived Observing Astronomical Society[12] (OAS), whose members were "gentlemen possessing astronomical instruments for the purpose of securing concerted observations". Johnson subsequently supplied 37 papers to *MN*, many on eclipses.

Denning[13] recorded in *Astronomische Nachrichten* in 1872 that the late Edmund Salter of Manchester had been able to see twelve stars in the Trapezium with his "12 inch reflector of superior quality". Despite this impressive instrumentation, Salter, though contributing to the OAS[20], did not join the RAS. Born in 1819 in Wiltshire[14], he lived in Hulme in Manchester and in Ashton-under-Lyne and was Inspector of Schools under the British and Foreign School Society. Unfortunately he was "the victim of a melancholy accident at the Peterborough Railway Station" in 1870.

Probably less surprisingly, a further OAS correspondent, and subscriber to the *Astronomical Register*, who provided details of a range of observations[15] around this time, Henry Ormesher of Patricroft, near Manchester, did not join the RAS either. He was a rare working man in our list of observers, a foreman boiler maker, born in nearby Eccles in 1829. One wonders if he might perhaps have worked at engineer/astronomer James Nasmyth's works which was sited in Patricroft[1].

Three additions to the RAS ranks appeared in 1873: Joseph Ridgway Bridson of Bolton and Belle Isle Windermere, John Berger Spence of Erlington Hall, Manchester, and Joseph Hough of Rossall School, Fleetwood. Bridson was born in Horwich in 1831 and went into the family bleaching and calico-printing company in nearby Bolton, the family residing at Bridge House adjacent to their works. (His father was mayor of Bolton.) A champion yachtsman, founder of Windermere Yacht Club in 1860, he later leased the whole of Belle Isle in Windermere as a country residence. He became a subscriber to the *Astronomical Register* in 1869, prior to joining the RAS. He was also president of Bolton Photographic Society[16]. His son of the same name became an admiral. He was also related to Mary Augusta Ridgway Bridson, former Prime Minister Tony Blair's grandmother.

Spence was born in Cumberland in 1839 and was a metal and chemicals merchant in Manchester (his father, a leading chemicals manufacturer, was Justice of the Peace for the County of Lancaster). He was a member of the Royal Institution and a Fellow of the Geological Society, the Royal Geographical Society, the Chemical Society, and the Royal Society of Literature[17]. Born in Leeds in 1837, Hough was originally an engineer, then worked at Lord Wrottesley's private observatory[18], some of his observations being reported in *MN*[19]. Later graduating from Cambridge, in the 1870s he was assistant natural-science master at Rossall and then headmaster of Burnley Grammar School.

The Rev. James Pearson of Fleetwood joined the RAS in 1874. A native of Preston and attending the grammar school there before matriculating at Cambridge, he was 15th wrangler in 1848. A varied career saw him as a curate in Scarisbrick near Ormskirk, a maths master in Norwich, and professor at the Royal Military College, Sandhurst, before returning to clerical positions and becoming vicar of Workington and then Fleetwood in 1871[20]. He published one *MN* paper, in 1879[21], on the adjustment of 'equatoreal' telescopes, and wrote widely on tides. He also produced a paper for *L'Astronomie*, '*La Date du Commencement de l'Ere Chretienne*', which he suggested was out by three years.

George Russell Rogerson of Waterloo near Liverpool also joined in 1874. Born in Fazakerley, Walton-on-the-Hill, then a village outside Liverpool, in 1839, he was a solicitor, public notary, freemason, and captain in the 8th Lancashire Artillery Volunteer Corps. He was also a Fellow of the Royal Geographical Society and the Royal Society of Literature[22] but was apparently most noted as an early member, then chairman, of the National Dog Club, a forerunner of the Kennel Club[23]. He was an observing colleague of R. C. Johnson (below). He donated his observatory to his old school, Liverpool College, in 1886 and in the 1890s migrated to Australia.

David Winstanley, then resident at the Doctor's Cottage, Blackpool, was elected an FRAS in 1875, as was John Brise Colgrove, 'Head Master of the Modern Side' at Rossall School. The former was born in Manchester in 1846 and was initially a photographer in Newton Heath, but in 1881 he is recorded as an "inventor of scientific instruments", in Richmond, Surrey. His only contribution to the RAS appears to have been the donation of an unspecified item to the library in 1882[24]. However, he had sent an observation of a possible daylight aurora, seen from Blackpool, to *Nature* in 1871. Colgrove was born in Buckinghamshire in 1840 and taught in a prep school from an early age before entering Cambridge, being awarded his MA in 1872. He was later headmaster of Loughborough Grammar School and was a keen member of the Alpine Club, he and two colleagues from Rossall being the first to scale the Matterhorn without guides[25] in 1876. He was a member of the RAS for 56 years without contributing to *MN*.

Although he was not yet an FRAS (he did not join until 1891), 1875 saw the first published work[26] from Father Walter Sidgreaves, S.J., from the observatory at Stonyhurst College, a Jesuit boarding school near Clitheroe. Stonyhurst was the primary observatory in Lancashire for many years with annual reports in the major journals[27]. Father Sidgreaves was from Grimsargh near Preston (born 1837) and attended Stonyhurst as a pupil before becoming a teacher there. He was temporary director of the observatory from 1863 to 1868, in the absence of Father Perry, and was then Perry's assistant, taking part in the Venus transit expeditions to Kerguelen Island and Madagascar. He took over the directorship after Perry's unfortunate demise in 1889[1]. Originally most interested in meteorology and terrestrial magnetism, he later undertook the spectroscopy of stars, particularly novae, producing numerous papers for *MN*[28].

Another assistant to Father Perry at that time was William Carlisle. Born in London in 1842, he became a brother at the seminary at Stonyhurst in the 1860s and in the 1871 census was recorded as "astronomer/domestic servant"(as was colleague Joseph Hostage). He travelled to Belgium with Perry that year to help with magnetic-survey observations and accompanied Perry and Sidgreaves to Madagascar in 1882. His telescopic observations were also acknowledged in a number of Perry's *Monthly Notices* papers[29] on Jupiter's satellites and occultations, and in one by the Rev. W. J. Crofton, S.J., on Barnard's Comet of 1888[30]. By 1881, he had the more formal appellation of 'clerk to the director' and was now Father Carlisle, S.J. (William Crofton only appears to have been briefly at Stonyhurst; by 1891 he was at St. Bueno's College in St. Asaph before becoming headmaster of Wimbledon College.)

Next actually to join the RAS, in 1876, was Richard Coward Johnson of Blundellsands, near Liverpool, who had already sent an observation of the crater Archimedes to the *Astronomical Register* (signed as "rcj") in 1868. He was born in Liverpool in 1840 and was initially an accountant for the family coal-merchant's business, later recording himself as "coal proprietor", living at The Hall, Higher Bebington on the Wirral, where he had his observatory[31]. He owned a 9¼-inch telescope, being one of the first amateurs to use silver on glass mirrors, and in due course contributed two papers to *MN*[32] (28 years apart). He also helped to form the Liverpool Astronomical Society, being president in 1882, and was a long-time member of the Liverpool Literary and Philosophical Society from 1863[33]. He travelled extensively in the near east in the 1870s with cleric–explorer–naturalist Henry Baker Tristram, contributing appendices of astronomical observations to one of Tristram's books.

In 1877, we find Thomas Gregory, assistant master at Merchant's College, Blackpool, joining the RAS[34]. Born in 1849 in Manchester, he was the son of the principal of the school for the sons of merchants. The following year, two more Lancashire schoolmasters joined, Benjamin Templar of Birkdale, Southport[35], and William Hobson from Whalley Range in Manchester[36]. Templar, born in Bristol in 1829, ran a school in Salford before moving to Southport where he died a year after joining the RAS. Hobson was born in Armagh in 1843 and studied, then taught, at a Quaker training college in Yorkshire, before becoming proprietor of a school in Manchester. He later returned to Ireland as a tutor.

Sir Franz Arthur Friedrich (known as Arthur) Schuster was born in Frankfurt in 1851 but made his name in Manchester where his father's textile business was located. After working briefly for the family firm he became a student at Owens College and subsequently carried out research into spectra at Cambridge (spending a year with Kirchoff in Heidelberg). He was invited by the Royal Society to lead an expedition to Siam (now Thailand) to photograph the spectra of the corona during an eclipse in 1875. He was elected an FRAS in 1877, FRS in 1879, became professor of applied mathematics at Owens (by then part of the Victoria University) in 1881, and succeeded Balfour Stewart as professor of physics in 1888. He became its first Dean of Science when the independent Manchester University was created[37]. Along with extensive work in other areas, he had five papers in *MN* on the Sun[38] and later published a key paper for the study of stellar atmospheres, 'Radiation through a Foggy Atmosphere', in *Astrophysical Journal* in 1905.

Arthur Edward Nevins of Liverpool (born 1853) became an FRAS in 1879, publishing the same year[39] his views 'On the practical Advantages of Hartnup's Method of testing Chronometers' as determined during numerous long-distance voyages. Originally in the navy, he then followed in the footsteps of his father, the distinguished John Birkbeck Nevins, by training in Edinburgh as a medical doctor and becoming a member of the Royal College of Surgeons. He practised in Stoke before joining his father's practice back in Liverpool[40] along with his brother.

A perhaps unlikely, but well-known, name gave an astronomical talk (on damping oscillations of his own telescope) at the Manchester Literary and Philosophical Society in 1879, as reported in *The Observatory*[41] — its president James Prescott Joule FRS, already famous for his studies of heat. Joule was born in Salford in 1818 and worked in the family brewery business there before concentrating on his scientific experiments[42], particularly after building his own laboratory at his father's home in Whalley Range.

There was only one addition to the RAS in 1880, Rev. William Smith of Chorley. Born in Cheshire (1844) but brought up in Lancashire, he started out as a boiler maker like his father before becoming a well-travelled Primitive Methodist minister who also gave lectures on astronomy[43].

1881–1889

The Liverpool Astronomical Society (LAS) came into being in 1881[44], catering at first for amateur astronomers in the vicinity of the city, "a kind of halfway resting-place between the amateur public and the Royal Astronomical Society", but thanks to its energetic first secretary William Henry Davies[45] it soon became a national and even international entity. (There was a branch in Pernambuco, of which the Emperor of Brazil was an honorary member.) At its peak importance in the late 1880s it had more than 600 members, but only a small minority actually lived in and around Liverpool (56 within 12 miles in 1886), and many of these were on the other side of the Mersey, in Cheshire, including its early president and major observer, Rev. T. H. E. C. Espin[46].

Born in Hertfordshire in 1831, Davies ran a business in Liverpool making pianos. (Indeed, he published a series of articles in the *English Mechanic* on 'How to make a pianoforte'.) He contributed numerous papers to LAS meetings and in 1884 joined the RAS. His son of the same name (born in Liverpool 1857) was also active on the council of the LAS and was a piano teacher. Only a few of the other local members contributed papers to the Society's journal or its meetings, though, and like Davies senior these were generally also in the RAS, as below. (A few later joined the BAA rather than the RAS, including council member Walter Sang, a civil and mechanical engineer from Edinburgh (born 1836) who lived in Sefton Park in Liverpool and was a variable-star observer[47], and the LAS librarian[48] Charles Albert Defieux, a New York-born (*c.* 1850) restaurant manager in Liverpool who later became a mechanical and electrical engineer before emigrating to Canada.)

The splendidly named Squire Thornton Stratford Lecky joined the RAS in 1881 while living in Bootle. He was a master mariner and lieutenant in the Royal Naval Reserve (later retiring as Honorary Commander RNR)[49]. Born in County Down in 1838, he ran away to sea when he was 14, was subsequently second mate on a China clipper sailing out of Liverpool, and then joined the Indian Navy. Rejoining the merchant marine, at one point he attempted to run the blockade of Charleston harbour during the American Civil War. He became an authority on navigating the Pacific Ocean and the coasts of South America, and his book *Wrinkles on Practical Navigation* ran to fifteen editions. He later worked as marine superintendent for the Great Western Railway in Milford Haven, overseeing their ferry services. His son was also a Lieutenant in the RN.

James Cook of Preston had been one of the original committee of the OAS and supplied observations of Jupiter[11] to Denning, but did not join the RAS until 1881. Cook built his own refracting telescopes and was one of the group Denning organized to carry out a systematic search for the hypothetical inner planet Vulcan. Born in Lancaster in 1829 (his RAS obituary incorrectly says 1839), he is listed[50] in 1869 as a "coal proprietor and merchant". He moved to the University of Sydney in 1884 and worked there building equipment for the next 25 years[51].

The next Lancastrian FRAS, in 1882, was actually a Welshman[52]. Isaac Roberts was born in Denbighshire in 1829 but was apprenticed to a firm in Liverpool when he was 15, eventually becoming its manager. Setting up on his own as a building contractor in Liverpool, he became one of the most prominent master builders in the area and accumulated a substantial fortune. By 1878, he had his own observatory, at first in Rock Ferry on the Wirral, then from 1883 in Maghull outside Liverpool[53]. An early member of the LAS, he was its president in 1885–1886. He became interested in the possibilities of astrophotography and in 1888 sent to the RAS what is reckoned to be the first ever photograph of a galaxy (M31 with its companions)[54]. He also published the first book of astronomical photographs, in 1893, by which point he had sold his business and relocated his observatory ('Starfield') to Sussex. In all, he made around a hundred contributions to astronomical journals, 79 of them in *MN*. He was elected an FRS in 1890 and won the RAS gold medal in 1895. His second wife was American/French astronomer Dorothea Klumpke.

John Wilson Appleton of Toxteth Park also joined the RAS in 1882. He was another early member and Secretary of the LAS, reports of whose meetings were carried by *The Observatory* from 1883[55]. He had been born in Liverpool in 1835 and was originally an accountant, recorded as having a "counting house and works" in Toxteth. Later he was a schoolmaster and he was also a Wesleyan preacher.

Though not yet in the RAS — he joined in 1887 — Rev. John Bone from Lancaster had a letter to the *English Mechanic* concerning a lunar crater commented on in the *Astronomical Register* in 1882[56]. He was on the provisional committee for the proposed British Astronomical Society (subsequently Association) in 1890[57]. Born in Southwark in 1835, he was a curate in Southport from 1865 before becoming a vicar in Lancaster[58]. He was also involved in the Lancashire Philosophical Society and founded the Lancaster Astronomical and Scientific Association in 1903[59].

Frederick Charles Green from Breightmet near Bolton (where he was born in 1853) was elected an FRAS in January 1883[60] but died of consumption on the Isle of Man four months later at the age of only 29. Educated at Bolton School, he had originally been a clerk in the shipping trade and had a great interest in sailing, but became a master cotton bleacher at his brother's works.

An intriguing inclusion in *The Observatory*[61] that year was a review of 'A New Mechanical Sky-Map', "a handy and useful contrivance", made by Theodore Grosse of Manchester. From the description it is evidently a variant of what is now referred to as a planisphere. Grosse was a civil engineer born in Dresden, Saxony, in 1851, but was living in Manchester by 1875 and was also in the machinery-export business.

Next to join the RAS, in 1885, was another LAS member, the Rev. Canon James Hardy Honeyburne, who, in his own words[62], had "a 3¼-inch telescope, in a little back yard in Liverpool". Born locally in 1845, he was a Wrangler at Cambridge[63] and taught at a grammar school before being ordained. He was the incumbent of parishes in Everton and Toxteth Park and later a vicar in Southport. He also served as an Honorary Canon of Liverpool and Rural

Dean of Southport. The same year saw Captain Benjamin Thomson RNR of St. Helens join the RAS[64]. Born in Dumfries in 1845, he went to sea when he was 15 and obtained his master's certificate in Liverpool in 1869. He was a freemason, recorded as being with the Hong Kong Lodge in 1889, later retiring to Sussex.

We can note that by the end of the 1884–85 session, there were 28 RAS Fellows with an address in Lancashire[65], including Rev. William Owen Williams of Liverpool who had been elected in 1868 when living in Pwllheli[52] in what was then Carnarvonshire. He was born on Anglesey in 1817 and was a 'Welsh Calvinistic Methodist minister' in Toxteth Park. He was a lunar observer whose work was noted in the *Register*[66]. (The number of Lancastrian Fellows reached 31 in 1895, then remained about the same for the rest of our time period.)

Next, later in the year, was Richard Wilding of Fulwood, Preston, already an LAS member, who was the 'curator' of Preston Observatory and owned a 19-inch reflector. He appears to have been initially interested in double stars but became director of the Photography Section of the BAA from 1898[67]. Born in 1842 in Preston, he was a cotton manufacturer "employing 377 adults and 147 children" in 1881. He later moved to Kent.

Elected an FRAS in 1886 while at Cambridge reading mathematics and law, John David McClure (eventually Sir John, LL.D.) gave his address in 1890 as his home town of Wigan (born 1860). He had previously been a grammar-school assistant master and obtained a degree in music at Owens College. He worked as a University Extension Lecturer, then became professor of astronomy at Queen's College, London. Later Headmaster at Mill Hill School, raising it to be "one of the chief Nonconformist public schools in the country", he was knighted in 1913[68].

Rev. Samuel Hickling Parkes of Swinton Industrial School, Manchester, was elected an FRAS in 1887[69]. (The school was for pauper children, being seen as a more productive alternative to the workhouse.) His uncle, of the same name, an optical instrument maker in Birmingham, had joined the RAS in 1882. The Reverend was born in 1849 in Staffordshire and in 1871 was recorded as a "student of theology". A Wesleyan minister, he was living in Bolton in 1891 but unlike his uncle is, for some reason, not in the 1890 list of RAS Fellows.

A further LAS stalwart and sometime president, James Gill, was elected to the RAS in 1888 and later also joined the BAA. Born on the Isle of Man in 1840, he trained sailors in navigation and seamanship in Liverpool. He was Principal of the Navigation School at the Sailor's Home and then headmaster of Liverpool Corporation's Nautical College[70]. He wrote *A Text Book of Navigation and Nautical Astronomy*.

Rev. (Thomas) Joseph Walshe was another Liverpool resident elected in 1888[71]. Born in 1862 in Ireland, and trained at Ushaw College in Durham, he was a Catholic priest (eventually Right Reverend Monsignor) and an 'officer' at a college for theological and humanities students. He was also noted for his support of the women's suffrage movement and was awarded an honorary master's degree by Liverpool University in 1920.

Yet another clergyman, the Rev. George Burgess, was proposed for the RAS by Fellow Wesleyan Methodist preacher (and one might guess relative) the Rev. John Burgess, at the end of 1889, while living in Urmston, just outside Manchester[72]. Born in Leicestershire in 1844, he had been in Lancashire since the 1870s but in 1893 he emigrated to New Zealand as a Congregationalist parson. Robert Lethbridge Tapscott gave his affiliation as Owens College when proposed at the same meeting as Burgess, but was a civil engineer in Liverpool by the time he was elected after the usual two-month gap[73]. Born in Liverpool in 1857 and graduating at King's College London in 1876, he worked for the Lancashire and Yorkshire Railway. He was also a member of the Institution of Civil Engineers (contributing a paper 'Railways in India' to Liverpool Engineering Society[74]), a Fellow of the Geological and Meteorological Societies, and a member of the Society of Arts. He held a patent for a "machine for cleaning and polishing boots or shoes". He appears to have emigrated to the USA in 1897.

1890–1901

The intriguing character George Higgs was next to sign up in the RAS. George Daniel Sutton Higgs (born Daniel Sutton in Devon in 1841), the son of an agricultural labourer, somehow acquired a significant and surprisingly broad education[75] and by 1861 was a watchmaker's apprentice. A few years, and name changes, later he moved north, setting up business in Liverpool where he was listed as "George Higgs, watchmaker". He used his technical skills to construct a remarkable high-quality solar spectrograph and by the late 1880s was supplying photographic spectra to the RAS[76]. In 1893 he published a notable *Photographic Atlas of the Normal Solar Spectrum*. His work was considered as good as any from professional observatories[77] and George Ellery Hale visited the laboratory at his home. Higgs was a prominent member of the LAS from 1886 (later becoming its president), the BAA, and Liverpool Physical Society[78].

Thomas William Brownell, then of Moss Side, Manchester, also joined the RAS in 1890[79] and a couple of years later was one of the early members of the BAA. Born in 1856 in Hulme, Manchester, he was an 'inspector of board schools' there for many years. Another to join was (Lawrence) Neville Holden. Born in Lancaster in 1864 and educated at the local grammar school, he was a solicitor there and succeeded his father as Coroner for the district and then Registrar for the county court. Scientifically, he was honorary director of the Greg Observatory at Escobeck near Lancaster[1], mainly collecting meteorological records, and a founder member of the Lancaster Astronomical and Scientific Society[80].

The end of 1890 saw the arrival on the scene of the British Astronomical Society, almost immediately renamed the British Astronomical Association, which took over from the now rather ailing Liverpool society as the primary national 'amateur' organisation. (The RAS was considered more for 'professionals' though of course most of its members were themselves amateurs, in the normal sense.)

Thomas Weir was a founder member of the BAA in 1890 and the original secretary of the North-West Branch of the Association two years later. He became an FRAS in 1899[81]. After financial problems in the North-West Branch, he defected to the new Manchester Astronomical Society (MAS) in 1903. He travelled to the solar eclipses in Norway in 1896 and Spain in 1900. An engineer, born in Scotland in 1843, he moved to England and worked for many years for the Vulcan Boiler and General Insurance Company in Manchester.

The first Lancashire resident elected to the RAS in 1891 (apart from Rev. Sidgreaves, see earlier) was George Price Blackwood Hallowes[82] of Didsbury. He was born in Cumberland in 1867 and educated in the Isle of Man and worked for the Surveying Branch of the Post Office. After his time in Lancashire, he was later based in various other parts of the country. He had supplied an observation of a bright meteor seen from Manchester in 1887[83] and also became a member of the BAA. He had been involved in astronomy from the age of 17 and was a regular observer of the Moon and variable stars with a 12½-inch

Calver reflector.

Father Sidgreaves' Stonyhurst colleague Rev. Aloysius Laurence Cortie, S.J., also joined in 1891, though he was then at St. Bueno's College in North Wales, where he was ordained. He was later president of the North-West Branch of the BAA. Born in London in 1859, and a pupil at Stonyhurst, he had become a teacher there in 1885 and returned to this post in 1895. He became director of the observatory in 1919[84]. He travelled to several solar eclipses and produced numerous papers in *MN* on sunspots and their magnetic effects[85] as well as on the spectroscopy of novae. In total he made 141 contributions to various publications and was a delegate at the first General Assembly of the IAU in 1922.

A further new Fellow in 1891 was John Billington Booth JP. Born in Preston in 1821, Billington Booth and his widowed mother became partners in a spindle-making business[86] and by the age of 50 he had risen to "magistrate, landowner, merchant (machinery), spindle and fly maker (master employing 31 men and 38 boys)", and staff at his Overleigh House included a butler. He was also chairman of Preston Gas Company, patenting an ignition device, and was a member of the Historic Society of Lancashire and Cheshire and of the Society of Arts[87].

Also elected in 1891, but more eminent scientifically, was Oliver Joseph Lodge D.Sc., LL.D., FRS, professor of physics in University College Liverpool (our first entry from that establishment, which had been established in 1881). A key early player in the field of practical electromagnetism[88], in 1894 Lodge made what is considered the first ever radio transmission. He was a keen defender of the idea of the all-pervading ether, even after the advent of General Relativity; his only appearance in *MN* is his part in an argument with Eddington and Jeans at the RAS meeting where the results from the 1919 eclipse results were discussed[89], though he did regularly communicate to *Nature* on astronomical topics. He had been born in Staffordshire in 1851 and worked in the family pottery business before obtaining a degree in physics. (He had a letter in the *Astronomical Register* in 1872[90].) He moved to Liverpool in the university's inaugural year and left to become the first Principal of the University of Birmingham in 1900. He was knighted in 1902. He was a president of the British Association, an active member of the Fabian Society, and also a spiritualist with a committed belief in life after death. Another of the new RAS Fellows in 1891 was Arthur Laidlaw Selby. He was born in Atherton (1861) but worked at the Clarendon after graduating in Oxford, and from 1890 spent the rest of his career as assistant professor and then professor of physics at the University College of South Wales and Monmouthshire in Cardiff[52]. His RAS obituary does not reference any astronomical work[91].

Rev. James Barnes Brearley of Oldham and Thomas Torrens Knowles M.A. were elected in 1892. Also a Fellow of the Royal Geographical Society, Brearley was born in Manchester in 1862 and attended Manchester Grammar School. He was a 'clerk in holy orders' and gave his address as St. James' Church in Oldham, though he shortly afterwards removed to Leicestershire and then Somerset. (He is not in the list of Fellows for 1896.) He matriculated at Cambridge[92] in 1900 but isn't recorded as graduating (he died in 1909). A 19th Wrangler at Peterhouse[93], Knowles (born 1857, in County Antrim) was a Cambridge Extension lecturer in chemistry, Lancashire County Council lecturer in physics, and science master at the Royal Grammar School, Lancaster, when he joined the RAS. (He too is missing from the 1896 list of Fellows.) He was later vice-principal of Liverpool College.

The year 1892 had also seen the formation of a North-West Branch of the

BAA, centred on Manchester. Of the eighteen members who turned up at its first meeting, at most eleven were from Lancashire, including four current or future FRAS — Banks, Brothers[1], Hallowes, and Weir — but the numbers quickly expanded. Another early member was Thomas Thorp. Born in Besses o' th' Barn between Manchester and Bury in 1850, he later lived in nearby Whitefield. Originally an architect, he was engineer to the local council and had a business manufacturing his own patented inventions, such as 'penny-in-the-slot' and rotary gas meters. He built his own telescopes for observatories at his home and at a cottage in Prestatyn in North Wales and was an expert on spectroscopic gratings[94] but did not join the RAS until 1902[95].

The next RAS Fellow, in 1893, was John Spencer[96] of Crawshawbooth, a village in the Rossendale Valley on the edge of the Pennines. Born there in 1823, in 1891 he was recorded as a "retired stone traveller"; he had earlier been a quarry master, and appropriately, was a Fellow of the Geological Society (and lived at Rock House, at the end of Rock Terrace). Joining him was Edward Turner Whitelow[97], a civil engineer of Deansgate, Manchester. Originally from Yorkshire (born in 1854), though his family moved to Salford while he was young, he worked for an engineering firm involved with railway and iron-making companies. By 1891 he had become a "consulting engineer and patent agent", with a business in Manchester trading in textile machinery, particularly to the Far East. He built an observatory at his home in Birkdale, Southport[98], and installed a telescope originally owned by Rev. Dawes[1]. At first making double-star observations, he became expert in photographing sunspots, collaborating with Janssen at Meudon. He eventually donated his instruments to Stonyhurst College. As well as the RAS and the Institution of Civil Engineers, he was also a member of the LAS, was on the council of the North-West Branch of the BAA, and later became president of the MAS.

Existing Fellow William Benjamin Hutchinson moved to Southport in 1894. He had been an FRAS since 1888, when he gave his address as The Observatory, Liversedge, in Yorkshire, and was president of the LAS in 1890–91. Born in London in 1863 and educated at Eton, he had spent time exploring in Africa before following his father into engineering. Adept at building his own instruments he was mainly an observer of the Moon and Saturn; he unfortunately died at the age of 35[99].

Though not a Fellow of the RAS, Davis Edmonson Benson (born in Moss Side in 1860) seems to have been a member of almost everything else. A civil engineer in Southport[100], he joined the Institution of Civil Engineers in 1886 and was subsequently in the Southport Society for Natural Science (president in 1900), the Royal Photographic Society of Great Britain, the LAS and, from 1894, the BAA. Writing extensively on mirror making, he was noted for his photographs of the Moon, and travelled to Spain in 1905 (with the Rev. Killip, see below) to photograph the eclipse of the Sun. Despite not being a member, he did attend RAS meetings and some of his work was referenced in *MN*[101].

Moving on to 1895, the next Lancashire resident to be elected FRAS was Charles Josephus Green[102]. (He used the style M.R.C.S., though his name is not apparent in the records of the Royal College of Surgeons[103].) He had been born in Melbourne, Australia, in 1846 but trained at Bart's in 1865–66. He was a house surgeon in Huntingdonshire County Hospital and by 1878 resided in Preston, with a surgery next door to his house.

Also in 1895, Professor Thomas Hamilton Core became president of the North-West Branch of the BAA[104]. He was later the first president of the MAS, which effectively replaced the North-West Branch in 1903. A Scot (born in

Lanarkshire, 1836), he had been one of the first professors of natural philosophy (along with Balfour Stewart) at Owens College in 1870 and lived in Fallowfield. Although he lectured on astronomical topics, he does not appear to have worked in the field. A much more active member of the North-West Branch from 1895 was Albert Alfred Buss who made around 60 contributions, mainly on magnetic and solar phenomena, to the *JBAA*, *The Observatory*, *MN*, and *Nature* between 1900 and 1932[105]. He also ran the Lee Observatory in Chorlton-cum-Hardy, Manchester[106], and eventually joined the RAS in 1908 while living in Ashton-on-Mersey. Born Frederic Albert Hermann Alfred Buss in the Grand Duchy of Baden in 1860, but a Swiss subject, he was a civil engineer.

Proposed by the RAS president Sir R. S. Ball, no less, Rev. Robert Killip was elected an FRAS the following year while living in Sale in Cheshire. From a Manx family, he had been born in Liverpool in 1853 and worked in a shipping house there before training as a Wesleyan minister. This led to various moves around the northern counties, though he was back in Liverpool by 1901 and subsequently resided in Southport. A member of the BAA and secretary of the LAS from 1902, he was a noted planetary observer[107]. He successfully photographed the solar eclipse of 1905 in Spain, along with his Southport neighbour D. E. Benson (above).

He was followed by William Banks from Bolton. Born in the nearby village of Egerton in 1850, he was the proprietor of William Banks and Co., who were manufacturers of optical and photographic equipment. He later specialised in telescopes[108] and published *Telescopes: Their Construction, Adjustment, and Use, with plans and details of Observatories; also full instructions for grinding, figuring and silvering Newtonian Mirrors*, which was in part an advertisement for his 'Popular Equatorial Mount for Telescopes' and the 'Banks Focimeter'.

Additions to the list of Fellows in 1897 were the Rev. Edward Spry Leverton, John Sisson Slater M.A. LL.D., and John Watson. Leverton was at the time headmaster at the grammar school in Kirkham, in the Fylde. Born in Cornwall in 1859 and educated at Marlborough and Oxford[109] (M.A. 1886), he was previously in holy orders in Sussex and was later rector of a church in Northampton before returning to Cornwall as vicar of Menheniot and canon of Truro cathedral. Another to be proposed by R. S. Ball, Dr. Slater was a barrister with chambers in Temple who otherwise lived in Lytham St. Annes where he had been a master at Seafield House School[110] from the 1870s, subsequently doubling up as lawyer and school principal. Born John Sisson in 1855, he was originally from a small village in Westmorland. Watson was then living in Sheffield but shortly afterwards moved to Blackburn. A Scot, born in 1844, he was chief engineer of an iron works in Warrington (then in Lancashire). He had travelled widely, including to India and Australia, and visited numerous observatories. He was involved with the North-West Branch of the BAA, was a vice-president of the LAS, and from 1907 to 1910 was president of the MAS[111].

Lancashire-born academic Sir Edmund Taylor Whittaker FRS was elected an FRAS in 1898, though his inclusion is a little ambiguous as it is not obvious whether he already had astronomical interests while still in Lancashire. He was born in Southport in 1873 and went up to Cambridge from Manchester Grammar School, graduating as Second Wrangler in 1895 and becoming a Fellow of Trinity College. He served as RAS Secretary from 1901 and became an FRS in 1905. He was appointed Royal Astronomer of Ireland at Dunsink Observatory and professor of astronomy in Dublin the following year, publishing seven *MN*[112] papers on variable stars and orbits. Primarily a mathematician, though, he wrote numerous books, starting with *A Course of*

Modern Analysis in 1902 and *Analytical Dynamics* in 1904. He was appointed professor of mathematics in Edinburgh in 1912 and was knighted in 1945[113]. Whittaker's Cambridge students included future astronomical greats Sir James Hopwood Jeans[46] and Sir Arthur Stanley Eddington[46], both of whom had Lancashire connections. Jeans was born in Ormskirk in 1877, but his family moved away when he was young, while Eddington, though born in Westmorland in 1882 and brought up in the south of England, attended Owens College in Manchester, residing at Dalton Hall from 1898 to 1902.

In 1899 Samuel Chatwood was added to the RAS list. An engineer born in 1833 in Edenfield, a village in the Rossendale Valley, he built up a business in Bolton, Chatwood's Patent Safe and Lock Co., making bank safes (employing 123 men and 26 boys in 1881). He also opened offices in London and took out various patents, not just on lock mechanisms but also bicycles. He was a member of the Institutions of Civil Engineers and of Mechanical Engineers, and of the Iron and Steel Institute[114], as well as the Society of Arts. When elected to the RAS he lived in Worsley, outside Salford, where he had a 9½-inch Cooke refractor (which is now in Wanganui, New Zealand[115]). His son Arthur Brunel Chatwood (born in Birkdale 1862) worked for his father's company, managing the London office, before becoming Astronomer at the Nizam of Hyderabad's Government Observatory in 1908[116].

Moving on to 1900 and 1901 (we take the end of the RAS 'year' in July as the endpoint for inclusion), we have three further FRAS. William Harrison Pearsall was a master at the Higher Grade School, Dalton-in-Furness (the Furness peninsular then being part of Lancashire). He had been born in Worcestershire in 1860 and was a schoolmaster there until moving to Dalton in the 1890s. Beyond his interest in astronomy, he was secretary of the Botanical Society and edited their journal[117]. His son, William Harold Pearsall FRS, was professor of botany at Sheffield University and then UCL. Thomas Marginson Nightingale from Bolton had recently obtained a B.Sc. from the Victoria University in Manchester[118]; he was only 28 when he joined the RAS. He remained in Bolton and was a master at the Municipal Secondary School throughout his career. Finally, there is the Rev. George Vickars-Gaskell[119]. Born in Kent in 1857, he was actually trained as a civil engineer before becoming a long-serving vicar in Grange-over-Sands. He had joined the BAA in 1899. We should, though, note one further Lancashire-based Fellow in the 1900 list, the Rev. Henry Glanville Barnacle[120]. A Church of England clergyman, born in London in 1849, he was the head of St. John's College in Grimsargh near Preston. A Cambridge graduate, he had started out as an assistant at the Royal Observatory, becoming an FRAS in 1874 and the same year travelling to observe the Transit of Venus from the Sandwich Islands[121]. He was ordained in 1879, becoming a curate in Yorkshire and a vicar in Cheshire before arriving in Lancashire. In 1911 he emigrated to Australia and was a founder member of the West Australian Astronomical Society.

In summary, it is evident from the above that there were few successors to the earlier Lancashire based 'grand amateurs' such as Lassell, Nasmyth, Dawes, or Baxendell. Isaac Roberts and George Higgs were certainly major players, though, along with Fathers Sidgreaves and Cortie at Stonyhurst, while the Rev. Johnson and A. A. Buss were the most productive of the others. Indeed, few of the RAS Fellows ever contributed any observations to their society. In terms of any additional recruitment through the more widespread opportunities offered by 'amateur' societies and journals, the effect seems to have been small.

The few active members of the LAS based in Lancashire were often already RAS Fellows, with only half a dozen or so subsequently moving into the senior organization. Similarly, despite the large enrolment into the BAA, especially after the formation of the North-West Branch (almost fifty with addresses in Lancashire signed up in 1892 alone), only two early members went on to join the RAS (though four others joined both almost simultaneously). Nevertheless, there were about 60 new FRAS with Lancashire connections in the thirty years covered here, compared to 50 in the previous fifty years. Socially, the Lancashire RAS Fellows were much like their predecessors in the earlier part of the century, with a preponderance of clergymen, business and factory owners, school masters, and engineers.

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REDISCUSSION OF ECLIPSING BINARIES. PAPER 18: THE A-TYPE SYSTEM OO PEGASI

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OO Peg is a detached eclipsing binary system containing two late-A-type stars in a circular orbit with a period of 2·985 d. Using published spectroscopic results and a light-curve from the *Transiting Exoplanet Survey Satellite* (*TESS*) we determine their masses to be 1·69 ± 0·09 and 1·74 ± 0·06 $M_{\odot}$ and their radii to be 2·12 ± 0·03 and 1·91 ± 0·03 $R_{\odot}$. The *TESS* data are of high quality, but discrepancies in the radial velocities from two sources prevent a precise mass measurement. The primary star is definitively hotter, larger, and more luminous than its companion, but its mass is lower (albeit to a significance of only 1·1σ). Using published apparent magnitudes and temperatures, we find a distance of 238·8 ± 6·1 pc, in agreement with the *Gaia* DR3 parallax. Although both components are in the δ Scuti instability strip, we find no evidence of pulsations. More extensive spectroscopy is needed to improve our understanding of the system.

Introduction

In this series of papers[1] we have been systematically reanalysing known detached eclipsing binaries (dEBs) in order to determine their physical properties to high precision. The main improvements *versus* previous work stem from the availability of high-quality light-curves from space missions such as *Kepler*[2] and *TESS* (*Transiting Exoplanet Survey Satellite*[3]) — see ref. 4 for a review.

This work is important because dEBs are our primary source of direct measurements of the basic properties (mass and radius) of normal stars[5,6]. They are widely used to calibrate physical processes included in theoretical models of stellar evolution[7,8], such as atomic diffusion[9], convective-core overshooting[10], and the size of the core[11]. A high precision in the measurements of the stellar properties is vital for reliable results[12] and can approach 0·2% precision in mass and radius in the best cases[13].

OO Pegasi

In this work we present an analysis of OO Pegasi (Table I) based on published spectroscopy and new space-based photometry. The eclipsing nature of OO Peg was found using data from the *Hipparcos* satellite[16,22]. A first detailed analysis was presented by Munari *et al.*[23] (hereafter M01) with the aim of assessing the expected quality of results from the then-forthcoming *Gaia* mission; of the three systems in that paper V505 Per and V570 Per have already been revisited by the present author using the new *TESS* data[24,25]. M01 used only *Hipparcos* photometry and radial-velocity (RV) measurements from ground-based spectroscopy in the 850–875-nm region, to represent the type of observations that *Gaia* was expected to obtain. Due to these limitations they were only able to obtain masses to 2% and radii to 4% precision.

A subsequent analysis of OO Peg was presented by Çakırlı[21] (hereafter C15) who added new spectroscopic RV measurements and a more extensive light-curve from the All Sky Automated Survey (ASAS[26]) to determine the properties of the components more precisely. C15 also measured the atmospheric parameters of the components, their projected rotational velocities, and the reddening and distance of the system. He searched for but found no evidence of pulsations in the light-curves from *Hipparcos* and ASAS, despite both components being in the δ Scuti instability strip[27].

TABLE I

Basic information on OO Pegasi.

Property	*Value*	*Reference*
Right ascension (J2000)	$21^h41^m37^s{\cdot}70$	14
Declination (J2000)	$+14°39'30''{\cdot}8$	14
Henry Draper designation	HD 206417	15
Hipparcos designation	HIP 107099	16
Gaia DR3 designation	1770729907069675392	14
Gaia DR3 parallax	4·2534 ± 0·0245 mas	14
TESS Input Catalog designation	TIC 314847177	17
U magnitude	8·650 ± 0·010	18
B magnitude	8·635 ± 0·021	19
V magnitude	8·354 ± 0·018	19
J magnitude	7·676 ± 0·023	20
H magnitude	7·633 ± 0·027	20
K_s magnitude	7·555 ± 0·018	20
Spectral type	A7 V + A8 V	21

The apparent mangitudes in Table I come from a variety of sources. The *U* magnitude is from Oja[18] and relies on just two observations so may not reflect the brightness of the system outside eclipse. This number is not used in our analysis, but the consistency between the distances measured in the various passbands (see below) suggests it does represent an out-of-eclipse measurement. The *BV* magnitudes are from the *Tycho* experiment[19] on the *Hipparcos* satellite and each comprise the average of 55 measurements well-distributed in orbital phase. The JHK_s magnitudes are from 2MASS[20] and were obtained at a single epoch corresponding to orbital phase 0·615, which is not within an eclipse.

Photometric observations

OO Peg has been observed just once by *TESS*, in sector 55, beginning on 2022/08/05 and concluding on 2022/09/01. A second set of observations is scheduled for sector 82 and will occur in 2024 August if the spacecraft remains healthy. The observations from sector 55 were obtained with a cadence of 600 s, which is lower than desired and decreases the information content of the data.

The available light-curve from *TESS* was downloaded from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[28]. We used the simple aperture photometry (SAP) data from the *TESS*–SPOC data reduction[29]. A quality flag of "hard" yielded a total of 3412 data points (Fig. 1). We rejected the data in the time interval BJD_{TDB} 2459804·25 to 2459811·70 to avoid a stretch of data with the eclipses either partially covered or not observed at all, leaving 2831 data points for further analysis. These were normalized using LIGHTKURVE, converted to differential magnitude, and the median magnitude of the sector subtracted.

A query of the *Gaia* DR3 database† returned a total of 56 objects within 2 arcmin of OO Peg. Of these, the brightest is fainter by 4·23 mag in the *G* band and 3·98 mag in the G_{RP} band. A small amount of third light is therefore expected to contaminate the *TESS* light-curve of OO Peg, at the level of approximately 1%.

Light-curve analysis

The components of OO Peg are small compared to their orbital separation, so the system is suitable for analysis with the JKTEBOP‡ code[30,31], for which we used version 43. We defined the primary eclipse to be the deeper of the two eclipses, star A to be the component eclipsed at primary eclipse, star B to be its companion, and the primary eclipse to occur at orbital phase zero. In the case of OO Peg star A is both hotter and larger than star B, by small but significant amounts.

The JKTEBOP fitted parameters included the fractional radii of the stars (r_A and r_B), expressed as their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$), the central surface-brightness ratio (J), orbital inclination (i), orbital period (P), and a reference time of primary minimum (T_0). A circular orbit was assumed, after confirming that allowing for orbital eccentricity has a negligible effect on the values of the fitted parameters.

* 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

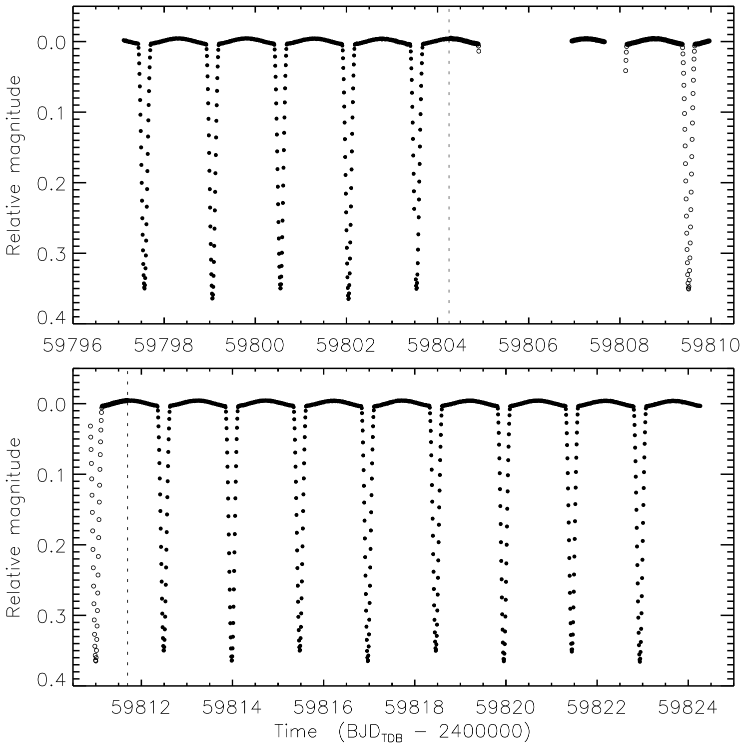

FIG. 1

TESS short-cadence SAP photometry of OO Peg. The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median. The data rejected from the analysis are shown using open circles, and the corresponding cutoff times indicated with vertical dashed lines.

Initial attempts to fit for third light returned values that were very small and slightly less than zero. An experiment with it fixed to a value of 2%, to account for the nearby stars discussed above, yielded a solution with significantly larger residuals and a noticably poorer fit to the eclipses. We therefore fixed third light to zero.

Limb darkening was included using the power-2 law[32–34] defined according to

$$\frac{F(\mu)}{F(1)} = 1 - c(1 - \mu^{\alpha}), \tag{1}$$

where $\mu = \cos\gamma$, γ is the angle between the observer's line of sight and the surface normal, $F(\mu)$ is the surface brightness at position μ on the stellar disc, c is the linear coefficient, and α is the nonlinear coefficient. As the two stars are very similar we assumed their limb-darkening behaviours to be identical. Initial fits showed that we were able to fit for one but not both of the limb-darkening coefficients, so we fitted for c and left α fixed at a theoretical value[35,36].

The relatively low 600-s sampling rate of the *TESS* data was accounted for by numerically integrating the model to match[37]. In effect we calculated the model at five points, each spaced by 120 s, and averaged the results before comparing to an observed data point. We found that this had a negligible effect on the results, but continued to do so as the increase in computation time was not a problem. The coefficients of two quadratic functions, one for each half of the *TESS* sector, were also included to normalize precisely the light-curve to zero differential magnitude.

We found no evidence for changes in the orbital period for OO Peg, in agreement with the results of C15. We therefore included the observed time of primary minimum from the *Hipparcos* light-curve calculated by M01 (2448499·1545 ± 0·0020) to help constrain the orbital ephemeris more precisely. This step lowered the uncertainty in P by approximately a factor of three.

The resulting best fit is shown in Fig. 2 and the parameters are given in Table II. Uncertainties in the fitted parameters were calculated using both Monte Carlo and residual-permutation simulations[38,39], and the larger of the two options chosen for each parameter. The two error-estimation algorithms were in good agreement for all parameters, as expected because there is no obvious systematic noise present in the data. The uncertainties in the all-important fractional radii are encouragingly low at 0·17% and 0·27%, despite the relatively poor sampling rate of the *TESS* photometry.

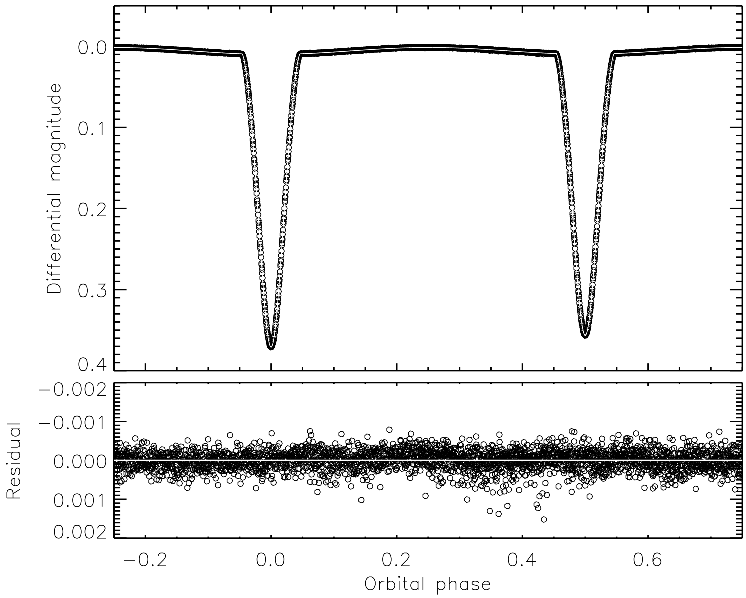

Fig. 2

The 600-s cadence *TESS* light-curves of OO Peg (open circles) and its best fit from JKTEBOP (white-on-black line) *versus* orbital phase. The residuals are shown on an enlarged scale in the lower panel.

TABLE II

Parameters of OO Peg, with their 1σ uncertainties, measured from the TESS sector-55 light-curves using the JKTEBOP code.

Parameter	*Value*
Fitted parameters:	
Primary eclipse time (BJD_{TDB})	2459813·984151 ± 0·000007
Orbital period (d)	2·98465593 ± 0·00000049
Orbital inclination (°)	83·629 ± 0·013
Sum of the fractional radii	0·30576 ± 0·00020
Ratio of the radii	0·8983 ± 0·0038
Central-surface-brightness ratio	0·96661 ± 0·00016
LD coefficient c	0·709 ± 0·014
LD coefficient α	0·431 (fixed)
Derived parameters:	
Fractional radius of star A	0·16107 ± 0·00028
Fractional radius of star B	0·14489 ± 0·00039
Light ratio ℓ_B/ℓ_A	0·7794 ± 0·0065

Radial-velocity analysis

M01 published a set of 21 RVs for each component of OO Peg, which are tabulated in the paper. The spectra on which they were based were deliberately obtained at quasi-random times in order to simulate a dataset that might be expected from *Gaia*. As a result, two spectra are too blended to give precise RVs and there is only one spectrum near second quadrature. We reanalysed the RVs from M01 to confirm their results, and followed those authors in omitting the RVs from the two most blended spectra.

To fit the RVs we used JKTEBOP and the orbital ephemeris from Table II. The fitted parameters were the velocity amplitudes of the two stars, K_A and K_B, and the systemic velocity (V_γ) of the two stars. We also allowed for a change in T_0 to insure against ephemeris drift or period changes, but all solutions were consistent with the ephemeris given in Table II. Separate fits were obtained with V_γ either assumed to be the same for the two stars or allowed to be different. The error bars of the RVs for each star were scaled to give a reduced χ^2 of $\chi^2_\nu = 1{\cdot}0$ *versus* the best fit. Parameter uncertainties were calculated using the Monte Carlo procedure[24]. The results are given in Table III.

It was immediately clear that our star A is the *secondary* component for M01, something that can happen easily when the primary and secondary eclipses are of similar depth and the photometric data are quite scattered. We accounted for this in our analysis. We note that this is also apparent in C15 (see his fig. 4) but not commented on by that author. Our K_A agrees with M01, but our K_B and V_γ do not agree within the uncertainties. We also notice that there is a counterintuitive result that the r.m.s. residuals are lower for star A when the V_γ values of the two stars are required to be the same — this occurs because of the rescaling of the RV uncertainties combined with the RV measurements having a range of uncertainties.

C15 obtained 15 spectra of OO Peg from which 15 RVs were obtained for star A and 14 for star B. C15 fitted spectroscopic orbits to the spectra from his own observations together with those from M01. We first modelled the RVs from C15 separately. Four of the RVs for star A and three for star B are close to conjunction so suffer from blending and contribute little to pinning down

K_A and K_B, so we ran solutions with those omitted. The results were similar to those for all RVs, and we adopted them as our standard datasets for the RVs from C15.

Table III shows that there are significant discrepancies between the solutions of different RV datasets, both calculated in this work and *versus* the literature. We also consistently find that K_A is larger than K_B, thus star A is less massive than star B (although the difference is of similar size to the uncertainties). Some of these discrepancies are driven by small-number statistics, and some are likely due to differences in V_γ from the differing RV-measurement processes used by M01 and C15. The biggest discrepancy is in the K_B values from the two sources of RVs, which differ by 4 km s^{-1}.

We made the choice to fit the RVs from M01 and C15 simultaneously, both with the combined and independent V_γ values (Fig. 3). In each case we scaled the error bars of the individual datasets to give $\chi^2_\nu = 1$ and subtracted the best-fitting V_γ before fitting the combined data. Our results are in between those for the two RV sources separately, as expected. The K_A values are consistent over all solutions so we adopt a value of 112·6 ± 1·2 km s^{-1}. The error bar is the quadrature addition of the 1·1 km s^{-1} uncertainty in Table III and the 0·5 km s^{-1} which is the largest difference between the adopted K_A and the other fitted values.

For K_B we adopt a value of 109·1 ± 2·8 km s^{-1}, where the uncertainty is the quadrature addition of 0·9 km s^{-1} and 2·7 km s^{-1} following the same argument. This K_B is unfortunately rather uncertain, which prevents the measurement of the masses of the stars to high precision.

Physical properties and distance to OO Peg

Using the photometric and spectroscopic results from Tables I, II, and III, we have determined the physical properties of the OO Peg system using the JKTABSDIM code[41]. The results are given in Table IV and show that the masses are measured to 5·2% (star A) and 3·3% (star B), and the radii to 1·4% (both stars). This is not the desired 2% precision[5,42] due to the uncertainty in the value of K_B. The mass measurements agree well with those of M01 but not C15; the radius measurements disagree with both. In particular, the R_B value from M01 (1·37 ± 0·05 $R_\odot$) is extremely low. Our results are based on a careful analysis of

TABLE III

Spectroscopic orbits for OO Peg from the literature and from the reanalysis of the RVs in the current work. K_A and K_B values values were not given by M01, so we have calculated the values that would reproduce their mass measurements. All quantities are in km s^{-1}.

Source	K_A	K_B	$V\gamma$	$V\gamma_{,A}$	$V\gamma_{,B}$	*r.m.s residual star A*	*star B*
M01 (our calculation)	112·0	110·1	8·47±0·46				
C15	111±2	114±3	6·7±0·1				
M01 (our calculation)	112·1±1·6	107·6±1·0	10·8±0·7			5·1	6·7
M01 (our calculation)	112·4±1·7	107·6±1·0		11·4±1·2	10·5±0·8	5·4	6·6
C15 (our fit, V_γ same)	112·9±1·6	111·8±1·2	5·5±0·9			5·1	3·2
C15 (our fit, V_γ different)	112·3±1·5	111·5±1·3		7·6±1·2	3·9±1·2	4·2	3·1
Combined (V_γ same)	112·7±1·1	109·1±0·9	0·2±0·7			5·1	5·9
Combined (V_γ different)	112·5±1·0	109·0±0·9		0·3±0·8	−0·4±0·7	5·1	5·6
Adopted values	112·6±1·2	109·1±2·8					

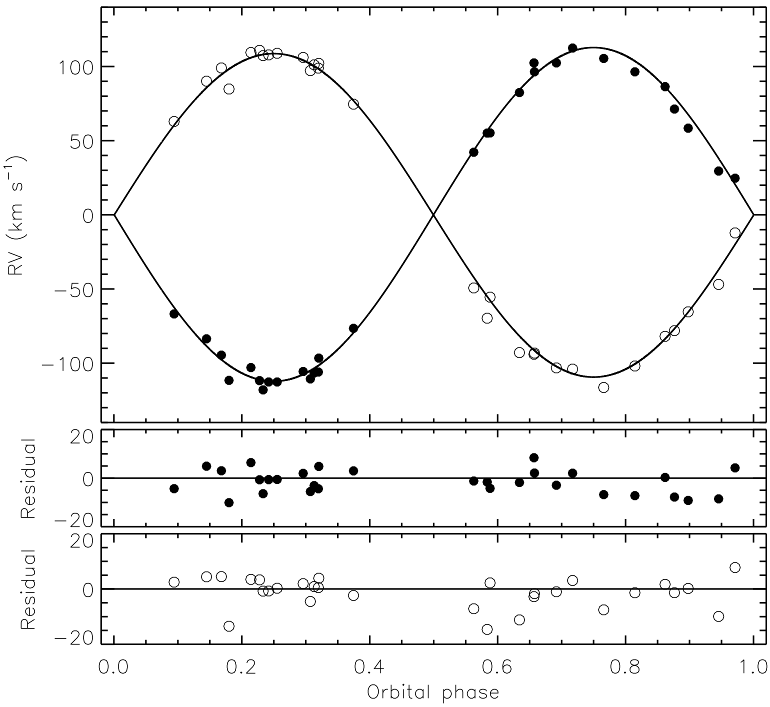

FIG. 3

RVs of OO Peg from M01 and C15 (filled circles for star A and open circles for star B), compared to the best fit from JKTEBOP (solid lines) with a separate V_γ value for each star. The residuals are given in the lower panels separately for the two components.

TABLE IV

Physical properties of OO Peg defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 40). The $T_{\rm eff}$ values are from C15.

Parameter	*Star A*	*Star B*
Mass ratio M_B/M_A	1·032 ± 0·029	
Semi-major axis of relative orbit ($R^N_\odot$)	13·16 ± 0·18	
Mass ($M^N_\odot$)	1·689 ± 0·088	1·744 ± 0·058
Radius ($R^N_\odot$)	2·120 ± 0·029	1·907 ± 0·027
Surface gravity (log[cgs])	4·013 ± 0·011	4·119 ± 0·005
Density ($\rho_\odot$)	0·1774 ± 0·0027	0·2515 ± 0·0040
Synchronous rotational velocity (km s^{-1})	35·93 ± 0·50	32·32 ± 0·45
Effective temperature (K)	7850 ± 350	7600 ± 450
Luminosity log($L/L^N_\odot$)	1·19 ± 0·08	1·04 ± 0·10
$M_{\rm bol}$ (mag)	1·77 ± 0·20	2·14 ± 0·26
Interstellar reddening $E(B-V)$ (mag)	0·09 ± 0·02	
Distance (pc)	238·8 ± 6·1	

the available RVs and much higher-quality light-curves from *TESS*, so should be preferred to previous values.

M01 determined the effective temperatures ($T_{\rm eff}$s) of the stars from a comparison between the observed and synthetic spectra, finding $T_{\rm eff,A}$ = 8770 ± 150 K and $T_{\rm eff,B}$ = 8683 ± 180 K. The ratio of these values agrees well with the surface-brightness ratio measured from the light-curve (Table II). Using these $T_{\rm eff}$s and the apparent magnitudes of the system (Table I), we determined the distance to OO Peg using the *K*-band surface-brightness method[41] and calibrations from Kervella *et al.*[43]. The interstellar reddening was determined by requiring the *UBV* and *JHK* distances to agree, *via* manual iteration, resulting in $E(B-V)$ = 0·21 ± 0·03 mag and a distance of 245·2 ± 4·9 pc. This reddening is rather larger than expected — the STILISM* on-line tool[44,45] gives a value of 0·037 ± 0·018 mag — and the distance is also 2σ beyond the value *Gaia* DR3[14] value of 234·1 ± 1·3 pc.

C15 determined rather smaller temperatures of $T_{\rm eff,A}$ = 7850 ± 350 K and $T_{\rm eff,B}$ = 7600 ± 450 K, *via* comparison with reference-star spectra. Using these values instead of the ones from M01, we obtain $E(B-V)$ = 0·09 ± 0·02 mag and a distance of 238·8 ± 6·1 pc. This $E(B-V)$ is in much better agreement with the STILISM value, and the distance is also consistent with the *Gaia* DR3 parallax at the $0{\cdot}8\sigma$ level. We therefore adopt these $T_{\rm eff}$s and $E(B-V)$ as our final values in Table IV. Supporting evidence for these lower temperatures are the catalogue $T_{\rm eff}$s of 7476 ± 149 K given in v8 of the *TESS* Input Catalog[17] and 7347 ± 17 K from the *Gaia* DR3 APSIS pipeline[46,47]. Both catalogues treat point sources as single stars, but in the case of OO Peg this is a reasonable approximation due to the similarity of the two components.

C15 measured $E(B-V)$ = 0·29 ± 0·01 from the strength of the interstellar Na *D* lines; such a large reddening is highly inconsistent with our results and would require the stars to have $T_{\rm eff}$s in the region of 10 000 K for the distances measured in the optical to match those measured in the IR.

Summary and final points

OO Peg is a dEB containing two components with late-A spectral types, on a circular orbit with a period of 2·98 d, whose eclipsing nature was discovered thanks to the *Hipparcos* satellite. We have presented a reanalysis of the system based on a space-based light-curve from the *TESS* mission and published spectroscopic parameters. The *TESS* light-curve is of high quality and allows the fractional radii of the stars to be determined to 0·2% precision; star A is clearly larger, hotter, and more luminous than its companion. However, our reanalysis of published RVs from two sources yields both a disagreement in the value of $K_{\rm B}$ and the measurement of a lower mass for star A than star B. This discrepancy would be problematic for stellar evolutionary theory, but is thankfully not significant due to the uncertainty in the measured masses. Using published apparent magnitudes of the system and $T_{\rm eff}$ values of the stars, we have determined a distance to the system in agreement with the *Gaia* DR3 parallax.

Both components of OO Peg are in a region of the luminosity *versus* $T_{\rm eff}$ diagram where a high fraction of stars show δ Scuti pulsations[27], but are not known to pulsate. We therefore calculated a Fourier transform of the residuals of the JKTEBOP fit using version 1.2.0 of the PERIOD04 code[48]. No significant periodicity was found up to the Nyquist frequency of 72 d^{-1}, with a noise level

*https://stilism.obspm.fr

of approximately 0·01 mmag from 1 d^{-1} to the Nyquist frequency. Lower-amplitude pulsations may be present but would require significantly more photometry to measure.

We made a brief comparison of the masses, radii, and $T_{\rm eff}$s of the stars to the PARSEC 1·2S theoretical stellar-evolutionary models[49,50]. Agreement was found for a solar chemical composition and an age of $1{\cdot}0 \pm 0{\cdot}3$ Gyr, which supports the lower $T_{\rm eff}$ values found by C15 *versus* those obtained by M01.

The quality of our results has been limited by the imprecision of the spectroscopic parameters measured for the system: both the RVs and the $T_{\rm eff}$s are quite uncertain. Conversely, the *TESS* data allow high-quality measurements of its photometric parameters. Further work should therefore concentrate on performing a more extensive spectroscopic analysis of OO Peg. Forthcoming data releases from the *Gaia* satellite may well help.

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★https://www.cosmos.esa.int/gaia

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CORRESPONDENCE

'To the Editors of 'The Observatory'

An Old Idea

In a recent review[1], Heavens noted that "the notion of the de Sitter space-time as due to a fluid was not considered reasonable in 1973 since the pressure would be negative." Interestingly, that idea was first proposed by Erwin Schrödinger[2], just a few months after Einstein's first paper[3] on relativistic cosmology; Schrödinger noted "that the completely analogous system of solutions already exists for the field equations in their original form — without the terms [corresponding to the cosmological constant] introduced by Mr. Einstein [citation corresponding to my ref. 3]. The difference is superficially very small: The potentials remain unchanged, only the energy tensor of matter gets another form." [my translation]. Such a fluid has "a constant density and constant, spatially isotropic inner tension". I wonder if such a fluid would have been considered acceptable earlier if it was described as being under tension rather than having negative pressure.

Einstein[4] replied that he had considered it as "the most obvious possibility when writing my paper", but that it was "not worth a mention". He considered two possibilities, first that the (negative) pressure of the fluid is a universal constant and second that it is not. He dismissed the first case since it amounts to replacing p with Λ and moving it to the left-hand side of the field equation and assumed that that couldn't have been what Schrödinger had meant. I don't know if that is what Schrödinger meant, but it is what is usually thought of as 'dark energy' today (though, depending on the definition, dark energy could have an equation of state other than $p = -\rho$, possibly depending on time as well). As the second possibility entails "not only the hypothesis of the existence of a non-observable negative material density in interstellar space but also a hypothetical law for the space-time distribution of this matter density", Einstein saw it as not viable since it led "too deeply into the thicket of hypotheses".

Although Schrödinger was a polymath (*e.g.*, he was an expert on human colour vision), his interest in General Relativity was not a fluke; in his later years, like Einstein he distanced himself from quantum theory (his famous cat thought experiment intending to demonstrate the absurdity of the Copenhagen interpretation, which became the leading interpretation of quantum mechanics) and, again like Einstein, pursued classical unified field theories (also, like Einstein, with little if any real success).[5]

Even though a fluid with $p = -\rho$ has the same effect as the cosmological constant, the two are not the same, and, as far as we know, both could exist. That possibility was famously invoked by Weinberg[6] to explain the observed value of the cosmological constant, which is much smaller than expected by many on the basis of arguments from quantum field theory: the expected huge value (corresponding to a fluid) exists, but is *almost* cancelled by a 'bare' *negative* cosmological constant, the fortuitous cancellation being explained by the weak Anthropic Principle. There is a tendency to interpret the cosmological constant as a negative-pressure fluid, not because of an equation of state different from $p = -\rho$ (with which all observations are compatible), but because of the hope to understand why it exists, why it has the value it has, what the physical mechanism behind it is, and so on. However, the Einstein field equation has two physical constants, Λ and G. Similar questions could be asked about the latter as well (why is it non-zero, why is gravitation much weaker than other forces, what is the 'mechanism' behind it), but rarely are.

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2023 December 11

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REVIEWS

The Barnard Objects: Then and Now, by Tim B. Hunter, Gerald O. Dobek & James E. McGaha (Springer), 2023. Pp. 344, 23·5 × 15·5 cm. Price £32·99/$44·99 (paperback; ISBN 978 3 031 31484 1).

E. E. Barnard has always been one of my astronomical heroes, and a reprint signed by him is a treasured possession. This new addition to *The Patrick Moore Practical Astronomy Series* has been compiled by three deep-sky enthusiasts and writers who all made practical observations of these objects. One recalls the excellent modern edition of the *A Photographic Atlas of Selected Regions of the Milky Way* prepared by Dobek a few years ago (see *The Observatory*, **131**, 320, 2011), while the many colour images by Hunter reproduced upon glossy paper in this new book look quite superb.

A comprehensive Foreword by William Sheehan admirably sketches Barnard's life. Barnard was a perfectionist who personally inspected all the prints intended to be bound into his atlases, and whom I have found from archival sources was overly fond of last-minute proof corrections. Barnard brought out a book of photos of the Milky Way and of comets in 1913, and a later Milky Way atlas appeared posthumously.

The term 'Barnard Object' refers here to anything the great man caught upon a photographic emulsion. They range from comets to deep-sky objects, and in particular the dark nebulae which he catalogued in such detail. It also should have been mentioned that he took some photographs of Mars in 1909 which were excellent for their time. He was well aware of the differential colour sensitivity of the plates of his day, so that stars would often not show up in the same order of brightness as they did to the naked eye. The authors provide very comprehensive lists and descriptions of the objects Barnard recorded, with modern colour images of many of them added for comparison alongside the plates and charts from Barnard's atlases. Barnard's photography was extensive but covered only a part of the sky.

Chapter 1 gives a potted history of photography and astrophotography, with details of the instrumentation used by Barnard. Chapter 2 gives an overview of nebulae in general. In the next chapter there are very useful lists of atlases, catalogues, and surveys covering all the different classes of celestial objects, not just the dark nebulae, right up to the present day. So we can find full details of the catalogues by Abell, Arp, Collinder, Gum, Lynds, Shapley-Ames, Sharpless, Van den Berg, and all the rest. To have all this information collected in one place is very useful.

Chapters 5 and 6, respectively, discuss visual observation and modern imaging techniques, while Chapter 7 examines and illustrates a selection of the Barnard Objects. Barnard's *A Photographic Atlas of Selected Regions of the Milky Way* was edited and published four years after his death by Frost and Calvert. Mary Calvert's charts showed 52 dark nebulae that had been identified from Barnard's notes, but which she did not label. Furthermore, for reasons discussed by the authors, catalogue numbers 176–200 were not used, the 1927 *Atlas* starting again at No. 201. As a result, the authors set out to assign objects to the missing numbers, and in Chapter 8 they make a good job in dealing with this historical omission. In Chapter 9 the authors in similar vein list the 31 objects described by Barnard in the *Atlas*, but which were neither catalogued nor charted therein.

The authors devote Chapter 9 to setting Barnard's work in a modern context. Many of his objects are known today as regions of active star formation, while the term 'dark' is now limited to the visible spectrum. Some objects are recognized as Bok globules. A short summary of our current understanding of the Milky Way galaxy is given. Tables of the objects, a glossary, further references, and an index conclude the book.

If I have one small quibble it concerns the arrangement of the illustrations upon the pages. These, particularly where comparisons with the past are presented, are often spread over as many as five pages. But the captions are always collected upon the first of those pages, hindering their practical usefulness. Cost probably precluded a larger format, but it would definitely have been better. And for the British reader, I would have preferred the terms (photographic) fixer instead of fixator, and (sodium) thiosulfate for hyposulfite.

This small point aside, I can thoroughly recommend this book. It clearly is the product of a huge amount of research and observational effort. It is written with authority and has a flowing style, and crammed with the fascinating detail that only such practical specialists in this field can provide. Patrick Moore would have approved! — Richard McKim.

Models of Time and Space from Astrophysics and World Cultures. The Foundations of Astrophysical Reality from Across the Centuries, by Bryan E. Penprase (Springer), 2023. Pp. 305, 23·5 × 15·5 cm. Price £27·99 (paperback; ISBN 978 3 031 27889 1).

When you first leaf through this book, you get the impression of an all-around blow of the changes in knowledge about space, time, and matter. The extensive table of content ranges from Polynesian navigation, early star maps, Kant's philosophy, Einstein's relativity, quantum physics, dark energy to the multiverse. The cover symbolizes this mixture, showing a surreal collage of Tehran's monumental Azadi Tower, placed with shadowy persons on a lunar-like surface with the glowing Fingers of Creation in the background. How does the author manage to fit the wide-ranging topics into a 300-page book? Is he a polymath with a clear concept or are we faced with a hodgepodge of popular snippets of knowledge?

Bryan Edward Penprase has studied physics at Stanford University, receiving a PhD in astrophysics from the University of Chicago. Currently, he acts as Vice President of Sponsored Research and External Academic Relations at the private Soka University of America (SUA) in Aliso Viejo, California. We read in the introduction: "The deeper cultural roots of astrophysical reality and the ways in which space and time craft objective reality and our subjective experience are typically not part of the discussion in university classes." This deficit has motivated Penprase to offer a suitable course at SUA that "enables students to comprehend how physics and astrophysics shape our observable universe and how the process of building a cosmic perspective creates a deeper understanding of the human condition that transcends cultures and makes us all 'planetary citizens'." The book is based on his lectures and is aimed at readers "interested in the fields of historical and cultural astronomy, as well as for anyone interested in learning about the latest finds from the field of physics and astrophysics." Does it live up to these high standards?

The soft-cover book is printed on high-quality paper, a good choice given the many full-colour illustrations, showing historical charts, modern astronomical images, or graphics (some made by the author himself). Presentation and layout of the medium-format publication are convincing. The text is fluid, informative, and easy to understand. It contains a few mathematical calculations (*e.g.*, for time dilation) and formulae, like the Maxwell equations. The content is organized more or less chronologically and reflects the current state of knowledge. There are 15 chapters with up to nine subchapters. References (literature, internet sources) are given below each chapter.

The first three chapters deal with early views on geography and the starry sky. We learn a lot about ancient cultures, the first astronomical instruments, and historic star charts. Many illustrations may be new to the reader. However, some (like Morden & Berry's 1690 world map) are too detailed for the format chosen. Chapter 4 profiles important figures in astronomy for their practical and theoretical achievements, featuring objects, innovative instruments, and methods. We meet Hevelius, Huygens, Cassini, Bradley, Descartes, Newton, Wright, and Kant. They are followed in the next chapter by other giants — people and telescopes. Herschel and Lord Rosse are celebrated for their revolutionary reflectors that revealed the nature of the Milky Way and the spiral structure of galaxies, respectively. We have now arrived at the transition from the 19th to the 20th Century with their large refracting telescopes erected at Lick, Yerkes, and Lowell Observatory. Chapter 5 covers the revolutionary achievements of astrophysical methods, especially spectroscopy. The Mount Wilson Observatory with the 100-inch *Hooker* reflector is representative of the enormous development. Hubble determined the distance of the Andromeda Nebula, confirming the extragalactic nature of galaxies, and discovered the expansion of the Universe, represented by Hubble's law. This led to the idea of a Big Bang.

Penprase now turns to an essential source of astronomical information: light. Its finite and invariant speed paved the way for Einstein's Theory of Special Relativity. It ultimately led the genius to General Relativity, treated in Chapter 8, the largest in the book. Newton's ideas about space, time, and gravity were changed fundamentally. We learn about the strange predictions of Einstein's theories and how they were tested. Black Holes and relativistic cosmology close the chapter. Another giant instrument symbolizes this era: the giant 200-inch *Hale* reflector on Palomar Mountain. It proved Hubble's law to enormous distances, where extreme objects, like quasars, were discovered. The instrumental progress, driven by new questions arising from the data, was unstoppable. It led to satellite astronomy, represented by the *Hubble Space Telescope*, the *James Webb Space Telescope*, and *Gaia*. The latter instrument revealed the construction of the Milky Way, finalizing Herschel's work. The following chapter shows how telescopes on Earth and in space revealed the large-scale structure of the Universe. In this course the author discusses the existence of a cosmic horizon, 46-billion light years away, which limits our observable universe. On the other hand, detailed ideas about the early Universe were developed due to the discovery of cosmic background radiation and new theoretical concepts such as inflation.

In the next three chapters, Penprase turns the attention to the microcosm. The quantum world is a strange place, governed by uncertainty and probability. The works of Curie, de Broglie, Heisenberg, and Schrödinger are discussed, leading to quantum mechanics. Photons, electrons, and protons were just the first members of a fast-growing zoo of particles, found experimentally and eventually arranged in the Standard Model. Its keystone is the Higgs boson, predicted in 1964 and detected at CERN in 2012. The author also addresses the essential role of quantum physics in the Big Bang and black holes — this is where the microcosm and macrocosm meet.

Chapter 14, 'Exploring the Invisible Universe', is a collection of speculative objects or concepts that have arisen from observations or theoretical considerations. Examples are Sirius B, planet X, neutrinos, black holes, gravitational waves, and dark matter/energy. Some cases are closed, others are still open, like a ninth planet (in place of poor Pluto) or the dark fractions of the Universe. The book ends with the 'Physics of the Vacuum and Multiverses'. That chapter contains an interesting review of Freeman Dyson's important essay, *Time without End: Physics and Biology in an Open Universe*. Published in 1979, *i.e.*, before the discovery of accelerated expansion, it offers an astonishing look at the future of an ever-expanding universe.

The wide range of topics obviously fits into a 300-page book — the content is anything but a hodgepodge. Penprase provides a competent and up-to-date overview of important scientific and historical aspects of astronomy and astrophysics. He succeeds in turning his ambitious university lectures into a book for the general reader. The common thread is the cultural anchoring of ideas about space, time, and matter. That's the bright side of the book — but sadly there is also a dark one.

In my private hit list of reviewed books with the most errors found, Penprase's unfortunately ends up in one of the top places. If they arose during the publication process, the author must be blamed for not carrying out a thorough final check. In the opposite case, one would have to question his expertise. Since no systematic pattern can be seen in the occurrence of the errors, I suspect that both Penprase and Springer are responsible for them. The severity of the errors ranges from mere typos to wrong content. We find them in the ordinary text, figures/captions, references, and index. Some are systematic in nature, particularly when it comes to incorrect spelling of names or inconsistent capitalization. For reasons of scientific seriousness and historical accuracy, I cannot dispense with my findings. So, the review has a perhaps boring but necessary second part.

Let's start with incorrect first/last names (the correct one is given in [ ]). In almost half of the cases, the text contains both the correct and incorrect spelling, sometimes just a few lines apart. We have: Bernard [Barnard], Curtiss [Curtis], Durer [Dürer], Francois Englert [François], Francois Arago [François], Friedman [Friedmann], Harlowe Shapley [Harlow], Herchel [Herschel], Johan Galle [Johann], Johann Hevelius [Johannes], Joannes Regiomentanus [Johannes], LangevinJolliot [Langevin-Jolliot], Leibnitz [Leibniz], Lemaitre [Lemaître], Martin Schmidt [Maarten], Michelle [Michell], Nevill Maskelyne [Nevil], Nicolaus Visscher [Nicolas], Percivall Lowell [Percival], Rene Descartes [René], Roemer [Rømer], Roentgen [Röntgen], Scrobosco [Sacrobosco], Schrodinger [Schrödinger], Steven Hawking [Stephen], Wein [Wien]. The last case appears as "Wein Displacement" on page 170, which should read "Wien's displacement law". The index contains 11 of these names, four are incorrect, three correct, and four indifferent (*e.g.*, Shapley, H.). The references mostly give the correct spelling, exceptions are "Schrodinger", "Lemaitre", and "Rene Descartes".

Next some examples of inconsistent capitalization (often concerning proper names): lick / Lick, Yerkes observatory / Observatory, black body / Black Body, Higgs boson / Boson, helium / Helium, hydrogen / Hydrogen, general relativity / General Relativity, dark energy / Dark Energy, Hubble Space telescope / Telescope, dark ages / Dark Ages. On page 203 we read "The Discovery of the CMBR…" and in the author's Fig. 13.2 we find "Quarks Combine" (but "nuclei form"). An interesting case appears in the references of Chapter 7: "Phillips, T. (2022). *James cook and the transit of venus*". Aperture is not given consistently, writing 36″ and 36". The focus length issues on page 55 look like typos: "150-long lens telescope" [150-feet long lens telescope] and "150 feet-" [150-feet].

Other cases are "WIMPS" [WIMPs], "TypeIa supernovae" [Type Ia] and "2015" [1915] for the year of Einstein's Berlin talk. Some terms look cryptic, like $\pi + > = ud >$ on page 236; it should be $\pi^+ = < ud >$.

Examples of errors concerning figures and captions: Fig. 4.5 presents "drawings of Saturn" — we see Jupiter. Fig. 5.1 should show "Herschel's 48-inch diameter reflecting telescope" — this is his 18·7-inch reflector. On page 80 the captions of Fig. 5.3 and Fig. 5.4 are swapped. Fig. 10.2 shows our emitted radio signals, now reaching a distance of 125 light years. The circular region (looking more like an oval) correctly contains nearby stars like Capella, Aldebaran, and Arcturus, but curiously also the Coma Cluster of galaxies, 330 million light years away! In Fig. 10.7 we see data of the *Wilkinson Microwave Anisotropy Probe* (*WMAP*), called "Wilkinson Microwave Anisotropy Explorer" in the caption, while the text on the facing page gives the correct name. According to the author, Fig. 10.10 shows "the shape of the light cone". Actually, the popular graphic does not show the light cone, but the scale function R(t), giving the distance between remote objects depending on cosmic time. In an expanding universe the light cone is pear-shaped. This error is systematic. Fig. 12.4 shows the particles in Gell-Mann's diagrams of the SU(3) symmetry group (the theory is incorrectly termed "8-fold path", instead of "eightfold way"). Among them is the Ω (a fermion), called "W-boson" in the caption (the same appears in Fig. 12.5). In Fig. 12.7 the shown Λ hyperon is wrongly called "L particle". Obviously, there is a problem with uppercase Greek letters.

Finally, we come to content errors, the most critical category. Here is a selection. On page 25 we read that Aristarchus has placed the Moon "at a distance of about 70 Earth radii" — the canonical value is 19. On page 49 the author writes: "Flamsteed's chart pioneered the use of labelling stars in order of their brightness with a number, a designation which we now call 'Flamsteed numbers'." The British astronomer did not label the stars. Moreover, the numbers (later introduced by Bode) order the stars by right ascension and not brightness. This is particularly strange because Penprase cites my paper on the subject in the references, which gives the correct version! Newton's *Principia* was published in 1687, not in 1686 (p. 67). On page 74 it is claimed that Herschel has developed a "catalog that included the positions of thousands of galaxies and faint stars". Actually, he published three catalogues, listing in total 2500 nebulae and star clusters — but no faint stars. Object positions (coordinates) are not given. It is also claimed that Herschel used a platform "where he could lay flat for many hours with a view of the sky". He never did this, but always stood on the platform and looked through the eyepiece at the tube opening. We further read that he "discovered many new comets" — there were none! In the references to Chapter 8, Herschel's 1785 paper is cited, writing "*Read at the royal society*" (note the lower-case letters); the journal *Philosophical Transactions of the Royal Society* (plus volume and page) is not mentioned. On page 81, Penprase claimed that the Fourth Earl of Rosse observed "Mars' two moons in 1877". Only the outer moon, Deimos, was seen (by Dreyer and Rosse). Obviously, this error is due to an often-used source (N. English, 2018*). On page 82 we read that a white dwarf has an "inert core of Helium and Carbon" — there is no helium in the core. Fig. 8.9 and Fig. 8.10 on page 144 are misleading. The former plots a "beam of light in a curved space" as a straight line, which makes no sense; light must follow the curved coordinate lines! The latter shows the case in flat space. On page 174 the author writes that Bessel and Fraunhofer measured star positions. Fraunhofer constructed an excellent refractor for

*See review in *JAHH*, **26**, 964, 2023.

Bessel, but his own measurements are neither mentioned in his publications nor in the surviving manuscripts. On page 183 we learn that the galaxy NGC 7320, located in the foreground of Stephan's Quintet in Pegasus, is a member of the Virgo Cluster. This is ridiculous — the galaxy cluster is located on the opposite side of the sky! On page 255 the violation of "CP parity" is mentioned. However, because CP already stands for "charge and parity", we have an unnecessary repetition. Chapter 13.3 is titled "Supersymmetry and Symmetry Breaking" but the latter subject is not treated.

It looks like I'm pretty pernickety. Some problems are certainly a matter of opinion, but ultimately there are too many errors for such an ambitious book. The reader should expect a flawless and consistent presentation. — Wolfgang Steinicke.

More Than Curious: A Science Memoir, by William H. Press (Darwin-Finch Publishing Company), 2023. Pp. 589, 22·9 × 15·2 cm. Price $15 (about £12) (paperback; ISBN 979 898954972 6).

I've never met Bill Press. I've never corresponded with him. I've seen him once.* But after having read this book, I feel that I've known him all my life, or even all his life. At 589 pages, this is a rather long memoir, but it is the short version. A longer one, with more details on things probably of interest only to his family but also containing things he doesn't want made public until after all concerned will have died, is in escrow and will be made available "someday... but not soon". Maybe I'll live that long. At times, I thought that I must have got the long version by mistake, as the memoir is very candid. (Whether it is honest can be judged only by those involved, though I do recognize many of the names and have met some of the corresponding people and in those cases Press's descriptions usually jibe with my experience, even if separated by decades — some folks never change — so perhaps I can assume that the rest is equally honest.) Feelings are probably mutual, as I've heard some stories about Press which I won't repeat here.

Press was born in 1948 in New York City, of Ashkenazi Jewish heritage, moved with his parents to California in 1955 (his geophysicist father Frank becoming a professor at Caltech; in 1965 he moved back east to MIT), attended Harvard as an undergraduate, was a doctoral student at Caltech (with Kip Thorne), briefly a postdoc at Caltech, an assistant professor at Princeton, a professor at Harvard from 1976 (when he became the youngest professor up until that time) to 1998 (and 1982–1985 chair of the astronomy department). He then went on to become deputy laboratory director at the Los Alamos National Laboratory (LANL) before moving to the University of Texas at Austin in 2007 and switching fields somewhat, becoming a professor with a joint appointment in the computer-science and integrative-biology departments. He and his first

*That was at a conference in Melbourne in 1995 where, before his talk, he introduced himself to the audience as the front end of the Press–Schechter horse. Paul Schechter was sitting in the audience behind me. It was a conference on gravitational lensing. There was a debate about the value of the time delay between variations in the two images of the gravitationally lensed quasar 0957+561, the first gravitational-lens system discovered[1], with a shorter delay implying a larger Hubble constant and *vice versa*. (That mirrored the general debate about the Hubble constant; at the time the 'tension' was between 50 and 100 km/s/Mpc.) Press was wrong in that case. I was watching from the wings while the Hamburg group got it right[2,3]. Most have probably forgotten that now; perhaps more will remember his quip, still true today, that someone knows the Hubble constant to two significant figures, but we don't know who that person is. To his credit, Press, in an aside to another story involving potential extraterrestrial intelligence, admits that his two papers on this topic were "just incomprehensibly *wrong*" [his emphasis].

wife Margaret were both children of Caltech professors. He also worked at the Lawrence Livermore National Laboratory as a doctoral student, working for, among others, Edward Teller. He was later science advisor to Obama (his father had been the same for Kennedy, Johnson, Nixon, and Carter). He was one of the players in the revitalization of relativistic astrophysics in the 1960s and 1970s, working on a wide variety of topics. He is perhaps best known, at least to those outside of his fields, as one of the authors of *Numerical Recipes* (a book about various numerical algorithms, including explanations and working coded examples).

The book consists of seventy chapters centred around various topics, though they usually refer to more than just the topic in the title. It is mostly chronological, though occasionally there are flash-forwards. It is well written, funny, and provides an insider's view of many interesting events. The more one knows about the fields Press has worked in and the people involved, the more one will get out of it, but probably most readers of this *Magazine* would enjoy reading it (except perhaps those bits about themselves which are perhaps a bit too candid). Unlike many (auto)biographies with many more pages per year when the subject was young than later on, the level of detail is roughly constant throughout the book, though the emphasis is sometimes different (for example, the reader learns much more about Press's first wife than about his second).

Press fills us in on topics such as internal discussions of hiring committees in academia, field trips with the CIA as a member of JASON (a group of advisors to the US military), conferences behind the Iron Curtain, and internals from various consultant groups to the US Government, although it is never clear if all the reasons as to why he was selected to so many posts are actually mentioned; connections certainly played a role: "I always found the level of inbreeding at this level of scientific leadership staggering, even when benefitting from it." The following anecdote describes his status in such circles: "When I walked around the table to introduce myself, Gene Fubini was amused. 'Bill, you've reached a level where you don't have to say who you are. Just sit down and say, General, I am glad that you can be here with us today.' "

Membership in various advisory committees at times gave Press, as far as protocol was concerned, the rank of a one-star general or admiral. As the years go by, Press spends more time on government consulting and less on science, hob-nobbing with the elite of US society in business, the military, and academia; his memoir might set a record for name-dropping. But he is also honest about himself: when invited to a black-tie affair, he asks the CIA if there is a rosette associated with the gold-plated medal so that he could wear the former. There wasn't, as "most recipients don't want to advertise the fact".

His extracurricular activities meant that by the time he was gently kicked out of LANL, he had become out of touch with astrophysics. While still at LANL he had joined a statistics group in order to do 'real work' after his management career had ended. His long-time mentor John Bahcall encouraged him to talk to the biologists at the Institute for Advanced Study, possibly because Bahcall was suffering from a rare, fatal blood cancer (though his colleagues didn't know it at the time). His background as "an astronomer doing biology in a statistics department", together with his connections, led to his being recruited by the University of Texas at Austin by someone (the dean) whom he had never met, in an effort to re-establish a statistics department, getting tenure and $1 million start-up money (in addition to a chair endowed to the tune of $2 million) despite having only two published papers in biology. His connections pulled him, in 2009, into membership (and later one of the two Co-Vice Chairs) of the President's Council of Advisors on Science and Technology, meeting with Obama for an hour or so about three times a year, and later to the post of treasurer of the American Association for the Advancement of Science. The last two chapters provide a close look at the transition from the administration of Obama to that of Trump and Press's response to COVID (with which he might have been infected), which included writing the book during the lockdown, before a twenty-one page small-print index ends the book. (The book otherwise consists of a preface and seventy occasionally sectioned chapters; there are no footnotes or figures, and language and style are very good; Press credits Kip Thorne with teaching him how to write.)

Although also published as a traditional book, Press has chosen to publish it *via* Creative Commons License CC BY-NC-ND 2.0, which means that anyone can redistribute it (even commercially) as long as credit is given and it is reproduced in its entirety. It is thus legally available as an eBook in various formats (including PDF — which I have — which presumably corresponds in appearance to the printed version). I'm sure that he doesn't need the money, and the book will thus reach an even wider readership.

All interested in the history of academia in general and astronomy in particular in the last sixty years will surely benefit from this memoir, a real page-turner which is not only highly entertaining but also from which almost everyone will learn something interesting. There isn't much time left, but I would like to see similar works by others of Press's generation (and, later, by younger people, though my guess is that, for various reasons, Press's generation of astronomers probably had the most fun). — PHILLIP HELBIG.

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Accreting White Dwarfs: From exoplanetary probes to classical novae and Type Ia supernovae, by Edward M. Sion (IoP Publishing), 2023. Pp. 233, 26 × 18·5 cm. Price £120/$159 (hardbound; ISBN 978 0 7503 2040 5).

Author Edward M. Sion of Villanova University begins this volume beautifully, with a chapter on what is known about non-accreting white dwarfs. There are all the familiar equations for degenerate matter (relativistic or non-relativistic), the Chandrasekhar limit but Chandra is not cited, only a 2007 book ascribed to Ostlie & Carroll (though the reference list says Carroll & Ostlie), the historic cooling curve, ways of holding metals in atmosphere *versus* letting them sink, and so forth. There is also a wonderful colour–magnitude diagram for 15000 white dwarfs as observed by *Gaia*. The bright ones track a cooling curve for CO stars of 0·8 $M_{\odot}$; a second concentration appears at around A0 following a track for a mass around 0·75 solar masses; and the cool, faint end turns up, as expected from extra energy input when the CO core starts to crystallize. The author claims this as the first empirical evidence for the phenomenon.

This chapter, the ensuing six, and two appendices, however, suffer from the now-common problems of no unified list of references and no index of any kind. Those 15000 white dwarfs do not all appear individually, but very many stars do, and I was left wishing that Chapter 1 had included a paragraph on "naming of white dwarfs." Quite a few of the accreting ones are variables, with decodable names like WZ Sge, V471 Tau, and U Gem. SDSS is recognizable as

Sloan Digital Sky Survey, and some memory-dredging yielded EG = Eggen–Greenstein (who are not cited anywhere for their then-enormous lists) and LTT = Luyten Two Tenths (meaning the proper motions), but is G for Giclas or Gliese, and who are GD, HE, and HS? Oh, yes! One of those non-existent indices should surely have listed the more prominent stars by name.

Topics treated in some detail include (*i*) metals in WD atmospheres (ground up planetary material has replaced accreted interstellar stuff as the best-buy explanation), (*ii*) "Roche-Lobe detached Post-common Envelope Main Sequence-White Dwarf Binaries" candidate for longest list of modifiers, but also a good discussion of weak, strong, and very strong magnetic fields, with plausible mechanisms for creation of the strong fields, and (*iii*) the zoo of cataclysmic-variables, historically introduced with initial basic understanding of explosions and the importance of donor companions, properly credited to Leon Mestel, Willem Luyten, Robert Kraft, and John A. Crawford (not any of the Crawfords we knew). Not a word, however, for the Gaposchkins, who apparently coined the cataclysmic variable name, and who over decades compiled very many light-curves of eclipsing binaries and other variable stars. Chapter 7 ends with the 'single degenerate' scenario for producing type Ia supernovae. The double-degenerate case is barely mentioned, and perhaps "accreting a whole other star" would not be the best description of the process of two merging. The dedication on page *vii* tells us that the book was written during a two-year period when the author was mourning the death of his wife of 52 years. I therefore refrain from a compilation of grammatical and similar infelicities, but the volume contains some excellent and very useful material, and one might wish for a second edition with a publisher who values whole books and not just downloadable chapters. —Virginia Trimble.

Galaxy Formation, Third Edition, by Malcolm S. Longair (Springer), 2023. Pp. 798, 24 × 16 cm. Price £89·99 (hardbound; ISBN 978 3 552 65890 1).

A volume of Springer's *Astronomy and Astrophysics Library*, this third edition brings previous editions up to date without leaving out too much history of the field. The result is a very long book, perhaps the reason why the preface ends with "Good Luck!" Probably no stranger to most readers, Longair is a prolific scientist, has written several books, and is an excellent lecturer. (I had the pleasure of hearing him, along with Allan Sandage and Richard Kron, at the 1993 Saas-Fee course *The Deep Universe*[1] (reviewed here[2]) — his second stint as a lecturer there, after 1978 with Martin Rees and Jim Gunn[3,4]. Some of his lectures can be found in good audio and video quality on YouTube.) The first edition has also been reviewed in these pages[5].*

Others have noted, confirming my impression, that Longair's presentations are often much more general than their titles. That is also the case here, with, of the twenty chapters, arguably only one complete chapter and one section of another actually about galaxy formation. However, rather than much forest and few trees, it surveys the entire landscape including the forest and many other types of tree (as well as other plants and animals) within it. As such, this book, aimed at final-year undergraduates and/or first-year postgraduates, would be a good introduction to a number of topics: theoretical cosmology, observational cosmology, the cosmic microwave background, star formation, dark matter, the early Universe, large-scale structure, General Relativity, Big-

*A sentence from Pagel's review in this *Magazine* is quoted on Springer's web page for the book, where one can also learn that it is available in paperback for $69·54 and as a PDF file for $53·49.

Bang nucleosynthesis, galaxy evolution, the intergalactic medium, and so on. I see that as an advantage rather than a disadvantage: it is good to have all that material presented in a uniform fashion at a uniform level by someone who actually knows it all. The reader is referred to more detailed accounts when necessary (in particular, the books by Peacock[6,7] and Baumann[8] are often mentioned, as well as other books by Longair). An additional advantage is that both theory and observation are covered.

The twenty chapters are collected into four parts: 'Preliminaries' (large-scale structure, galaxies, galaxy clusters, though starting off with a summary of the entire book), 'The Basic Framework' (theoretical and observational cosmology), 'The Development of Primordial Fluctuations Under Gravity' (including dark matter, correlation functions, and the CMB), and 'The Post-recombination Universe' (galaxy formation and evolution, the intergalactic medium, the early Universe). There are several figures, some in colour, scattered throughout the book, most taken (with attribution) from the literature. Each chapter has its own bibliography, often several pages of small print. Also in small print are a thirty-page(!) main (subject) index and a five-page author index. There are a few footnotes (fortunately no end notes) and references are provided in author/year style within the text.

Although perhaps setting a record for missing hyphens in two-word adjectives, otherwise the style and language are very good (though, of course, even better is a lecture in Longair's Scottish accent) with very few typos, and one could either read the book from cover to cover or dip into it for information on particular topics, as the chapters are to a large extent self-contained and necessary references to others are given. Previous editions have sold well, and that will surely be the case for this one too. The book is a good introduction to its many topics for those wanting to go further and a good summary for those for whom the almost eight-hundred pages are enough. Essentially everyone interested in any of the topics should have a copy of this book. — PHILLIP HELBIG.

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Winds of Stars and Exoplanets (IAU S370), edited by Aline A. Vidotto, Luca Fossati & Jorick S. Vink (Cambridge University Press), 2023. Pp. 290, 25 × 18 cm. Price £98/$130 (hardbound; ISBN 978 1 009 35278 9).

The organizers of the symposium behind these proceedings have sought to cover a great variety of processes associated with 'winds': radiatively driven mass loss by the most luminous stars carrying ~ $10^{-5}\, M_{\odot}\, y^{-1}$ steadily (and an order of magnitude more in eruptions), flows from cooler, solar-type stars having mass-loss rates nine orders of magnitude smaller, and the erosion of atmospheres of exoplanets, caused mostly by activity of their host stars. For some decades, the communities studying the first two subject areas have been well catered to separately by, *e.g.*, the biennial 'Cambridge Workshops on Cool Stars, Stellar Systems and the Sun' and the series of IAU Symposia focussing on massive and Wolf-Rayet stars; here, they and the newer exoplanet communities are brought together. To what extent members of the different communities interacted at the symposium is not evident from these proceedings: there is no record of discussion (just a 'Q&A' embedded in one of the contributions) nor a conference summary.

The very diverse strands are, however, brought together in a comprehensive, magisterial survey by Stan Owocki of the physical processes driving the outflows from stars and planets — ranging from the CAK formalism of the line-driven winds of massive stars, through the solar corona and wind, spin-down, planetary winds and mass loss, followed by a discussion of magnetospheres of stars and planets. The proceedings continue with a section on observational evidence for winds, led by reviews on low-mass stars, high-mass stars, and planets. Unlike high-mass stars, where there is an abundance of mass-loss diagnostics, the greatly smaller mass-loss rates of lower-mass stars and planets restricts possible observables, primarily to the Lyman-α line profile, observable only from space and much impacted by interstellar absorption, or the weaker but more easily observable 10830-Å He I line. These reviews are accompanied by a number of shorter papers on individual objects or topics. The following section entitled 'Ingredients of Winds' again leads with reviews covering the three subject areas complementing and often expanding on material presented earlier. I am acquainted with only one of the subject areas but found all these reviews to be informative and well referenced. The lead review in the fourth part of the Proceedings, 'Flow-Flow Interactions', considers interaction of stellar winds with the ISM — but a colliding-wind system is the subject of one of the short contributions. The fifth part considering the relevance of winds contains mainly shorter papers touching on a variety of topics.

The production of the proceedings is mostly acceptable, but the editing could have been tighter. There is a problem with the diagrams. Many of them were produced in colour, which are referred to in the captions, but these are not always discernable on the printed page. This is not a new problem. Many of us have used colour for the on-line versions of our papers but taken care to choose symbols and line styles so that the figures would also be useful to the reader of the monochrome printed page. The authors should have been encouraged to do the same: although colours can be seen on the on-line version or preprints, it is the printed volume that is being reviewed here. Conference proceedings containing reviews and short communications giving a snapshot of current work are often suggested as a good means for beginners to get started in a new field; the present volume gives entry to three. — PEREDUR WILLIAMS.

The Philosophy and Practice of Science, by David B. Teplow (Cambridge University Press), 2023. Pp. 391, 25 × 18 cm. Price £54·99/$69·99 (hardbound; ISBN 978 1 107 04430 2).

In 1931, the UK government first published the now familiar *Highway Code*, an advisory booklet which formalized the system of road users' signals and behaviours that had evolved through the increased use and popularity of all varieties of road transport in the early decades of the century. Four years later (1935) a compulsory practical test for drivers of motor vehicles was introduced. Sixty-one years later (1996), a theory test as precursor to the practical test, and based to a large extent on the *Highway Code*, was also made compulsory.

I mention this history because as I read the current tome, for it surely does meet the essentials in the definition of that word with 770 references and 752 footnotes, I was fleetingly, but all too often, drawn to the analogy with UK road users and their regulation. All analogies are imperfect, but as this work discusses the Philosophy (Highway Code?) and Research Practice in science (actions of all road users?) it may not be a totally inappropriate one. Few research scientists as eminent as Teplow have ventured into what might be considered the dangerously choppy waters in which philosophers of science like to sail. As a result, I wonder if the philosophizers have all too often been looked upon as 'meddlesome priests' in the hard-nosed world where real work is being done. As Dylan wrote, "You don't need a weatherman to know which way the wind blows." Or do you?

In this respect, the current text is a comprehensive, informative, and sympathetic introduction to the view from both sides ('nowhere' might philosophically be more appropriate!) and as such is to be lauded as an exceptional and welcome act of diplomacy. It begins with discussion of such philosophical fundamentals as, what is science?, what is a fact?, what is knowledge?, what is truth? There follows a substantial treatise on the evolution of the so-called Scientific Method, with a timeline covering no fewer than five millennia and featuring no fewer than twenty six 'influencers'. Not until late on in the timeline, in the 16th Century, did many of the names become familiar to me and, unrepresentative as they might be, my highlights were firstly noting Robert Boyle's (1627–1691) ten rules of good scientific writing (all of which, as Teplow notes, remain entirely relevant today) and particularly in wondering if his eighth item presaged the practice of meta-analysis, a technique only relatively recently in vogue. The other highlight was the final entry, that of Paul Feyeraband (1924–1994) — jester, savant or, in modern parlance, just an archetypal disruptor? After a full seventy-six pages of carefully catalogued, albeit not entirely linear, 'progress' to distil the essence of the, or perhaps more realistically, *multiple* Scientific Methods, for the final entry to be a philosopher who proposes that there is no such thing and that in science practice anything goes, or should go, in an anarchistic maelstrom, cannot fail but raise a smile. Needless to say this is not where Teplow leaves the discussion and the nuanced position of horses for courses (Methods for Disciplines) is well made.

The middle section of the book (160 pages) is devoted to an exposition of 'Science in Practice'. This ranges from guidelines for the initial selection of research topics, *via* the development of theories and their testing (verification, falsification, or even the possibility that neither is possible) through to the more philosophical aspects of knowledge and understanding, if indeed any at all are claimed to result from the research. In the later sections, detailed practical issues such as statistical significance are discussed (unshakeable believers in $p<0{\cdot}05$ beware!) and although the 'c' word is vastly overused these days, the 'Replicability Crisis' comes under appropriate scrutiny.

The somewhat shorter final chapter (40 pages) discusses 'Science as a Social Endeavor'. Despite its relative brevity, it shines a focussed light on many hard questions and home truths, some of which, inevitably, are not easily reconciled. How does one guard against future Replicability Crises when the ethos of "no one remembers who is second" prevails? Can scientific research always be immune to non-epistemic values and be the value-free ideal that many wish it to be, or, more dangerously, assume it is? Indeed, in some circumstances would such immunity even be desirable? Another example, too recent for inclusion in this book, which would be ripe for discussion in this context is how the scientific community should in future avoid, or vigorously respond to, the reported "extremely productive author" phenomenon[1]. In the age of ubiquitous AI, these questions and others surely have an extra special relevance and urgency.

Beyond the attention of the two main participants in this saga (philosophers, researchers) this last chapter is the one that should be thrust into the public gaze. With public trust in science on a knife edge in some disciplines, these are important concepts and tensions to be appreciated. Airing them more widely might help bridge the sometimes barren chasms between those sceptical of all received scientific wisdom, the unthinking 'follow the science' herd, and those in danger of infection by scientism.

Overall the book is a dense, encyclopaedic *tour de force*, which cannot be taken or read lightly. I assume it is aimed primarily at those starting out on a research career, although as a refresher for the longer-in-tooth it will contain some surprises and even more sobering reminders. For anyone willing to invest the time and effort, it is hard to see anything but significant reward resulting.

But what of the nagging road-user analogy? The UK government's Road Traffic Act (1988) Section 38 contains the following paragraph: "A failure on the part of a person to observe a provision of *The Highway Code* shall not of itself render that person liable to criminal proceedings of any kind but any such failure may in any proceedings (whether civil or criminal…) be relied upon by any party to the proceedings as tending to establish or negative any liability which is in question in those proceedings."

Although it would no doubt be a policy in danger of being labelled as draconian, what if nascent researchers were required to pass a formal 'theory test' on their knowledge and understanding (whatever those two are!) of the concepts, both philosophical and practical, presented in this text before setting out on the practicalities of post-graduate research? Their subsequent thesis and its defence would represent the final 'practical driving test', cognisant of the principles already imbued by the theory test. From a quick trawl of the internet and personal contacts, it seems that some training akin to a theory test is indeed already offered in the UK, but it appears to be sporadic and very much a minority sport at the moment. However, without such a scheme one might wonder if the awarding of the degree of Doctor of Philosophy is bordering ironic and acceptable merely as an innocent, quirky anachronism, somewhat akin to the persistent titles of some of the awards in the UK's honours system. Teplow's teaching at UCLA of courses featuring this book's material promises to be an educational green shoot heading in the right direction. Hopefully it will not be another 61 years before others catch up! — Dave Pike.

Reference

(1) John P. A. Ioannidis, Thomas A. Collins, & Jeroen Baas, 2023.bio Rxiv https://doi.org/10.1101/2023.11.23.568476

White Holes: Inside the Horizon, by Carlo Rovelli (Allen Lane), 2023. Pp. 157, 19·8 × 11·8 cm. Price £14·99/$19·49 (hardbound; ISBN 978 0 241 62897 3).

This book is a quick read, not only because of the small format (and not all that many pages), but because, like Rovelli's other books, it is very well written (more precisely, I can judge only the translation, by Simon Carnell, at least as far as the language goes; like his other popular-science books, the original is in Italian). Rovelli, an active researcher in the field of loop quantum gravity, has written several popular books, and even landed a bestseller[1] (reviewed in these pages[2]). Like many of his other popular-science books, it is a mixture of standard knowledge and his own work. The table of contents lists only the three parts, though each has five or six chapters.

The first part is mainly about *black* holes, mostly standard stuff, though it would be difficult to find a better presentation of the basics. White holes are taken up in the next part. Most readers will probably have heard of them, but most also probably have some misconceptions, which Rovelli clears up (for example, their gravity is attractive; time reversal reverses the first derivative of spatial coordinates, not the second). In practice, it is difficult to distinguish black from white holes from outside the horizon. While nothing can come out from behind the horizon of a black hole, nothing can cross the horizon of a white hole from outside. However, just as a distant observer, due to the gravitational redshift and time dilation, never actually sees anything cross the horizon from outside (and hence doesn't see the actual collapse to form a black hole), neither does such an observer actually see anything emerging from a white hole. Where Rovelli departs somewhat from standard lore is his idea that when the matter forming the black holes has been sufficiently compressed that quantum-gravity effects play a role, quantum tunnelling can transform a black hole into a white hole.

In the third part, Rovelli discusses his resolution of the black-hole information paradox as well as the concept of time and the relation between time-reversible microphysics and the macroscopic arrow of time. Hawking radiation is such a phenomenon which provides an arrow of time, and as a result white holes are not exactly time-reversed black holes. According to Rovelli, while large white holes are unstable, turning into black holes, small ones are stabilized by quantum-gravity effects. To the 'extremely interesting if true' category belongs his idea that dark matter could consist of Planck-mass white holes, which is certainly compatible with observations. Unfortunately, such dark matter would be more difficult to detect directly than most other dark-matter candidates.

The book is non-technical but takes care not to over-simplify things. Rovelli justifies leaving out technical details because the non-expert reader could not follow them while the expert reader would be bored by them; both can benefit from his personal takes on various topics. (In one case, a long end note is devoted to providing a technical explanation to a qualitative description in the main text.) There are many references to Dante's *Paradise Lost*, not just in relation to non-Euclidean geometry (something other authors have also noticed) but also in a more general sense. Those tie in with Rovelli's general view of the world, also mentioned in his other books. Whether one shares it is perhaps a matter of taste; I find it to my liking, at least as long as it regards physics. Personal reflections which stray a bit further from the main text are set apart by their lack of capitalization; while both such reflections and setting them apart are good ideas, I would have chosen another way to indicate them.

While not all might share Rovelli's more speculative ideas about physics, I noticed no actual mistakes in the book* and the language and style are a cut above most books I've reviewed in these pages. There are a few black-and-white figures throughout the text. There are no footnotes, and end notes provide footnote-style comments and/or references (usually to technical literature). The

*Well, Karl Schwarzschild didn't exactly "lose his life on the Eastern Front" in the First World War. He contracted pemphigus while serving in the army (for which, at over 40 years old, he had volunteered). Since that is an autoimmune disease, it probably had nothing to do with the war. He left military service, returned to Göttingen, died a couple of months later at 42, and was buried there. All the same, writing three papers (including one with the famous Schwarzschild solution) while suffering from pemphigus and "despite the incessant artillery fire" is impressive enough.

seven-page small-print index is especially thorough considering the length of the book.

This is a well-written and interesting book accessible to a broad readership. Although one might not agree with his more speculative points (which might turn out to be wrong), most will probably learn something from it and might be inspired to follow up the references in order to learn more. — PHILLIP HELBIG.

References

(1) C. Rovelli, *Seven Brief Lessons on Physics* (Allen Lane), 2015.
(2) P. Helbig, *The Observatory*, **136**, 155, 2016.

Io: A New View of Jupiter's Moon, edited by Rosaly M. C. Lopes, Katherine de Kleer & James Tuttle Keane (Springer), 2023. Pp. 375, 24 × 16 cm. Price £129·99 (hardbound; ISBN 978 3 031 25669 1).

Io After Galileo: A New View of Jupiter's Volcanic Moon, edited by Lopes and J. R. Spencer, appeared as a 'first edition' in 2007, but was not reviewed in these pages. This little world is a fascinating place, and all that molten sulphur takes me back to my career in the chemical laboratory. Tidally squeezed and heated, Io exhibits active volcanism and sports an exotic atmosphere. It emits 100 terawatts. Some light elements form a tail around its orbit. The sodium component of the tail is remarkably bright, and by 2023 was being successfully imaged by amateur astronomers even with small-aperture telescopes equipped with narrow-band filters.

That Io's darker poles had first been spotted by Barnard is mentioned in an historical summary early on, but the first low-resolution map made by the Pic du Midi observers in 1943–44 is not mentioned. The latter shows seven or eight intriguingly circular dark patches, of which several actually coincide with volcanoes, and I feel that it should be better known.

Early chapters discuss the moon's formation and evolution. Next comes Io's surface, where geological processes have eliminated the cratering record. I was particularly interested in Chapter 6 where Katherine de Kleer and Julie Rathbun show how, after the close of the *Galileo* mission, hotspots continued to be mapped by the limb-occultation technique, or imaged directly (with adaptive optics) by the *Keck* telescope. These data revealed four persistently active volcanoes. Different classes of eruption are now recognized, with even a suggestion of explosive or Strombolian-type activity.

Further chapters review the bulk composition of Io, its plumes, atmosphere, and magnetosphere. In Chapter 10 the authors discuss how Io can serve as a model for a tidally heated exoplanet, in particular planets b and c in the TRAPPIST-1 system. Future investigations by telescope and spacecraft feature in Chapter 11, written by Alfred McEwen *et al.* The latter missions include *JUICE*, scheduled to arrive in 2031.

A multi-author work such as this one needs a very detailed index, and I don't believe five pages are quite good enough. There are few names: 'Galileo' could equally be the philosopher or the space probe. 'Sulfur' is not indexed, although S_2, SO, SO_2, and sulphur ions are included. 'Volcano' and 'volcanic' are conspicuous by their absence. It would also have been convenient to have had (at the front or back) a full page (cylindrical?) reference albedo map of Io showing all the features named in the text: the maps on pages 149 and 250 only include a few names. Another issue is the high price. These drawbacks aside, this latest review of Io is full of fascinating data, richly illustrated, crammed with references, and is much to be welcomed. — RICHARD MCKIM.

Other Books Received

Fundamentals of Particle Physics: Understanding the Standard Model, by Pascal Paganini (Cambridge University Press), 2023. Pp. 532, 26·5 × 18·5 cm. Price £54·99/$69·99 (hardbound; ISBN 978 1 009 17158 8).

A modern introduction to the Standard Model of particle physics, this substantial volume is intended for graduate and advanced undergraduate students, and includes exercises at the end of each chapter, thus providing lecturers with a useful text for courses.

Here and There

SOME CONFUSION HERE

… we live in the solar system of the Milky Way in which the centre is the sun. The sun has a large diameter of 864,000 miles and is 8·3 kiloparsecs from the earth. — *Theoretical and Natural Science*, **10**, 79–84, 2023.

OUT OF THEIR DEPTH

A way to augment existing power dam infrastructure, particularly during droughts, is to have floating solar systems on reservoirs. — *Victoria Times-Colonist*, 2023 December 23, p. A10.