THE OBSERVATORY

A REVIEW OF ASTRONOMY

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MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2025 February 14 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

Mike Lockwood, *President*
in the Chair

The President. The first speaker today is Dr. Chris Smith from Huddersfield New College and his talk is called 'Searching for Saturn's periodicities in the upper atmosphere'. Chris Smith graduated from Cambridge University with an MSci in 2002 and completed a PhD in atmospheric modelling in 2006 at UCL. He then trained to be a secondary science teacher at Newcastle University and between 2007 and 2022 worked with 11 to 18-year-olds. He currently teaches physics and maths at A level at Huddersfield New College in West Yorkshire.

Dr. Chris Smith. I would like to talk about my work to try to explain the 'planetary period oscillations' (PPOs) in Saturn's magnetosphere using models of the neutral atmosphere. To understand the problem, we first need some context around the structure of Saturn's magnetosphere. An important feature is the equatorial plasma disc, which rotates more slowly than the deep atmosphere of the planet. The disc is continually loaded with mass from the moons and rings, and is then spun up towards co-rotation by the transfer of angular momentum from the planet. This transfer is mediated by electric currents flowing along magnetic-field lines. The result is that the magnetosphere rotates much more slowly than the deep planet, and the connected neutral upper atmosphere — the thermosphere — where the currents flow also rotates significantly more slowly than the deep planet.

Given this context we can explain what the PPOs are and why they are such a puzzle. The PPOs are ubiquitous signals observed in the magnetosphere in various phenomena including magnetic-field perturbations and radio emissions. The majority of our information about these signals was gathered by the *Cassini* mission. The period of these signals is close to the rotation period of the planet, but they show several puzzling features: the period varies by a few percent on a time-scale of months; there are distinct periods in the northern and southern hemisphere; and these periods became locked together for about a year in 2013–2014. Given the context of a sub-corotating magnetosphere, the presence of the signals themselves is difficult to explain: how can there be planetary-period signals in a system that does not rotate anywhere close to the planetary period? The neutral atmosphere is an excellent candidate to resolve some of these problems.

Before I go on to talk about my work, I should mention that there is now good evidence that the PPOs are indeed driven from the neutral atmosphere by twin-vortex flows in the polar regions. Driving an MHD model of the atmosphere with these types of flows reproduces many of the observations. A twin-vortex has also been observed in infrared Doppler observations of the ionosphere, and the features of this vortex are consistent with a driver in the neutral atmosphere.

My work has been on constructing the nature of this twin vortex using numerical modelling and theory. My initial approach was to use a global circulation model of the thermosphere to produce a twin vortex that could explain the observed currents. To produce something approximating the observations required the model to be forced by an artificially imposed heat source. There were two key problems with this approach. First, a plausible source of the heating required is difficult to find. Second, and more critically, the thermosphere itself does not rotate close enough to the planetary period to be the origin of the signals.

A possible solution to the second problem is to push the location of the twin vortex deeper in the atmosphere. The thermosphere sub-corotates largely due to the coupling currents that transfer angular momentum to the magnetosphere. However, the stratosphere is sufficiently close to corotation that it could be the source of the PPOs. For this to be the case there needs to be a mechanism to extract sufficient field-aligned currents from the Hall conductivity that dominates this region of the upper atmosphere.

To investigate this mechanism I have explored various atmospheric-wave models to describe the required neutral flows. The first of these adapted a terrestrial model of circumpolar waves to develop a three-dimensional model of slowly westward-propagating Rossby waves. A problem with this model was that it was able to produce large enough currents only by invoking aurorally enhanced conductance. However, the prediction of waves propagating westward at a few percent of the planetary angular speed fits perfectly with the PPO periods being slightly longer than the likely deep planetary period.

The nature of Rossby waves also provided a possible heuristic model of the locking together of the northern and southern periods. Rossby waves are able to propagate westwards only with a small range of speeds. If the northern and southern Rossby waves each have their own range of possible propagation speeds, which vary independently, then it would be possible for them to lock together only when these ranges happened to overlap. This model qualitatively reproduces the observed locking behaviour, although the actual mechanism for them to lock together is not yet clear.

My most recent refinement to the Rossby-wave model has been to extend the beta-plane concept to ionospheric conductance. A beta-plane is an approximation in atmospheric-wave theory that represents the variation of the Coriolis parameter with latitude in a linear way. I applied the same approach to the variation of Hall conductance with latitude. This led to an explicit coupling equation between magnetospheric plasma flows and quasi-geostrophic Rossby waves, allowing me to investigate energy flow between the atmosphere and magnetosphere in a quantitative way: essentially, the magnetosphere can drive atmospheric waves, and *vice versa*.

Overall then, I have had some success in applying atmospheric-wave theory to this novel context. The next step is to try to build the physics of the centrifugal interchange instability into the magnetospheric component of the model, in the hope that this can provide an energy source for the Rossby waves that make up the twin-vortex. If successful this could provide an explanation, rather than just a description, of this fascinating and puzzling phenomenon.

The President. Thank you very much [applause]. Our next speaker is Professor Leah Morabito. She is UKRI Future Leaders Fellow at Durham University. Her work focusses on studying active radio galaxies at sub-arcsecond imaging with *LOFAR*, the low-frequency array. Recently, in the US, Leah won a military scholarship to fund her undergraduate studies and spent six years in the United States Air Force as an Air Battle Manager. During this time she was an MSc student at the University of Oklahoma when she worked with others on electromagnetic spectra and X-ray observations of quasars. Leah then went to Leiden University and hence to Durham, *via* Oxford. The title of her talk is 'The highest-resolution imaging at the lowest frequencies — sub-arcsecond imaging with *LOFAR*'.

Professor Leah Morabito. Thank you for the invitation to talk to the RAS and for the Rosemary Fowler Award for the work which I am going to talk about today.

If you took a picture with a very sensitive optical telescope, you would see hundreds to thousands of faint, distant galaxies. There are so many that they crowd each other in the picture: spiral galaxies next to elliptical galaxies, merging galaxies, irregular galaxies (and the occasional nearby star). However, if you looked at the same patch of the sky with a radio telescope, you would see something completely different. Radio images reveal the imprint of supermassive black holes in the form of radio-emitting jets of relativistic plasma. These jets are launched from supermassive black holes at the centres of massive galaxies, which are actively feeding on material in their host galaxy. Only about one in every one hundred galaxies has radio jets, so the radio sky is much emptier when compared to the optical sky, but radio provides us with important information on active supermassive black holes.

To study fully these radio-emitting jets, we must be able to study them in detail. This is where the *LOw Frequency ARray* (*LOFAR*) comes in. *LOFAR* is a radio telescope that is made up of hundreds of thousands of dipole antennae (similar to those in a car), which are located in eight different countries in Europe. These antennae are grouped into 'stations' of 96 dipoles each, and we can correlate the information recorded from each station to create images of the radio sky. Most of the stations are located in the Netherlands. By combining the signals from just these stations, we get *LOFAR*'s 'standard' resolution, which is poorer resolution than optical telescopes, but we can survey an area about eighty times larger than the Moon in a single image. If we include all European *LOFAR* stations, which span Ireland to Poland, we get a much bigger effective 'lens' for our telescope, and we can improve our resolution by a factor of 20 (see Fig. 1).

Combining signals from radio antennae up to 2000 km apart is technically and logistically challenging. The biggest challenge is correcting the data for distortions caused as the incoming radio waves pass through the ionosphere. What effect does this have on our images? Imagine that you're lying at the bottom of a swimming pool, looking up at the clouds. There might be a little gentle swaying as the water moves above you, distorting the image. Now, imagine that someone jumps into the pool right next to you. It would be incredibly difficult to describe the exact shape of the clouds above you if that happened. This is similar to what the ionosphere does to low-frequency radio waves. Sometimes, it is nicely behaved, and we need only small corrections — but sometimes we need many corrections in many different directions in the image to reconstruct what the radio sky looks like.

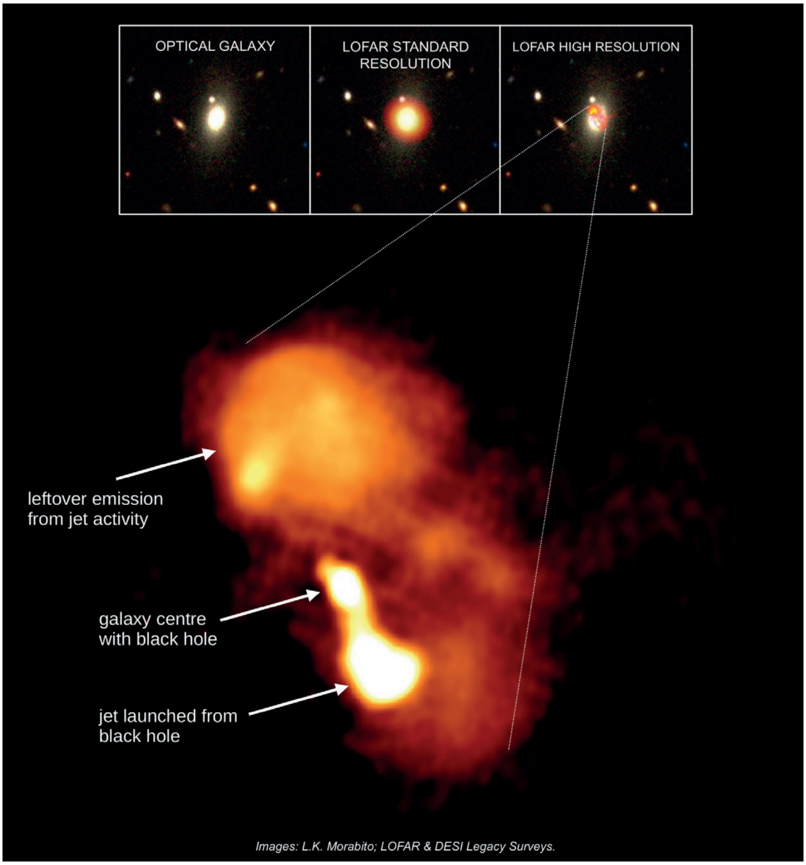

FIG. 1
An example of the resolving power of *LOFAR*.

Over the past decade, I have led efforts to develop a strategy for correcting the data. We have gone from doubt that it would ever work to huge successes — breaking the record for the highest-resolution images made using low radio frequencies! Today, high-resolution imaging is becoming routine thanks to our efforts to create a user-friendly data-processing pipeline that produces high-quality results. *LOFAR* is an exceptional instrument with major advantages that make it unique even in the era of next-generation radio telescopes like the *Square Kilometre Array* Observatory. High-resolution imaging with *LOFAR* can be done across a wide field of view, enabling blind and statistical studies. To get a similar resolution with other radio telescopes, one must go to higher frequencies at the cost of a drastically reduced field of view. *LOFAR* also matches the resolution of instruments at other wavebands, like optical, near-infrared, and X-ray, which is crucial for understanding how the emission at these different wavebands is related. The low-frequency coverage with high spatial resolution also enables studies of how the spectral-energy distribution changes across a wide range of radio frequencies; the information provided by *LOFAR* is necessary to constrain the initial injection index of the radio-emitting plasma. And finally, *LOFAR* can uniquely image a wide range of spatial scales from the same dataset, simply by choosing which stations to include. No other radio telescope is capable of simultaneously measuring diffuse degree-scale radio emission and compact sub-arcsecond-scale radio emission (and all spatial scales in between). All of these advantages make *LOFAR* uniquely capable of achieving science goals where other radio telescopes would struggle to compete.

Now that high-resolution imaging with *LOFAR* is routine, we are planning and enacting wide-area high-resolution surveys by post-processing current data, as well as deep images of selected 'famous fields' in the sky that are well-studied at non-radio wavebands. One of these fields is the *Euclid* Deep Field North. This field will have exceptional matched-resolution coverage from *Euclid* and *LOFAR*, providing a first-rate dataset to study star formation and supermassive-black-hole activity using a combination of spectroscopy and radio emission, all the way back into the early ages of the Universe.

The President. Thank you very much, Leah. Questions?

Professor Richard Ellis. If I have got this right, you said that you were finding more AGN through these high-resolution images?

Professor Morabito. Yes. This is quite technical but you can identify AGN using brightness-temperature measurements. There is an upper limit to star formation, the radio emission you produce in star formation. You really need high resolution to be able to detect high-surface-brightness sources because those high-surface-brightness sources are going to be your AGN. This is just a comparison in the GOODS North Field where they found 31 AGN, and the Elias N1 field where we find over 1500 using brightness temperature. Basically you predict what you get from star formation and if you get something above that as radio emission in terms of surface brightness it has to be due to AGN. That is frequency dependent so you need milli-arcsecond resolution to do this, *i.e.*, by using GHz frequencies, but at 144 MHz you can do it with 0·3-arcsecond resolution.

Professor Ellis. *JWST* is finding these puzzling little red dots so it would be wonderful if there is any overlap between your survey and these paradoxical little red dots.

Professor Morabito. I think that we will probably find things like this in the *LOFAR 2·0* Ultra Deep Observations (LUDO) survey because at present our deep fields are not deep enough to see these higher-z things, but LUDO should be able to see these kind of objects over the next few years.

The President. We are now experimenting by having a remote question for a remote speaker!

Dr. Pamela Rowell. Ian Robson has asked a question. "Great talk. In terms of data extraction and analysis what is the key lesson to be learned for the *SKA*?"

Professor Morabito. I would say that international *LOFAR* data processing is probably as close as we will get to *SKA* data processing in terms of what you are doing with the processing and the data volumes. I think that the key lesson is that we are going to have to be more efficient in how we process data. We have done very well in getting to a solution but for *SKA* and even now for LUDO when we are trying to process a lot of data at once, if you do a calculation based on the fact it takes 250 000 hours to make one wide-field image; it doesn't take that long now, but if you want to do this across the entire sky, it will take 75 years, which is not feasible. What we are really learning is how to process data efficiently in a large-scale non-interactive manner but I think although we have learned that we still have a long way to go.

The President. I have a question which I would ask over a glass of wine if you were here. You mentioned S/N problems early on. Have they got worse for any particular reason in recent times?

Professor Morabito. Because the ionosphere is impacted by the solar cycle and we are reaching a maximum, it has been an issue and we have seen that the data quality has decreased. *LOFAR* is currently off-line for an electronics upgrade which fortuitously coincides with the solar maximum. It does not mean that the data is not able to be calibrated, it just means that it has been a little more difficult.

The President. I was thinking about satellite-constellation noise but that may need several hours of discussion so let's leave it at that. Thank you very much again, Leah [applause].

We now come to the James Dungey Lecture to be given by Dr. Gabby Provan of the University of Leicester. She obtained a BSc Honours degree in Physics in 1993 and followed this with a PhD. She helped construct the *SuperDARN* radar in Iceland and I admire her courage in doing that. I tried to climb one of the antennae, got half way up and had to come down. Since her PhD she has worked on planetary aurorae, the magnetospheres of Earth, Saturn, and Jupiter using, in particular, the *Cassini* and *JUNO* spacecraft, and particularly looking at field-line currents associated with those aurorae. She also contributes greatly to the University of Leicester by looking after staff, so time pressures are high. She serves on the University Senate and Council. The title of her talk is 'The Northern Lights on Earth and other planets'. [It is expected that a full report will appear in a forthcoming issue of *Astronomy & Geophysics*.]

Dr. Gabrielle Provan. It's a real pleasure to be here today and to give the James Dungey Lecture, not least because James Dungey was one of the founding fathers of ionospheric physics, and it is a field which I have had the pleasure to work in for many years.

[The Northern Lights, or aurora borealis, rank among nature's most awe-inspiring light displays. For centuries, they have captivated those fortunate enough to witness them, inspiring myths, legends, and scientific curiosity. Despite their enigmatic beauty, it wasn't until the late 19th Century that scientists began unravelling the complex mechanisms behind these luminous phenomena.

The speaker began by examining Earth's aurorae in detail, showcasing stunning images and dynamic visualizations to illustrate their behaviour and variability, and continued by exploring the underlying processes that produce these dazzling lights, from the acceleration of charged particles in Earth's magnetosphere to their energetic collisions with atmospheric gases. How energy is transferred from the Sun to the Earth's system during auroral displays and the possible effect of this space weather on Earth was also discussed.

The speaker then extended the talk beyond Earth, exploring auroral displays observed on other planets within our Solar System, and considered the vivid ultraviolet aurorae of Jupiter, driven by the interplay of the planet's immense magnetic field and its volcanically active moon Io, as well as Saturn's auroral emission, and its temporal variability, followed by the more enigmatic aurorae observed on Uranus and Neptune.

Throughout the lecture the speaker focussed on using aurorae as diagnostic tools for understanding planetary magnetic fields, the properties of stellar winds, and the interactions between stars and planets. By studying aurorae on other planets, we gain critical insights into the habitability of exoplanets and the potential for magnetic fields to shield atmospheres from stellar radiation.]

The President. Thank you very much, Gabby. Questions? I have one. People often say that the last signal you can detect from Earth as you went away would be the auroral kilometric radiation (AKR). I am wondering if people are making predictions from the point of exoplanetary science on the difference between AKR, SKR, and JKR in terms of detecting what sort of planet we are talking about?

Dr. Provan. I do know that people are using radio signals to look for aurorae for different planets and extrasolar sources.

The President. These differences in the field-line-current systems for those sources are so fundamental that I think we should use that.

Dr. Stanley. We would have had some fantastic storms like the Carrington event that the ancient cave dwellers, in France, for instance, would have seen.

Dr. Provan. That is interesting when you look at the Northern Lights in myths and stories. That must also have occurred to the Romans and the Greeks given their latitude.

Dr. Stanley. Regarding the Carrington event, if you read his actual diary, rather than *Monthly Notices*, he did not continue his observations because he got back to cutting his trees. If you see the actual diary entry you will see that his arboreal interest supercedes his interest in astronomy.

A Fellow. I was looking to the future instead of the cave paintings. The *JUICE* mission is on its way to Jupiter and Ganymede now and I wondered what thoughts you might have both about what *JUICE* might discover about Ganymede and also Jupiter's aurora?

Dr. Provan. I had wanted to talk about Ganymede's aurora in this talk because it is the lack of wobbling of Ganymede's aurora that demonstrated that Ganymede has a salty, subsurface ocean. I'm looking forward to *JUICE*.

The President. Can I ask for a last round of applause for our James Dungey Lecturer. [Applause.] Thank you to Gabby and our other speakers tonight.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 26: THE F-TYPE LONG-PERIOD SYSTEM HP DRACONIS

By John Southworth

Astrophysics Group, Keele University

HP Dra is a well-detached eclipsing binary containing two late-F stars on an orbit with a relatively long period of 10·76 d and a small eccentricity of 0·036. It has been observed in 14 sectors using the *Transiting Exoplanet Survey Satellite* (*TESS*).

We use these data plus literature spectroscopic measurements to establish the properties of the component stars to high precision, finding masses of 1·135 ± 0·002 $M_{\odot}$ and 1·098 ± 0·002 $M_{\odot}$ and radii of 1·247 ± 0·005 $R_{\odot}$ and 1·150 ± 0·005 $R_{\odot}$. We find a much smaller third light than previous analyses, resulting in significant changes to the measured radii. These properties match theoretical predictions for an age of 3·5 Gyr and a solar metallicity. We present a spectrum of the Ca *H* and *K* lines in which chromospheric activity is visible from both components. The distance we find to the system, 77·9 ± 1·2 pc, matches the *Gaia* DR3 parallax value of 79·2 ± 0·3 pc.

Introduction

This work continues our series[1] of reanalyses of known detached eclipsing binary systems (dEBs) using new photometric observations primarily from the NASA *Transiting Exoplanet Survey Satellite*[2] (*TESS*). The aim is to use space-based data[3] to improve the measurements of the properties of the component stars and to add them to the *Detached Eclipsing Binary Catalogue*[4] (*DEBCat**).

In this work we present a study of HP Draconis (Table I), a late-F-type system with an eccentric orbit of relatively long period. Its variability was first noticed in photometry from the *Hipparcos* satellite[5], with a period of 6·693 d, and it was given its variable-star designation by Kazarovets *et al.*[6]. Its correct orbital period of 10·762 d was established by Kurpińska-Winiarska *et al.*[7] and refined by Milone *et al.*[8].

Table I

Basic information on HP Draconis. The BV magnitudes are each the mean of 94 individual measurements[12] *distributed approximately randomly in orbital phase. The JHK_s magnitudes are from 2MASS*[13] *and were obtained at an orbital phase of 0·89.*

Property	*Value*	*Reference*
Right ascension (J2000)	$18^h54^m53^s\cdot481$	14
Declination (J2000)	$+51^\circ18'29''\cdot79$	14
Henry Draper designation	HD 175900	15
Hipparcos designation	HIP 92835	5
Tycho designation	TYC 3552-394-1	12
Gaia DR3 designation	2144465183642116864	16
Gaia DR3 parallax (mas)	12·6153 ± 0·0516	16
TESS Input Catalog designation	TIC 48356677	17
B magnitude	8.54 ± 0·02	12
V magnitude	7·93 ± 0·01	12
J magnitude	6·853 ± 0·020	13
H magnitude	6·616 ± 0·016	13
K_s magnitude	6·565 ± 0·017	13
Spectral type	F9 V + F9 V	8

*https://www.astro.keele.ac.uk/jkt/debcat/

Milone *et al.*[8] presented an analysis of HP Dra, using radial velocities (RVs) from the Ca infrared triplet and the *Hipparcos* light-curve to simulate the then-expected performance of the *Gaia* mission. This work was updated by Milone, Kurpińska-Winiarska & Oblak[9] (hereafter MKO10) using additional RVs and *BV* photometry from Cracow[6]. That analysis resulted in measurements of the stellar masses and radii to 1% precision. The previous finding of apsidal motion[8] became only marginally significant in that analysis.

MKO10 found that 10% of the light in the system was produced by a source other than the two eclipsing stars, and noted that this was more than could be provided by nearby resolved stars contaminating the photoelectric photometry. They also presented cross-correlation functions in which no trace of a putative third component was visible. Possible explanations are that the additional light comes from an object with few spectral lines (*e.g.*, a white dwarf) or from two or more stars none of which are individually identifiable in the spectra.

Jalowiczor *et al.*[10] identified the object *Gaia* DR2 2144465183642117888 as a white-dwarf companion to HP Dra, with a common proper motion and an angular distance of 14″·405. As it is fainter by approximately 10 mag, it contributes a negligible amount of light to the *TESS* light-curve and thus is not responsible for the third light found by MKO10.

Baroch *et al.*[11] included HP Dra in their sample of dEBs expected to show apsidal motion dominated by the general-relativistic contribution. They analysed the first three sectors of *TESS* data but found no clear evidence for apsidal motion.

Photometric observations

HP Dra has been observed by *TESS* in 14 sectors (14, 15, 26, 40, 41, 53, 54, 55, 59, 74, 75, 80, 82, 86). In all cases data are available at 120-s cadence, and these were used for our analysis below. Lower-cadence observations (200, 600, and/or 1800 s) are also available for all sectors but were not used due to their poorer time resolution. The data were downloaded from the NASA Mikulski Archive for Space Telescopes (MAST*) using the LIGHTKURVE package[18].

We used the simple aperture photometry (SAP) light-curves from the SPOC data-reduction pipeline[19] for our analysis, and removed low-quality data using the LIGHTKURVE quality flag "hard". The data were converted into differential magnitudes and the median magnitude was subtracted from each sector for convenience.

Fig. 1 shows the light-curve from sector 86; the remaining sectors are similar so are not plotted. Some variability is visible in sector 86 and others (*e.g.* at times around BJD 2460637·5 and 2460651·0). This variability recurs on the orbital period of *TESS* so is an instrumental signal, not astrophysical.

Light-curve analysis

The components of HP Dra are well-separated and the light-curve is suitable for analysis using the JKTEBOP† code[20,21]. The profusion of data, the possibility of apsidal motion, and the expected change of third light with *TESS* sector, meant it was most efficient to model the light-curve from each sector individually.

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

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

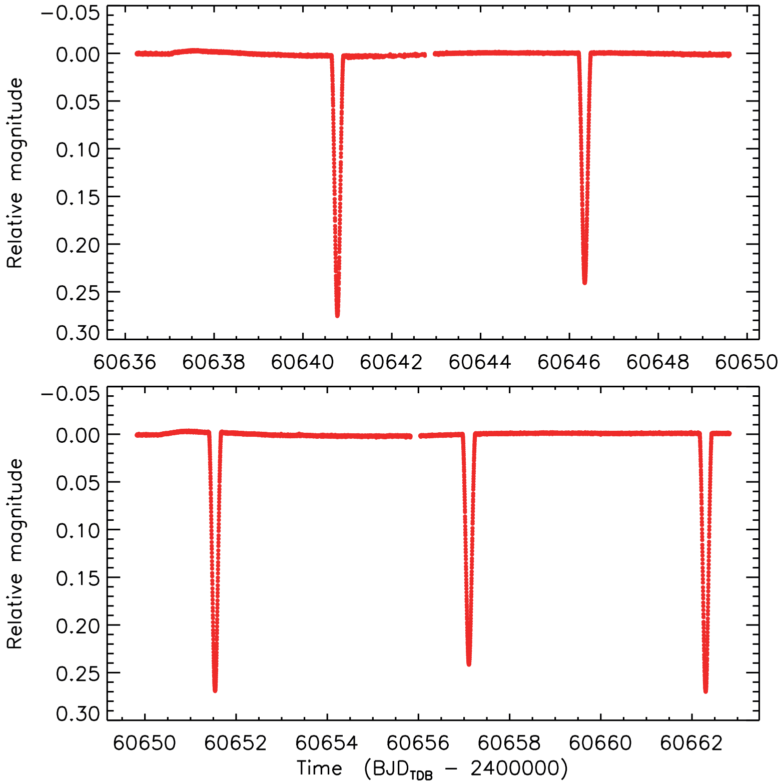

FIG. 1

TESS sector-86 photometry of HP Dra. The flux measurements have been converted to magnitude units after which the median was subtracted. The other 13 sectors used in this work are very similar so are not plotted.

The system is in eclipse for only approximately 10% of the time, so we removed data away from an eclipse to save computational time. This was done by detecting each fully-observed eclipse and retaining all data during eclipse plus an additional 0·1 d both before and after. Each eclipse was then normalized to zero differential magnitude by fitting and subtracting a straight line to the out-of-eclipse data, in order to remove slow variations of either instrumental or astrophysical origin.

For our analysis we defined star A to be the star eclipsed at the primary (deeper) minimum, and star B to be the one eclipsed at secondary minimum. The fitted parameters for each sector were fractional radii of the stars (r_A and r_B), the central-surface-brightness ratio ($\mathcal{J}$), third light (L_3), orbital inclination (i) and eccentricity (e), argument of periastron (ω), orbital period (P), and a reference time of primary minimum (T_0). The fractional radii were expressed as their sum ($r_A + r_B$) and ratio ($k = r_B/r_A$), and the shape parameters as the combinations $e \cos \omega$ and $e \sin \omega$, in both cases to decrease correlations between

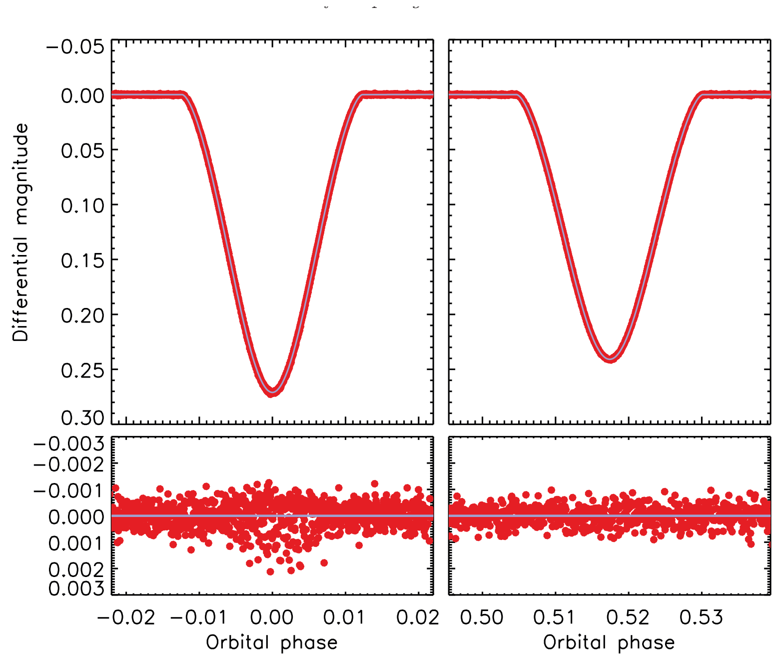

FIG. 2

JKTEBOP best fit to the light-curves of HP Dra from *TESS* sector 86 for the primary eclipse (left panels) and secondary eclipse (right panels). The data are shown as filled red circles and the best fit as a light-blue solid line. The residuals are shown on an enlarged scale in the lower panels.

TABLE II

Photometric parameters of HP Dra measured using JKTEBOP *from the TESS light-curves. The error bars are 1σ standard errors and were obtained from the scatter of the results for individual sectors.*

Parameter	*Value*
Fitted parameters:	
Orbital inclination (°)	87·5554 ± 0·0060
Sum of the fractional radii	0·08940 ± 0·00006
Ratio of the radii	0·9220 ± 0·0071
Central-surface-brightness ratio	0·95684 ± 0·00084
Third light	0·0049 ± 0·0020
$e \cos \omega$	0·027355 ± 0·000005
$e \sin \omega$	0·02411 ± 0·00016
LD coefficient c	0·6204 ± 0·0065
LD coefficient α	0·5548 (fixed)
Derived parameters:	
Fractional radius of star A	0·04652 ± 0·00017
Fractional radius of star B	0·04288 ± 0·00018
Light ratio ℓ_B/ℓ_A	0·814 ± 0·013
Orbital eccentricity	0·03647 ± 0·00011
Argument of periastron (°)	41·31 ± 0·19

parameters. Limb darkening (LD) was accounted for using the power-2 law[22–24] and we required both stars to have the same LD coefficients. The linear coefficient (c) was fitted and the non-linear coefficient (α) fixed at a theoretical value[25,26]. The *TESS* flux measurement errors were scaled to force a reduced χ^2 of $\chi^2_\nu = 1{\cdot}0$.

We found good fits for all sectors, and that for sector 86 can be seen in Fig. 2. The results between sectors are also in good agreement. The unweighted mean and standard error of the values for each parameter can be found in Table II. Uncertainties were also calculated using Monte Carlo and residual-permutation algorithms, with similar results to the standard errors in Table II.

Our results for some parameters (i, e, ω) are in good agreement with those that can easily be compared to the values from MKO10 (their table 4). We find a much smaller third light of 0·5% compared to their ~10%, and this changes the measured radii significantly.

Orbital ephemeris

Our analysis above yielded a mean time of primary eclipse for each sector, which are useful for establishing a precise ephemeris. We fitted a linear ephemeris to the times, obtaining

$$\text{Min I} = \text{BJD}_{\text{TDB}}\, 2459790{\cdot}615043(6) + 10{\cdot}76154354(16)E \qquad (1)$$

where E is the number of cycles since the reference time of minimum and the bracketed quantities indicate the uncertainty in the final digit of the previous number. The root-mean-square of the residuals is 5·2 s and the χ^2_ν is 2·0. This relatively poor agreement may be caused by spot activity on the stars affecting the eclipse shapes (see below). The uncertainties in the ephemeris in Eq. 1 have been multiplied by $\sqrt{\chi^2_\nu}$ to account for this. The times of minimum are given in Table III and the ephemeris is plotted in Fig. 3. The relatively larger uncertainty in the timing from sector 59 is because there was only one fully-observed primary eclipse in these data.

TABLE III

Times of published mid-eclipse for HP Dra and their residuals versus the fitted ephemeris.

Orbital cycle	*Eclipse time (BJD_{TDB})*	*Uncertainty (d)*	*Residual (d)*	*TESS sector*
−102	2458692·937603	0·000036	0·000001	14
−99	2458725·222208	0·000022	−0·000024	15
−72	2459015·783904	0·000028	−0·000004	26
−36	2459403·199411	0·000024	−0·000064	40
−33	2459435·484155	0·000017	0·000049	41
−3	2459758·330385	0·000016	−0·000027	53
0	2459790·615020	0·000021	−0·000023	54
2	2459812·138137	0·000006	0·000007	55
12	2459919·753581	0·000047	0·000016	59
50	2460328·692216	0·000024	−0·000004	74
53	2460360·976867	0·000022	0·000016	75
65	2460490·115396	0·000021	0·000023	80
70	2460543·923052	0·000024	−0·000039	82
80	2460651·538493	0·000024	−0·000033	86

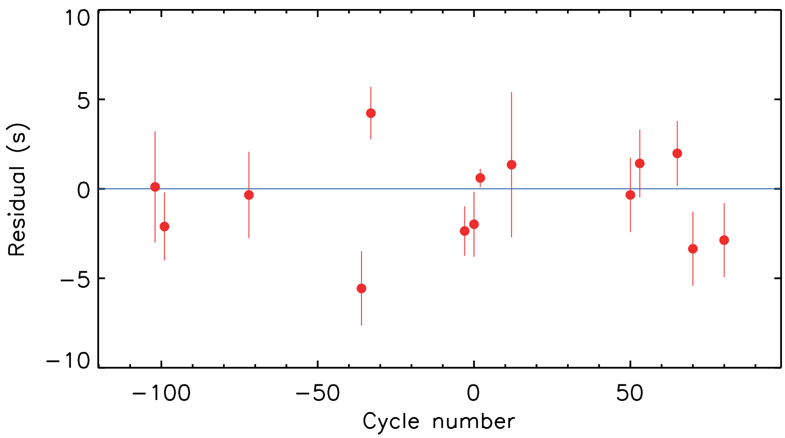

FIG. 3

Residuals of the times of minimum light from Table III (red circles) *versus* the best-fitting ephemeris. The blue solid line indicates a residual of zero.

We fitted a quadratic ephemeris as well, to see if apsidal motion was detectable, but the fit showed a negligible improvement and the quadratic variation was not significantly detected. We also tried to include historical times of minimum but found that they do not match the ephemeris above, suggesting the possibility of a light-time effect from a third body. We leave this matter to future work.

Radial-velocity analysis

We have reanalysed the RVs presented by MKO10 for two reasons: to provide an independent analysis; and to obtain the velocity amplitudes (K_A and K_B) needed for the next section (below). MKO10 performed a joint fit of their light-curves and the RVs, and proceeded directly to the masses and radii without passing through the intermediate quantities K_A and K_B.

The RVs in MKO10 comprise three sets: 17 RVs per star from the *Coravel* cross-correlation spectrometer[27], six spectra from the *Élodie* spectrograph[28] giving six RVs for star A and five for star B, and 29 spectra from the Asiago échelle spectrograph giving one RV per star per spectrum. The Asiago RVs were already published in Milone *et al.*[8]. We included all RVs in a single analysis, except for rejecting one discrepant Asiago RV taken near secondary eclipse.

We fitted all RVs simultaneously using JKTEBOP with a fixed P but allowing for a shift in T_0. We also fitted for K_A and K_B, the systemic velocity for both stars separately, $e\cos\omega$, and $e\sin\omega$. We also tried alternative approaches with $e\cos\omega$ and $e\sin\omega$ fixed at the photometric values and/or forcing the systemic velocities of the two stars to be the same, with essentially the same results but smaller error bars. The outcome of this analysis is the measurements $K_A = 61{\cdot}971 \pm 0{\cdot}056$ km s^{-1}, $K_B = 64{\cdot}067 \pm 0{\cdot}060$ km s^{-1}, and the plot in Fig. 4. The RV fit yielded an insignificant phase shift *versus* our orbital ephemeris, and $e\cos\omega$ and $e\sin\omega$ consistent with the light-curve analysis. The error bars were obtained from 1000 Monte Carlo simulations[29].

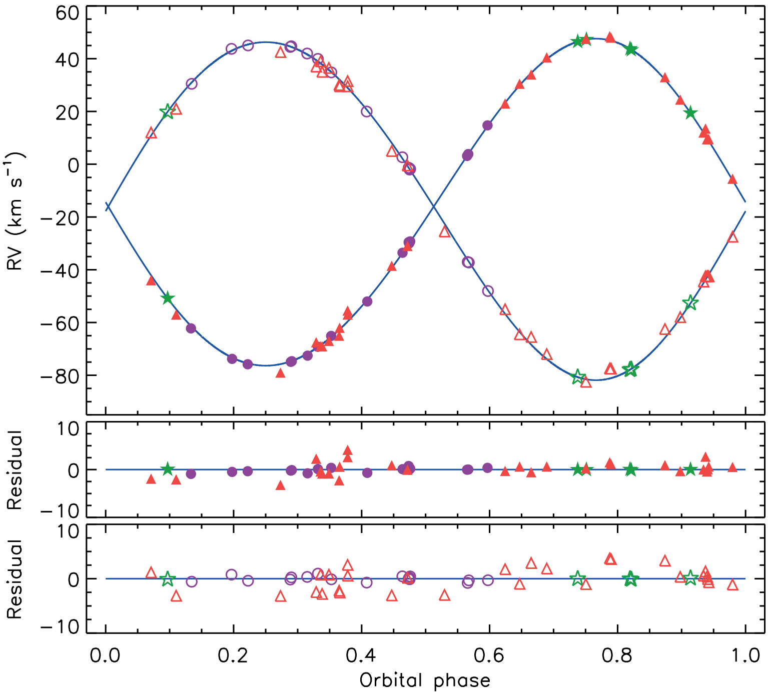

FIG. 4

RVs of HP Dra from MKO10 compared to the best fit from JKTEBOP (solid blue lines). The RVs for star A are shown with filled symbols, and for star B with open symbols. The residuals are given in the lower panels separately for the two components. RVs from *Coravel* are shown with purple circles, from *Élodie* with green stars, and from Asiago with red triangles.

Physical properties and distance to HP Dra

We calculated the physical properties of HP Dra using the JKTABSDIM code[31] with the photometric properties from Table II, and the K_A and K_B found above. We adopted the T_{eff} of star A to be 6000 ± 150 K from MKO10. For star B we calculated our own value based on that for star A and the surface-brightness ratio (Table II). The results are given in Table IV. Based on the data available, we have been able to measure the masses of the stars to 0·2% precision and the radii to 0·4% precision. These are among the most precise measurements currently available[32,4]. Compared to MKO10 we find almost identical masses, as expected, but significantly different radii (1·247 $R_\odot$ and 1·150 $R_\odot$ *versus* 1·371 $R_\odot$ and 1·052 $R_\odot$). We attribute this discrepancy to the much greater quality and quantity of the *TESS* light-curves compared to previous ground-based datasets, and to our somewhat different photometric solution with much less third light.

TABLE IV

Physical properties of HP Dra defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 30).

Parameter	*Star A*	*Star B*
Mass ratio M_B/M_A	0·9673 ± 0·0013	
Semi-major axis of relative orbit ($R^N_\odot$)	26·814 ± 0·017	
Mass ($M^N_\odot$)	1·1354 ± 0·0023	1·0984 ± 0·0022
Radius ($R^N_\odot$)	1·2474 ± 0·0046	1·1498 ± 0·0049
Surface gravity (log[cgs])	4·3012 ± 0·0032	4·3576 ± 0·0037
Density ($\rho_\odot$)	0·5850 ± 0·0064	0·7226 ± 0·0091
Synchronous rotational velocity (km s^{-1})	5·864 ± 0·021	5·406 ± 0·023
Effective temperature (K)	6000 ± 150	5935 ± 150
Luminosity log($L/L^N_\odot$)	0·259 ± 0·044	0·170 ± 0·033
M_{bol} (mag)	4·09 ± 0·11	4·32 ± 0·11
Interstellar reddening $E(B-V)$ (mag)	0·00 ± 0·01	
Distance (pc)	77·9 ± 1·2	

We determined the distance to HP Dra using the *BV* magnitudes from *Tycho*[12], *JHK*$_s$ magnitudes from 2MASS[13], and the surface-brightness calibrations from Kervella *et al.*[33]. No interstellar reddening was needed to align the optical and infrared distances, but we allowed an uncertainty of 0·01 mag for this deduction. Our most precise distance estimate is in the K_s band and is 77·9 ± 1·2 pc; this is consistent with the distance of 79·27 ± 0·32 pc from inversion of the *Gaia* DR3 parallax[14].

We performed a comparison of the measured masses, radii, and T_{eff} values of the component stars to theoretical predictions to infer their age and chemical composition. We found that a PARSEC 1·2 theoretical model[34] with an approximately solar chemical composition and an age around 3·5 Gyr provides an adequate match to our results. We leave detailed analysis to the future, preferably once a spectroscopic metallicity estimate is available to provide another constraint on the theoretical models.

Stellar activity

The *TESS* light-curve shows minor brightness modulations due to starspot activity, in addition to the instrumental variations discussed above. There are hints of a recurrence period of 11·0 to 11·5 d, in which case at least one of the stars is rotating slightly slower than the orbital period. The spot modulation evolves on a similar time-scale so this rotation period remains tentative. In a previous analysis of ZZ UMa[37] we found spot activity to be accompanied by a gradual change in the light ratio of the stars; this was searched for but not significantly detected in the current case.

In order to investigate the possibility of magnetic activity, we observed the Ca II *H* and *K* lines of HP Dra using the *Intermediate Dispersion Spectrograph* (*IDS*) at the Cassegrain focus of the *Isaac Newton Telescope* (*INT*). A single observation with an exposure time of 150 s was obtained on the night of 2022/06/07 in excellent weather conditions. We used the 235-mm camera, H2400B grating, EEV10 CCD, and a 1-arcsec slit and obtained a resolution of approximately 0·05 nm. A central wavelength of 4050 Å yielded a spectrum covering 373–438 nm at a reciprocal dispersion of 0·023 nm px^{-1}. The data were reduced using a pipeline currently being written by the author[38], which performs bias subtraction, division by a flat-field from a tungsten lamp, aperture extraction, and wavelength calibration using copper-argon and copper-neon arc-lamp spectra.

The spectrum was obtained at orbital phase 0·831 and is compared in Fig. 5 to a synthetic spectrum without chromospheric activity[35,36]. The Ca *H* and *K* line centres are clearly filled in by emission. The two stars had an RV separation of 118 km s^{-1} at this time (0·156 nm at 396·85 nm) and double-peaked emission with this separation is apparent. We conclude that both stars show chromospheric emission due to spot activity, and spot modulation of at least one star is visible in the *TESS* light-curves.

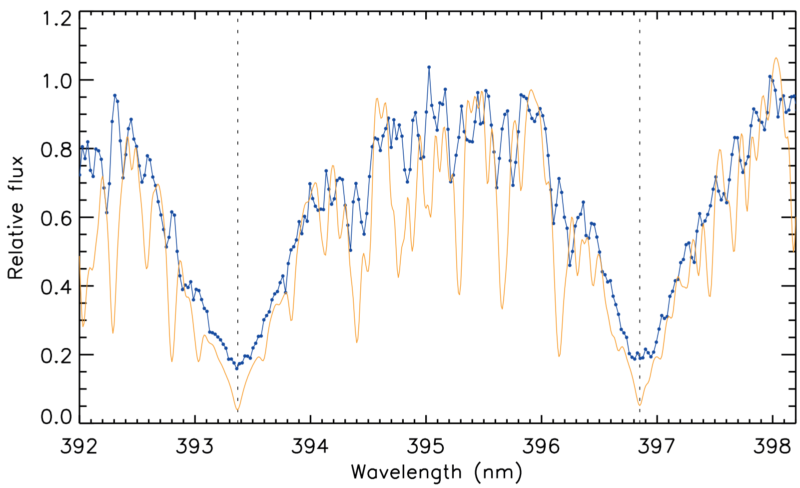

FIG. 5

Observed spectrum of HP Dra around the Ca II *H* and *K* lines (blue line with points) compared to a synthetic spectrum for a star with $T_{\rm eff}$ = 6000 K, log g = 4·2 and solar metallicity from the BT-Settl model atmospheres[35,36] (orange line). The *H* and *K* line central wavelengths are shown with dotted lines. The spectrum of HP Dra has been shifted to zero velocity and normalized to approximately unit flux.

Summary and conclusions

HP Dra is a dEB containing two late-F stars in an eccentric orbit with a relatively long period[39] of 10·76 d. It has a white-dwarf companion at an angular separation of 14″·4 and a hint of eclipse-timing variations caused by another, closer, companion. The *TESS* mission has observed it in 14 sectors, with full coverage of 63 eclipses (31 primary and 32 secondary). We modelled these light-curves and published RVs to measure the physical properties of the system. These properties are matched by theoretical predictions for an age of 3·5 Gyr and an approximately solar metallicity. The distance we find agrees with that from *Gaia* DR3. Both stars exhibit chromospheric activity in the Ca *H* and *K* lines.

HP Dra would benefit from a detailed spectroscopic analysis to determine the photospheric chemical composition and improve measurements of the stellar $T_{\rm eff}$ values. An analysis of its times of minimum light would also be helpful in checking for apsidal motion and the existence of a third body (in addition to the white dwarf). As the stellar masses are measured to 0·2% and the radii to 0·4%, and even without the suggested future work, the components of HP Dra are now among the most precisely characterized stars known.

Acknowledgements

This paper includes data collected by the *TESS* mission and obtained from the MAST data archive at the Space Telescope Science Institute (STScI). Funding for the *TESS* mission is provided by the NASA's Science Mission Directorate. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555. This paper includes observations made with the *Isaac Newton Telescope* operated on the island of La Palma by the Isaac Newton Group of Telescopes in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. This work has made use of data from the European Space Agency (ESA) mission *Gaia*[*], processed by the *Gaia* Data Processing and Analysis Consortium (DPAC[†]). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement. The following resources were used in the course of this work: the NASA Astrophysics Data System; the *Simbad* database operated at CDS, Strasbourg, France; and the arχiv scientific-paper-preprint service operated by Cornell University.

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REVIEWS

Geniuses, Heroes and Saints. The Nobel Prize and the Public Image of Science, by Massimiano Bucchi, translated by Tania Aragona (MIT Press), 2025. Pp. 208, 23 × 15 cm. Price $35 (about £27) (paperback; ISBN 978 0 262 55184 7).

This is the second book I have reviewed about the Nobel Prizes. The first one[1] concentrated on a selection of Prizes awarded in topics related to astronomy and analysed the reasons for awarding the Prize in each case. This book is very different: it is a broad review of Nobel Prizes as a whole (*i.e.*, all the Prizes awarded in the categories set out in Nobel's will), looking at the statistics and at how they affected the public view of science in general. It is an excellent translation (and slightly updated version) of an Italian original published in 2017.

The book starts with the origin of the Prize* and closes with a list of all Nobel winners up to 2024 in the three scientific categories recognised in Nobel's will: Physics, Chemistry, and Physiology or Medicine (Literature and Peace are not significantly discussed in the book). In between, there are chapters with such intriguing titles as 'How do you win a Nobel Prize?', 'How Einstein won the Nobel Prize and why he almost never received it', and 'How not to win a Nobel Prize: the story of Lise [Meitner] and other Prize 'ghosts'' (people who deserved but didn't receive a Nobel Prize).

*In 1888 April, Nobel (who developed dynamite) was shocked to read his own obituary in the paper, under the headline 'The Merchant of Death is Dead'. He realised that the journalist had confused him with his older brother Ludwig, who had died a few days earlier, but that the headline was aimed at him. Horrified that that would be how he would be remembered, he left a sum in his will to enable the foundation of a Prize for excellence in five fields — the three sciences listed above, literature and the promotion of peace — and indeed that is how he is remembered today.

Interestingly, Einstein received his Prize for discovering the photoelectric effect, not for relativity, which was too complicated for most scientists to understand and provoked strong opposition to him in the German scientific community, including by two Nobel winners (Lenard and Stark). As a result, he withdrew from appearing as an invited speaker at a scientific meeting in 1922 because he had been warned that he was on a list for assassination (partly because he was a Jew — another Jew, the Foreign Minister, had already been killed by gunmen a few months earlier). He kept a low profile after that. However, he was not present at the ceremony in Stockholm where the award was made — he was on a visit to Japan. He received the actual medal and certificate in July of the following year, at a conference in Gothenburg, at which the King of Sweden was sitting in the front row.

Einstein was not the only Prize winner to be absent from their award ceremony. Most were those awarded the Prizes for literature and peace, but there were some scientists who were either ill or unable to attend for other reasons (some were prisoners of war). Some Prizes were handed over in other countries, including in California. Most dramatically, three German scientists refused their Prizes in 1939 as a protest against the Nazi boycott of the Prize.

People who didn't receive the Prize were often nominated many times without success, for example Lise Meitner, nominated for both Physics and Chemistry. Many people think that Rosalind Franklin deserved a share in the Prize awarded to Watson and Crick, but the delay in recognising the double helix (which was crucially dependent on a famous X-ray image taken by her) meant that she had died before their nomination was accepted and the Prize cannot be awarded posthumously. More recently, Jocelyn Bell Burnell suffered from astrophysics not being recognised as physics (the Prize was awarded for the design and construction of the telescope). I note without comment that all three are women.

The author then takes his two final chapters to discuss both whether the award makes the Prize-winner more interesting and whether their physical appearance affects anything. Because the author is Italian, he uses the number of articles in the Italian paper *Corriere della Sera* as evidence, and there is some evidence, although the largest number of articles are naturally about Italian Prize-winners. Einstein is the most mentioned of the non-Italians. But a wider survey shows that some people (such as Einstein) were famous before their Nobel, others became famous because of the Nobel, and some were relatively unknown after their win. Why? National identity is one factor as is the type of discovery and the name attached to it, such as the double helix and Kroto and colleagues calling their new form of carbon 'fullerenes' after Buckminster Fuller — easily remembered. Another reason for winners being known to the general public is when the winner participates widely in public debates, even on topics outside their particular expertise.

Finally, there is their public appearance, exemplified by Einstein, whose general appearance so much resembles a caricature of a mad scientist. But in his youth, he also exuded a boyish freshness that made an Italian journalist describe him as like a saint! Other public figures tend to be treated in the same way, and a lay iconography emerged, making scientists into symbols of the social and cultural role of science. Many famous scientists (such as Newton and Pasteur) were regarded as models of asceticism in their disregard for anything (such as food) outside their research work. The model of a saint is emphasised by the relics that are kept after their death. Galileo's right hand is exhibited in the Galileo Museum in Florence, and Pasteur's body was embalmed and buried in a mausoleum in the Institut Pasteur in Paris.

Laureates are expected to be modest and humble about their work, to dress appropriately, and generally to behave with appropriate deference to important people. Those who abuse their privileged position by making inappropriate remarks become, in James Watson's words, "a nonperson" (he had criticized the intelligence of African Americans).

So — are scientists special or are they ordinary human beings? They are both, and the Nobel Prize gives a context for balancing this uncertainty — special enough as scientists to receive the Prize, but quite normal humans in daily life. The book finishes with an epilogue, entitled 'Geniuses, Heroes and Saints — how the Nobel Prize (re)invented the public image of science', reflecting his belief that any Laureate may be seen as one of these three categories. There is also an appendix, listing all the Nobel Laureates in the sciences from 1901 to 2024.

This was a fascinating book to read, but I found it very difficult to review because of the breadth of its coverage. I can nonetheless recommend it strongly. — Robert Connon Smith.

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Starborn: How the Stars Made Us — and Who We Would Be Without Them, by Roberto Trotta (Basic Books), 2023. Pp. 350, 24 × 16 cm. Price £22 (hardbound; ISBN 978 1 529 34608 4).

Spanning almost all the languages of Switzerland, Trotta was born in the Italian-speaking part, then obtained an MSc(Hons) in Physics from the ETH Zurich, and a PhD in Theoretical Physics from the University of Geneva, before spending a couple of decades at Oxford and Imperial College, working mainly in cosmology. After becoming Professor of Astrostatistics at the latter (where he remains a Visiting Professor) in 2019, he moved to SISSA in Trieste in 2020 to establish a new Data Science group and PhD programme (and was also Visiting Professor of Cosmology at Gresham College, 2019–2022). A recipient of many awards and member of many professional organizations, he has also been involved in university administration, not only within astronomy, and founded a consulting firm for statistics. This is his second book. He has appeared in these pages as the speaker at an RAS meeting (with the written version of his talk in the *Magazine*[1]), review author of conference proceedings on astrostatistics[2], author of an unusual book described in an unusual review[3] by one of the usual reviewers, and medal recipient[4].

This book is about how astronomy has influenced the cultural history of humanity, starting off with influences on the author, then covering how the night sky has become less important with time for most people, thoughts on life on a planet with no stars visible, early humans, clocks, navigation, the scientific revolution and its wider ramifications (in particular a good overview of various statistical measures; many mathematical innovations were made by astronomers), and astrology, before concluding with a chapter on the future.*

*That last chapter is similar to, but better than, the last chapters in two other books I've reviewed here[5–8].

At the end of all but the first chapter, there is a narrative concerning a human-like species on a world perpetually covered by clouds. That didn't really work for me* (the third chapter covers the same idea in a better fashion), but that's one of only two relatively minor points I didn't like (though it is at least debatable whether the letter Einstein signed urging that the USA develop nuclear weapons actually played a "crucial" role; even if Einstein regretted it, most historians agree that it would have happened anyway). The other point is the controversy over the name of the *James Webb Space Telescope* (*JWST*). For an alternative view, see ref. 9. Neither this review nor the book which it is about is the proper place for a detailed examination of the conflict (see ref. 9, follow the links, go down the rabbit hole, and form your own opinion), but it should at least be acknowledged that a significant fraction of astronomers (not just those making such decisions at NASA) don't think that a renaming is necessary. (Some have weakened their criticism: even if he personally did nothing wrong, Webb occupied a high position at NASA at a time during which some people were negatively affected by homophobia. Of course, one could levy the same charge against Nancy Grace Roman, his contemporary at NASA, but as far as I know, no-one has done so. Unfortunately, as was the case with Schrödinger (concerning whom exaggerated accusations have been debunked by professional historians of science[10]), many aspects of the cancellation remain, and the debunking gets less publicity than the accusations. Not only in books but also at conferences and so on it has become customary to mention one of a collection of tropes (*e.g.*, Jocelyn Bell should have been awarded the Nobel Prize); the purpose is not to stimulate discussion (quite the opposite: 'no debate'), but rather to signal to those in the know that one is on the right side of history.†)

The examples of the influence of astronomy on humanity cover not only traditional Western societies but also a variety of other ancient and modern societies. (However, one does not have to go so far afield — apart from exceptions like Chaucer and Milton — to find a male Moon and a female Sun: though it's the other way around in the Romance languages, in Germany it is the same as in Japan, Oceania, and among the Maori.) But little-known points from

*I've seen that before. For example, Harry Mulisch's *The Discovery of Heaven* (originally in Dutch, though I read it in German because it was a gift from a friend and my trepidation at reading translations (which might not be good even if the book is) was quelled since Mulisch himself, whose only native language is German, approved the translation) is a wonderful book but also contains what I find to be an annoying extra narrative at the beginning and end of each chapter. One of the main characters in the book is an astronomer (the two others are a linguist and a musician, thus covering three of my main interests) and is extremely well researched. Many readers here will know what astronomical details and people are mentioned even if the latter are not referred to by name.

†Even if the accusation is justified, I find it out of place in such a book, especially if one person is singled out. I have a similar complaint about a book[11] recently reviewed here[12], in which Feynman is the victim. The next two books I read after the one being reviewed now also take the stance that the *JWST* should be renamed. Other tropes mentioned in the book are the ideas that Ada Lovelace was the first computer programmer (see ref. 13 for a good debunking, particularly credible since the author would definitely describe himself as a feminist) and that the normal distribution implies that any deviation from the mean is somehow wrong or abnormal in the vernacular sense. (Gauss originally used the term 'normal' in that respect in connection with 'normal' (*i.e.*, orthogonal) equations. Later, probably *via* folk etymology, it was understood to mean that the distribution itself is normal because it is a very common distribution. In fact Pearson himself didn't like the name because he thought that it could create the impression that other distributions are somehow abnormal. To my knowledge no-one has ever used it in the sense which is mentioned in such criticism, but such criticism has become common through repetition; see ref. 14 for a typical example of the abuse of the term 'normal distribution' (a typical modern article in what used to be a good publication).)

Western culture are also mentioned, *e.g.*, the reason for the order of the names of the days of the week, each corresponding to a planet. Another interesting one, reversing the science-to-society direction: "Scottish physicist James Clerk Maxwell discovered social physics from a review by [John] Herschel of Quetelet's work."[15] And another: At the famous meeting between Napoleon and Laplace at which the latter allegedly said that he had no need for the hypothesis of God, also present were William Herschel and his wife.

There are only a few real typos (though 'Lippershey' for 'Lipperhey', an early telescope-maker, is presumably inspired by a misspelling in an English translation in 1831) or other goofs (*e.g.*, *Voyager 1* was launched in 1977, not 1967) and the overall style makes it a very readable book. There is a lot of information here, in that sense somewhat similar to another book[16] reviewed here recently[17]. Sometimes, though, a bit more precision would be useful; for example, whether "no one in antiquity could predict [a solar eclipse] reliably" depends on what one means by 'reliably'. Similarly, the relationship between tides, the shape of the Earth, and precession is a bit confusing, perhaps having been edited too much. Although Aristotle had the boundary between the imperfect sublunary and the perfect superlunary worlds at the orbit of the Moon, the Moon was thought of as part of the latter, not the former; when alluding to that, it is not clear whether the author agrees. Some things will probably remain speculation, for example, whether the fact that many societies, in many cases independently, consider(ed) the Pleiades to be the seven sisters, though most people can see only six and those who can see more can see more than seven, has been passed down from a time, at least a hundred thousand years ago, when seven would have been visible (proper motion having moved one of them too close to another to be resolved).

At the end of the book, after a couple of pages of acknowledgements and a shift to smaller type, are ten pages of notes, referring to passages in the text marked by superscripts, and containing further explanations (which I would prefer as footnotes), references, or both. References are in the form author, title, page, and refer to the twenty-eight-page bibliography where not only titles but also URLs (many of them for DOIs) are given. Such good references are particularly useful in a book such as this which is so wide-ranging that probably most readers will not be familiar with all of the topics. A fifteen-page index ends the book.

Apart from the two points mentioned above, which don't take up many pages, I enjoyed the book. It is very well written, better than those of many or most native speakers of English. It ranges from Neanderthals to the future and, while the astronomy is explained well, the emphasis is on its effect on humanity. — PHILLIP HELBIG.

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Special Relativity and Classical Field Theory: The Theoretical Minimum, by Leonard Susskind & Art Freeman (Penguin), 2017. Pp. 525, 20 × 13 cm. Price £10·99 (paperback; ISBN 978 0 141 98501 5).

I bought this book (along with several others which I have reviewed recently) in 2024 August in England, mainly because I had previously read and reviewed[1] another book[2] in the series which I found to be quite good; see that review for background. Like that other book, this one is well written and is constructed with a hybrid approach: first some maths, then some physics, then more maths as needed. A frequent complaint about books on Special Relativity is the lack of distinction between purely relative effects as described by the Lorentz transformation, real effects such as the age difference between the travelling and stay-at-home twin, and the appearance of rapidly moving objects. Regarding the last, I was happy to see Terrell rotation mentioned (though I can't find it in the otherwise good ten-page small-print index). Regarding the second item, it is pointed out that the twins differ because one accelerates and one does not. That is true, but one is left with the impression that the acceleration is the cause of the difference. Regarding the first, while it is the Lorentz transformation, it is the Lorenz gauge. (That is a common mistake — and probably not a typo, since there are relatively few typos — which is so common that I don't always mention in my reviews; I usually do mention it when the author gets it right.)

The structure is perhaps a bit unusual, starting with the Lorentz transformation then moving to classical field theory, then to the Maxwell equations, then to classical physics, essentially the opposite of the historical path. However, that does adhere to the theme of the theoretical minimum. While the history of science can be interesting for its own sake, and also provide valuable insight, the historical path is usually not the shortest if the goal is to acquire a good working practical knowledge.* Interestingly, Chapter 9, which connects Susskind's with the traditional approach, is said never to have made it to the video site on which the books in the series are based. (It's still not there, so presumably the corresponding video, if it ever existed, has been lost.)

There are a few black-and-white figures scattered throughout the text, and a few footnotes; no references or suggestions for further reading. (All in all, the books in the series are similar in their structure, though the lack of punctuation and strange mode of referring to equations named after people in the other book I reviewed are not present here.) Between the main text and the index are two appendices, on magnetic monopoles and vector operators. Despite the length, the book is a breezy read, due both to the writing and the somewhat

*All the same, Susskind doesn't merely present the material, but also offers his own comments on what is important and so on. I added two such comments to my collection of quotes: "Notation is far more important than most people realize" (p. 173) and "[P]hysics is always harder without the mathematics" (p. 279). Interestingly, just a few seconds before I had added one by Feynman on the same topic: "[M]athematics is, to a large extent, invention of better notations."

larger than usual typeface and interline spacing. It is a rather faithful rendition of the video lectures, which I recommend to those who prefer that medium to books. I'll probably read the other books in the series and if I find myself able to watch video but not read perhaps even watch all of the lectures. Groucho Marx noted that if one isn't having fun then one is doing something wrong and that the fear of the thorn shouldn't keep one from the rose. Both apply here, as Susskind's enthusiasm comes through well, acting as a glove to help one approach a somewhat thorny topic. — Phillip Helbig.

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(1) P. Helbig, *The Observatory*, **133**, 293, 2024.
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An Introduction to Brown Dwarfs. From very-low-mass stars to super-Jupiters, by John Gizis (IoP Publishing), 2024. Pp. 124, 26 × 18·5 cm. Price £75 (hardbound; ISBN 978 0 7503 3385 6).

An Introduction to Brown Dwarfs is an overview of the field of brown dwarfs, designed to bridge the gap from a general astronomy undergraduate education to doing research in the specific sub-field of brown dwarfs. I think that anyone interested in learning the basics of brown-dwarf astronomy will enjoy this textbook, as the tone throughout is both informative and accessible. The text includes insightful footnotes and interesting remarks on the history of the field, along with dozens of beautiful, colour figures that illustrate concepts clearly. In just eight chapters, Dr. Gizis covers all of the main areas of research in the brown-dwarf field, and explains many of the assumptions and customs of the field that are often discussed, yet rarely justified at conferences and in the literature.

The book explores brown dwarfs through a variety of lenses and contexts, but primarily focusses on two main paradigms: star-like and super-Jupiter-like. The text illustrates the similarities brown dwarfs share with both of these types of objects and the lessons that can be borrowed from both stellar and exoplanetary astronomy. The presentation and order of the text is logical and the narrative is easy to follow. Throughout the text, Dr. Gizis provides numerous resources for observational data, interior and atmospheric models, and other software and tools for brown-dwarf research. Highlights include tables of key photometric filters, thoughtful discussion of standard surveys and calibrations, helpful references to and figures of spectroscopic standards, highlights of key papers from the literature, and lists of models and software for different areas of research.

This text has only a couple of very minor issues, including a few errors and typos in the text and figures. Some minor choices in figure labelling or units could be more precise (for example, axes or legends occasionally omit key quantities), but these do not hinder comprehension. I also feel that some of the more interesting aspects of brown-dwarf research were overlooked, including rotation rates and angular-momentum evolution, as well as the role of magnetic fields and the presence of aurorae in brown atmospheres. However, after reading this textbook the reader will be well prepared to explore the literature on these topics themselves.

The printed version of the text comes in at 128 pages and while no exercises or problems are provided, a collection of Python Jupyter Notebooks intended to reproduce the plots and calculations of the text is advertised in the first paragraph of Chapter 1. At the time of writing this review, these Notebooks were not yet publicly available. — Megan E. Tannock.

Our Accidental Universe: Stories of Discovery from Asteroids to Aliens, by Chris Lintott (Torva), 2024. Pp. 265, 24 × 16 cm. Price £22 (hardbound; ISBN 978 1 911709 18 3).

Chris Lintott is well known as successor to Patrick Moore as presenter of the BBC's *The Sky at Night*, as well as a professor of astrophysics in Oxford and co-founder of the Galaxy Zoo citizen-science galaxy-classification project (which was integrated into to the Zooniverse platform of which Lintott was also the PI for 15 years). This isn't his first book but is the first which I have read. As the subtitle says, it is a book about actual (*e.g.*, pulsars), and potential (*e.g.*, extraterrestrial life) discoveries, many of them accidental. The chapters (the content of which isn't always obvious from their names) cover SETI; craters in general and Enceladus in particular; 'Oumuamua (an entire book[1] about which was reviewed in these pages[2]); comets, meteorites, asteroids, space weather, and near-Earth objects; the claims of detection of phosphine on Venus and Titan in general; deep-field astronomy and *Gaia*; radio astronomy and gravitational waves (with pulsars providing the connection); and the cosmic microwave background. The last chapter covers many more topics with less detail on each, such as the Carte du Ciel, modern surveys such as the Sloan Digital Sky Survey, Galaxy Zoo, exoplanets, brightness variations in Betelgeuse and Boyajian's Star, and a look to the future in the context of the *Vera Rubin Observatory*.

Many interesting facts are mentioned, some familiar (a (sidereal) day on Venus is longer than a year — though it's strange that its retrograde rotation isn't mentioned), some less familiar (fascinating details in the life of Grote Reber), and some a bit confusing (radio astronomy at Jodrell Bank jumps from the *Lovell* telescope to *e-MERLIN* without mentioning the highly successful *MERLIN*, the main difference being that the older *MERLIN* was an interferometer connected *via* microwave communication while *e-MERLIN* uses fibre-optic cables to connect the same telescopes). One of the usual cosmology errors occurs: although our Universe has a positive cosmological constant and will expand forever, the former is neither necessary nor sufficient for the latter. Like in the two books I read immediately before this one[3–6], there is the standard complaint about naming a telescope after James Webb (see ref. 4 for details).

There are a few errors I put down to carelessness: Venus is high in the western sky when at greatest eastern, not western, elongation; Harrison Schmitt and not Schmidt was the first scientist (and last astronaut) to set foot on the Moon — maybe just a typo; more puzzling is dating the dinosaur-killing Alvarez impact at five rather than sixty-six million years ago, though the periods before and after, Cretaceous and Paleogene, are correctly named; it's the Domesday and not the Doomsday book (perhaps the author was thinking of asteroid impacts).

There are many topics in science about which there is not yet a consensus, but I don't understand why Avi Loeb is criticized so harshly. While it is true that his book[1] on 'Oumuamua does contain "a reading list of over two hundred separate works, every single one of them with Loeb as a co-author" (most astrophysicists won't write that many papers in their entire career; at last count, Loeb is approaching a thousand refereed-journal papers), the end notes do provide references to the works of others mentioned in the text, whether or not they agree with Loeb.

There are a few black-and-white photos scattered throughout the book. Notes are footnotes, often providing additional humour. The main text is followed by a substantial collection of backmatter: a couple of pages of glossary, six on further reading (by chapter), a page of picture credits, almost ten pages of index in small print, and one paragraph about the author. This is not an attempt to survey astronomy systematically as a whole or even a part of it; rather than the definitive collection, it's more a 'best of', highlighting topics of interest to the author and probably the reader, providing more details than is usually the case on many of them. Despite my minor qualms, the book is an enjoyable read, presenting some topics not often encountered in popular-astronomy books and other more common ones from a new perspective. — PHILLIP HELBIG.

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(2) P. Helbig, *The Observatory*, **142**, 184, 2022.
(3) R. Trotta, *Starborn: How the Stars Made Us — and Who We Would be Without Them* (Basic Books), 2023.
(4) P. Helbig, *The Observatory*, **145**, 180, 2025.
(5) A. May, *Eyes in the Sky: Space Telescopes from Hubble to Webb* (Icon Books), 2024.
(6) P. Helbig, *The Observatory*, **145**, 186, 2025.

Eyes in the Sky: Space Telescopes from Hubble to Webb, by Andrew May (Icon Books), 2024. Pp. 176, 20 × 13 cm. Price £10·99 (hardbound; ISBN 978 1 8377 31275 5).

Not to be confused with any of a number of non-astronomy books or other items with identical or similar titles (such as the film *Eye in the Sky* with Helen Mirren or the unrelated song of the same name by The Alan Parsons Project), nor with *Eye on the Sky*[1,2] nor with *Eyes on the Skies*[3,4], nor *Eyes on the Sky*[5]*, this little book is about telescopes in space or, more accurately, about what they observe (it is not about the technical details of the telescopes themselves). May has a PhD in astrophysics and worked in academia and in government and private sectors before becoming a freelance writer and consultant. This book is part of the *Hot Science* series edited by Brian Clegg, in which both May and Clegg have written several books each; some of the latter's have been reviewed in these pages[6–9]. The author takes us through various space telescopes such as *HST*, *JWST*†, *Spitzer*, *Chandra*, *Fermi*, *Kepler*, *TESS*, *Herschel*, *Gaia*, and *Planck*, along the way providing the necessary essential background (the electromagnetic spectrum, different types of telescope optics, *etc.*), and highlighting their most important observations and basic astrophysical details about the objects observed. Of course, not all telescopes in space could be covered, but conspicuous by its absence is the very successful *ROSAT*.

*Amazingly, not reviewed in these pages!

†Including the now apparently obligatory (but here fortunately brief) remark that it should have not been named after Webb.

There are a few black-and-white figures scattered throughout the book, which ends with an index. All in all a very enjoyable and well written book for lay readers interested in astronomy, but also a good quick reference for those who need an executive summary of one of the space telescopes covered. — PHILLIP HELBIG.

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Modular Forms and String Theory, by Eric D'Hoker & Justin Kaidi (Cambridge University Press), 2025. Pp. 480, 25 × 18 cm. Price £59·99/$79·99 (hardbound; ISBN 978 1 009 45753 8).

Modular forms are not, perhaps, a topic close to the heart of many astronomers. Sinusoidal functions are periodic on an interval; more complicated functions can be expanded in a basis of them. Modular forms — elliptic functions such as the Jacobi theta function — can be viewed as generalizations of these, to capture the periodicity properties of tori of arbitrary shape. For those who wish to do (2-dimensional) quantum field theory on a torus (something that is an essential part of the standard formulation of amplitudes in string theory), modular forms will crop up to a greater or lesser extent.

This book provides a detailed account of modular form from a physics perspective, in the context of their application to string theory. It is written by two of the experts in the subject and gives a comprehensive mathematical physics account of modular forms. Certainly, this book is an essential reference for researchers working in this field. This is not a book to dabble into for a quick summary of the topic: it is a serious book for serious scholars in this area. It must, however, be candidly admitted that this will include few, if any, astronomers: to appreciate this book, a strong side interest in mathematical physics would be necessary. — JOSEPH CONLON.

The Stargazers' Almanac 2026. An Illustrated Month-at-a-Glance Guide to the Night Sky, compiled by Callum Potter (Floris Books), 2025. Pp. 28, 30 × 42 cm. Price £14·99/$24·99 (stiff paper; ISBN 978 178250 945 5).

The perfect Christmas present for anyone even remotely interested in the continually-changing pageant of the night sky, this *Almanac* has been the ideal guide for laymen and beginners for many years. For an observer located at a latitude around 50° North, the calendar-like *Almanac* can be hung up to display the sky in both northerly and southerly directions for each month. The constellations are clearly marked and so are the planets visible at the time. Highlights are pointed out (*e.g.*, Orion and its nebula in January) and a panel along the lower part of the chart shows the phases of the Moon. No telescope needed — just find a dark location and enjoy the celestial show. — DAVID STICKLAND.

William Dawes. Scientist, Governor, Abolitionist: Caught between Science and Religion, by R. de Grijs & A. Jacob (Springer), 2024. Pp. 272, 23·5 × 15·5 cm. Price £64·99 (hardbound; ISBN 978 3 031 38776 0).

On 1787 May 11, a fleet of 11 ships left Portsmouth, with some 1420 souls on board. This was the first of a planned series of voyages to take those who had been given sentences of banishment from the courts to the newly founded colony in Australia at Botany Bay. The journey took over eight months. Now known as The First Fleet it contained, in addition to those guilty of serious crimes, a new governor for the colony and a number of specialist midshipmen, one of whom, William Dawes, is the subject of the present volume.

Nevil Maskelyne, the Astronomer Royal, had commanded the Board of Longitude to set up an observatory ostensibly to observe the return of a comet which he predicted would re-appear in 1788 or 1789. Dawes had shown a promising command of navigation which he acquired at the Royal Naval Academy in Portsmouth and was also a good linguist, so he was sent to Greenwich to undertake further training under Maskelyne. Dawes had joined the Marines and had seen action in the West Indies against the French. He was regarded as amiable, kind, and truly religious, and what he saw of the slave trade there repelled him.

When The First Fleet reached Australia Dawes set up the first observatory in Sydney Harbour. He had been equipped with instruments from Maskelyne including a clock by Kendall (K1), a quadrant by Bird, and a sextant by Hadley, along with various meteorological instruments. On arrival, Dawes set up an observatory where he made regular measures of gravity, temperature, and atmospheric pressure, but also when the sky was clear at night (and he wasn't particularly impressed with the number of clear nights) he discovered several new nebulae and took observations of the Moon's parallax and the satellites of Jupiter. He was never able to find Maskelyne's comet.

When he left Australia in 1791 that essentially saw the end of his scientific work. He then went to Sierra Leone and in all spent four lengthy periods of time there. His moral and religious beliefs often saw him in conflict with authority. The pressure to ban slavery was being orchestrated by William Wilberforce and others. It had been decided that Sierra Leone would become a private colony incorporated by its own Act of Parliament, supported but not controlled by the British Government. It would be populated by freed slaves from the Americas. This appealed to Dawes who considered slavery to be an abomination. Enough evidence survives to give a good picture of a man who experienced Australia, West Africa, and the West Indies during particularly turbulent times to produce this excellent account which has been meticulously researched, particularly that part relating to his work on behalf of the Church Missionary Society in the West Indies which ultimately saw him at odds with senior members of the Anglican clergy.

The authors summarize him thus: "A genius or a polymath, a theorist par excellence yet lacking enough doses of savvy and pragmatism, his politically woefully inept worldview, combined with an abrasive personality, unmovable, alienating stances and religious convictions set in stone, rendered him a mere footnote in history, fading away from almost all opportunities to make a tangible real-world impact."

His last post took him to Antigua in 1813 where he remained until his death in 1836. This is a most welcome addition to the astronomical literature. His son, William Rutter Dawes, who suffered from ill-health during his youth and remained in England, barely seeing his father, but who rose to prominence in Victorian astronomy deserves similar consideration. — ROBERT ARGYLE.

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

All papers and *Notes* are subject to peer review by the normal refereeing process. Other material may be reviewed solely by the Editors, in order to expedite processing. The nominal publication date is the first day of the month shown on the cover of a given issue, which will normally contain material accepted no later than four months before that date. There are no page charges.

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

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

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

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CONTENTS

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