THE OBSERVATORY

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EDITORIAL

The end of 2023 marks an interesting point in the history of *The Observatory*: the first issue came out in 1877 April, 23 years before the turn of the 19th to the 20th Century; we now find ourselves 23 years on from the turn of the 20th to the 21st Century. The question we must now face is the relevance of the *Magazine* looking to the future. In those e-free days of yesteryear, *The Observatory* was an important means of communications, with reports of RAS meetings and other events appearing just two or three weeks after they occurred. Today, with two rounds of proofs to check and numerous other distractions, it can take months for such matters to come to light. And with on-line facilities such as arχiv, at least the preliminary results of research can also be made available in no time at all. The book reviews may still be a valuable feature of the *Magazine*, but publishers now seem less willing to send copies — ten years ago, we received around 100 books in the course of the year; to mid-August in 2023, only 24 had been received. Note that we have so far eschewed e-books!

And now to the matter of prices. A copy of the first issue cost one shilling — five new pence in today's money. Clearly inflation over almost a century and a half has had a staggering effect on prices to the point where the financial impact on individuals and institutions must be considered. The Editors have never sought to make a profit from sales of the *Magazine*, but around the last turn of the century managed to build a small reserve which enabled them to hold prices steady for the past 11 years. However, the steep rise in inflation of the last year or so — especially in the price of postage which now accounts for almost a third of the cost of production and delivery — has forced us to set new prices for 2024. Whether *The Observatory* will progress much further into the 21st Century is up to its subscribers!

Thus for the annual subscription for 2024, the price to institutions will be £120 or for those outside the UK £140 or $185; and for personal subscribers in the UK it will be £30 and for those outside the UK it will be £50 or $70.

MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2023 April 14 at 16^{h} 00^{m}
in the Geological Society Lecture Theatre, Burlington House

MIKE EDMUNDS, *President*
in the Chair

The President. Welcome to today's meeting. This is a hybrid meeting. Questions can be asked *via* the chat facility and will be read out by the Executive Director, Phil Diamond. It is my great pleasure to announce that Professor Richard Ellis, from University College London, has won the Gruber Prize for cosmology — well earned, of course. Also the Jupiter icy-moons mission from ESA (*JUICE*) launched successfully today and is on its way to Jupiter, so you can put it in your diaries for eight years' time [laughter]. The 203rd AGM will be held at 4pm on May 12th, followed by the Presidential Lecture with the intriguing title 'The Mechanical Universe', so it is not one to miss. I'll make sure that I don't! [Laughter.]

On to today's programme. I'm delighted to introduce Dr. Mark Clampin who is the Astrophysics Division Director in the Science Mission Directorate at NASA headquarters in Washington DC. Until 2022 August he was Director of the Sciences and Exploration Directorate at Goddard Space Flight Center, leading the Astrophysics, Solar System, Heliospheric and Earth Sciences Division together with a high-performance-computing office. At Goddard Space Flight Center he previously served as the *James Webb Space Telescope* Observatory Project Scientist and is Director of the Astrophysics Science Division and Deputy Director of the Science and Exploration Directorate. We look forward very much to hearing about 'NASA's Plans for the Future'.

Dr. Mark Clampin. [In NASA's Science Mission Directorate (SMD), the Astrophysics Division (APD) studies the Universe. It has been an amazing year for NASA Astrophysics, with *JWST* approaching its first-year anniversary of science operations. I will highlight some early results from *JWST*, and discuss the overall performance of the Observatory as we look towards future opportunities. The highest priority for APD is currently the *Roman Space Telescope*, which will conduct wide-field near-IR surveys to study dark energy and dark matter. I will review recent progress in developing *Roman* and its instruments. APD operates a broad portfolio of missions, ranging from *Hubble* and *Chandra*, Explorer missions such as *TESS*, and small satellites such as *Pandora*. International collaborations represent a significant component of APD's portfolio and include *JWST* and *Hubble*. Missions in development include partnerships with the European Space Agency for a gravitational-wave observatory, the *Laser Interferometer Space Antenna* (*LISA*); and *Athena*, an X-ray observatory. APD's current priorities are set by the 2020 National Academies Decadal Survey. I will review these recommendations, and discuss APD's response to the recommendation for a future 'Great Observatory', the *Habitable Worlds Observatory*.]

The President. Thank you very much. That was magnificent. So much to absorb. Let me ask for questions — firstly in the room.

Dr. Zbigniew Kolendowicz. You didn't mention interstellar missions. Are there any planned because we keep hearing rumours of a possible mission to Proxima [Centauri]?

Dr. Clampin. I would say that that is not really within the purview of the Astrophysics Science Division. I know that right now the heliophysics-science community in the US are pulling together their decadal survey and I believe that there is a mission that they are thinking about that would go beyond the bounds of our Solar System, but I don't know the exact details. I don't know if anyone is talking about going to another star right now.

Dr. Paul Wheat. You mentioned coronagraphs a few times. Can I assume that they are rigidly fixed to the telescope — they are not floating ones — and also what kind of distance are they from the collecting mirror, and when you move it to point it, is there a settling time due to the stiffness of the structure?

Dr. Clampin. The first part of your question refers to a star-shade, and one of the challenges that the decadal survey has given us is five years starting to develop the technology, so we have tried to focus on the available technology to do the high-contrast imaging, and we have chosen to focus on coronagraphs and not external star-shades. The other issue with external star-shades, of course, is that they are large deployable structures which require a lot of development work even after you have demonstrated that they can get you the contrast. The second part is a very good question. The stability of the structure is going to be an important part of the *Habitable Worlds Observatory* and we will be spending a lot of time thinking about how do you get to that ultra-high level of stability after you have slewed the telescope. In fact, active control will hopefully take care of a lot of that.

Reverend Garth Barber. Do you see any problems arising from the increasing amount of space debris and the fleets of satellites that are being launched in their thousands? It seems to be quite a crowded space. Does that affect your programme?

Dr. Clampin. The simple answer is yes. We do conjunction analysis for a lot of our low-Earth-orbit missions. Sometimes we get a warning and we have to do something to move them if necessary. Going in to the future I agree it's getting to be a bigger and bigger problem. I think that if you look at recent news reports in space journals you will see that it looks like the Federal Aviation Authority is going to be tasked with managing launches and space debris moving forward, certainly for the US in terms of regulation. Already within the agency we have a plan for the disposal of any mission. The proliferation of cubesats that are being launched is an issue.

The President. This is something the Society takes very seriously too. I note a *LISA* launch date of 2036. Was that optimistic or pessimistic?

Dr. Clampin. That is the date that the European Space Agency have given us as a working date. I really want to defer to them [laughter].

The President. Any further questions? Can I thank you again — that was absolutely splendid [applause].

We now move on to something that we all enjoy — the Harold Jeffreys Lecture for this year. For that I have to introduce Professor Rhodri Davies, who is a computational observational geodynamicist based at the Australian National University's Research School of Earth Sciences. He is internationally recognized and awarded for the research that links the evolution of the Earth's surface to the dynamical procedures within its interior. He has developed some of the most advanced tools available for simulating geodynamical processes, and used these alongside a variety of observational datasets to enhance understanding of mantle dynamics and its signature at the surface across a range of spatial and temporal scales. I have much pleasure in asking you to give this year's Harold Jeffreys Lecture entitled 'Linking intra-plate volcanism to underlying mantle dynamics'. [Applause.]

Professor Rhodri Davies. [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*. Most of Earth's volcanism occurs at tectonic-plate boundaries, where plates move away from one another to create mid-ocean ridges, or where one plate slides beneath another to form a subduction zone. However, an important and widespread class of volcanism occurs within plates, or across plate boundaries. These so-called intra-plate volcanic provinces, which include the most rapid and voluminous volcanic episodes recorded in Earth's history, are often associated with mantle plumes, hot buoyant columns that rise from Earth's core–mantle boundary to its surface.

It is becoming increasingly evident, however, that several of these provinces cannot be explained by the mantle-plume hypothesis and are likely driven by alternative mechanisms that involve the interplay between mantle flow and the base of Earth's rigid outermost shell — the lithosphere. The applicability and relative importance of these mechanisms, however, remains unclear, and likely varies from one geological setting to the next. In this talk, I showcase recent efforts to reveal the dynamical mechanisms underpinning Earth's intra-plate volcanic provinces, through observational geodynamics, where observational constraints from across the geosciences are fused and integrated with fundamental physical laws encoded in multi-resolution geodynamical models. Particular attention will be paid to those provinces that lie within, or adjacent to, Earth's continents.]

The President. Thank you very much indeed. I think that some of those pictures and diagrams could well be transferred to the Royal Academy, just down the road. Beautiful graphics — thank you for that presentation. Can I invite questions?

Professor Martin Barstow. I think I'm completely convinced. You say that you can't give details for individual systems but is there any predictive power inside what you are doing that might actually help you if you want to understand what might happen in the future in the current volcanic system and look ahead and predict future activity that you can then help and support populations through?

Professor Davies. One of the neat things about intra-plate volcanism is that it doesn't often lead to the large volcanic eruptions that we see in the subduction systems, at least in the short term, so they are not the major issues. Most major mass extinctions seem to correlate with events of plume head — the large igneous provinces. I'm not saying that we are on the edge of a mass extinction, I'm just saying what the relative importance is. If I use Australia as an example, we have some volcanic provinces that are on the edge of each progressive track and they are clearly the manifestation of a mantle plume. If you are close to the bottom of that track, there is possibly a mechanism there to produce current volcanism, whereas further up the track where it is older, it is highly unlikely that you will get an eruption in the future. In the newer volcanic provinces, such as that to the west of Melbourne, that last erupted 5000 years ago and work by Nick Rawlinson and others shows that seismically that region is still very slow and these losses may require melt in the mantle below these regions. Again they are not extinct, these volcanoes could erupt at any time but that doesn't mean they are going to erupt today or tomorrow, but there is no reason in that particular part of the world to assume that they are not going to erupt; whereas if you go back along the Hawaiian track there are probably not going to be any eruptions along that track.

Professor Chris Reynolds. Fascinating talk — a question about rotation of the Earth. On the time-scales you are talking about the Earth is a very fast rotator and at least in the astrophysical systems which are my bread and butter we are used to that fundamentally changing the way convection works. Can you comment on whether that is relevant, is there a latitude dependence on these phenomena — or differences between east and west or north and south?

Professor Davies. If I told you that the viscosity of the mantle was 10^{-21} pascal seconds, no. We think of this as a stoked system — inertia, centrifugal forces, Coriolis forces are all irrelevant. If you are looking at core dynamics, that is a different answer.

Professor Kathy Whaler. I've got a couple of questions about your mantle plumes. The seismic images that we all see and love show plumes as these great fat chunky things and I'm guessing that it's still thought that is the resolution you can get from tomography.

Professor Davies. That would depend on who you speak to. I can't envision scenarios when the volcanism is localized within a radius of 40 km and is underlaid by a plume mantle which is 1000 km wide. It doesn't make sense to me dynamically and also there are other expressions which are inconsistent with plumes being that broad. For example, the dynamic topology signature of other plumes are much more narrow, the melting is narrow, the swell is narrow, and I think there is some power in those — especially the work of French and others — to illustrate that there is something coherent below the hotspots. I'm not yet convinced on the length scales they talk about, but they are.

Professor Whaler. As kind of a follow-up, to some extent, again your statement depends on whom you ask. Do these plumes — for the way they interact in your models — have to originate very deep or can they be shallow, kind of 660-km depth, and would that result in a geochemical signature that you might be able to discern in the volcanism if you then sample it?

Professor Davies. First of all, if they come from deep they will still have to go through 660 km so I'm not sure you will get the discerning 660-km signature there. For me it's not a general answer, it will be different for many of the different intra-plate volcanic problems. In Hawaii and many other provinces there has been volcanism for 80 million years, so that means you need either a large source which is slowly tapped or a source that is self-renewing. I argue for the self-renewing source and that would be the core–mantle boundary because you would have the heat flux across the core to the mantle. The reason I argue for that over the large source is that buoyancy is proportional to volume so you have a very large source that is buoyant and wants to rise. At its onset it is going to rise very quickly to the surface so fluid-dynamically a large source doesn't actually work. You need a self-renewing source and the only boundary layer we have on Earth would be the core. That doesn't mean that if you go back to the 3D spherical models I showed, some of those plumes split and form plumelets in the upper mantle, because the viscosity is much lower, so the source would be ultimately deep, in my opinion, but you could produce shallower upwellings from that.

The President. Time has moved on, so I think I'm going to call a halt on questions. Thank you very much [applause]. May I remind Fellows that there will be a drinks reception in the RAS Council Room immediately after this meeting, and finally I give notice that the next monthly A and G meeting of the Society will be held on Friday, October 13th, but don't forget the AGM in May.

THE FIRST ISSUE OF *THE OBSERVATORY*

By Steven Phillipps

Astrophysics Group, University of Bristol

Two recent papers[1,2] reflected on the contents of the first volumes of *Memoirs* and *Monthly Notices of the Royal Astronomical Society*. Moving on fifty years, we complete the set of British professional journals by looking at the first issue of *The Observatory* in 1877.

According to H. H. Turner in 1913, in his supposedly anonymous 'From an Oxford Note-Book' column in this *Magazine*[3], William Christie started *The Observatory* "under the encouragement of John Brett and Warren De la Rue, who did not withhold material aid in the shape of £5 each. The first number is a remarkable one containing articles by William Huggins on 'The Photographic Spectra of Stars', by D. Gill on 'The Determination of the Solar Parallax', by G. H. Darwin on 'The Nebular Hypothesis and the Obliquity of the Axes of the Planets to their Orbits', and by J. Birmingham on 'The Variability of Stars', besides a fine drawing of Copernicus (the lunar formation) as frontispiece, by John Brett."

William Henry Mahoney Christie was 4th Wrangler in 1868 and Airy selected him to succeed Stone as Senior Assistant at Greenwich in 1871. He instigated photographic recording of sunspots and made spectroscopic observations of both the Sun and stars. He was advanced to the position of Astronomer Royal after Airy's retirement in 1881 and was responsible for designing the Observatory's then-largest telescope, the 28-inch. He had been elected to the RAS Council in 1872 and served in some capacity for 39 of the next 40 years, being president for 1888–90. Like his father Samuel, a mathematics professor, and his half-brother, also Samuel, he was an FRS, elected in 1881. He was knighted in 1904.

According to Brett, the frontispiece was merely a "Rough Drawing of Copernicus — made with a 4-inch refractor by Cooke — to be viewed at a distance of three or four feet from the eye", but Brett would have had higher standards than most observers as he was primarily a landscape artist, though a Fellow of the RAS well known for his forthright comments on the astronomical establishment[4].

Warren De la Rue FRS was the son of the founder of the eponymous stationery company (well known for manufacturing playing cards) and went into the engineering and chemical side of the business while spending his spare time on electrical experiments. He first communicated observations (of Saturn) made with his 13-inch telescope to *MN*[5] in 1850, being elected FRAS the following year. As well as his planetary drawings, he was also a pioneer in "celestial photography", especially of the Sun. He won the RAS Gold Medal in 1862 and was RAS president 1864–66.

Subtitled — as it was for many years — "A Monthly Review of Astronomy", *The Observatory* was initially edited by Christie and published by Taylor and Francis, Red Lion Court, Fleet Street, the Taylor family having been involved in printing astronomical journals since the earliest days of *Memoirs*. The first issue was dated 1877 April 20 and consisted of 32 pages. The consolidated Volume 1 covered 12 issues in the period up to 1878 April 1, with a total of 418 pages. The date of issue was moved to the first of the month as of 1878 January (with no issue dated in December).

Starting a very long-lived tradition, the first item reviewed[6] in Issue 1 was the RAS meeting of 1877 April, which took place just one week before Issue 1 appeared. The president, William Huggins, had thanked Mr Simms (of famous telescope makers Troughton and Simms) for donating a double-image micrometer and announced a grant of £250 towards Mr. Gill's expedition to Ascension Island to observe the opposition of Mars and of three minor planets. Brief particulars of the papers read at the meeting were given: Lord Lindsay[7] on heliometer observations of Juno made at Mauritius; Gill with two on his planned expedition; a lengthier description by Christie of a new form of spectroscope, which had led to some critical responses (which Christie faithfully recorded); Prof. Pritchard 'On the Comets of 1877' (to which Lindsay added a note from his assistant at Dun Echt, Ralph Copeland[7]) and on 'A Mechanical Solution of Kepler's problem' using a "mechanical contrivance he had devised"; Glaisher on elliptic-function solutions of the same problem (which were "not convenient in practice"); and Rev. Perry[7] on a search for Vulcan, while Perry and Lindsay reported some comments from French observers.

Originally an amateur observer of the planets, Sir William Huggins FRS became the most successful early astrophysical spectroscopist in Britain, his investigations proving that some nebulae were gaseous while others had star-like spectra. He won the Royal Society Royal Medal in 1866 and the RAS Gold Medal (with collaborator Professor William Allen) in 1867. In the latter year, he also made the first measurement of the radial velocity of a star (Sirius). From 1875 he was assisted by his wife Lady Margaret Lindsay Huggins (née Murray) and, working from their Tulse Hill Observatory, they produced many papers in their joint names. She had actually built her own spectroscope before meeting Huggins and played a leading role in obtaining photographic ultra-violet spectra. She became an Honorary Fellow of the RAS in 1903.

Starting out in the family clock-making business, Sir David Gill FRS became director of Lord Lindsay's observatory at Dun Echt in the 1870s, being appointed Her Majesty's Astronomer at the Cape of Good Hope in 1879. He refurbished and added to the instruments available, and besides his work on the solar parallax instigated the Cape Photographic Durchmusterung of half a million southern stars and was an early proponent of the Carte du Ciel project.

In a lengthy career, the Rev. Charles Pritchard was in turn a headmaster, a clergyman, an amateur observer (RAS president in 1866) and, from 1870, when already aged 62, Savilian Professor of astronomy in Oxford, where he was responsible for building up the university observatory (some of whose instruments were donated by De la Rue).

James Whitbread Lee Glaisher was Second Wrangler at Trinity in 1871 and was elected FRS just four years later. Primarily a pure mathematician (he had apparently produced 72 papers by 1873), his main astronomical work was in methods for combining observations. A member of Council continuously from 1871 to 1928, he was twice president of the RAS. He was noted for cycling around Cambridge on a penny-farthing. His father James Glaisher, a noted meteorologist and balloon 'aeronaut', was an RAS fellow for 63 years, and his uncle John Glaisher was also an astronomer.

There followed a brief description of Copernicus to go with Brett's drawing and then the review papers by Huggins, Gill, Darwin, and Birmingham alluded to by Turner, above. Huggins described the development of stellar spectroscopy, particularly the recording of spectra by photography, noting that "with the most sensitive dry plates … a very bright star will impress its spectrum in 15 minutes to half an hour". Gill discussed the difficulty in determining an exact distance to the Sun and the methods which could be used. Darwin explored reasons that could account for the rotation axes of the planets not being parallel to that of the Sun if they all formed from a rotating nebula, while Birmingham proposed that variability, particularly of red stars, was caused by a surrounding nebulous ring of uneven "obfuscation".

Sir George Harold Darwin, son of the naturalist Charles, attended Clapham Grammar School, run by Charles Pritchard (above), and was Second Wrangler at Trinity in 1868. He remained a Fellow there until appointed Plumian Professor in 1883. Among his numerous interests were the fission theory of the origin of the Moon and the study of tidal forces. He was elected FRS in 1879, winning their Copley Medal in 1911. He had won the RAS Gold Medal in 1892. His brothers Sir Horace, a botanist, and Sir Francis, a designer of scientific instruments, were both Trinity graduates, as was his son Sir Charles Galton Darwin who became director of the National Physical Laboratory.

John Birmingham, a descendant of the Earls of Louth, travelled widely in Europe before returning to Ireland (where he was a land owner and magistrate) and developing an interest first in geology and then astronomy. He discovered the nova T Coronae Borealis (see below) in 1866 (communicating his observation to Huggins). He also produced a catalogue of red stars which was published by the Royal Irish Academy and wrote widely in newspapers and magazines.

Next were reports on 'Comet I., 1877' and on 'The Meteor of March 17' by G. L. Tupman and 'Winnecke's Comet, II. 1877' by Pritchard. The Notes section (supplied by the editor) included a lengthy exposition on Friedrich von Asten's study of the perturbations of the orbit of Encke's Comet published in the *Bulletin de l'Academie de St. Petersbourg*. A Note on 'Sun-Spots, Faculae and Prominences' similarly reviewed Pietro Tacchini's observations from Palermo and the compilation of annual sun-spot numbers by Rudolf Wolf (Zurich). There were then Notes on 'The New Star of 1866 (T Coronae)' which was still showing signs of small variations, Secchi's 'Catalogue of Red Stars' (and some additions to it), 'Double Stars', 'A Remarkable Meteor', 'Mira Ceti' at its most recent maximum, 'Vulcan' ("no news of the supposed planet has reached us"), 'A new Comet', 'Another Comet' ("the third of this year"), and finally the report from Mr. Pogson, Government Astronomer at Madras (now Chennai).

George Lyon Tupman was an officer in the Royal Marine Artillery from 1855, rising to captain in 1873 and retiring as a lieutenant-colonel in 1880. He observed meteors while serving in the Mediterranean and joined the RAS in 1863 (being a fellow for just short of 60 years). He led the party which observed the 1874 transit of Venus from Honolulu, also organizing the other four official expeditions, and was co-opted by Airy to reduce the data at Greenwich. He observed the 1882 transit from New Zealand and had his own observatory in Harrow.

These Notes were followed by 'Astronomical Memoranda for May 1877', covering times of rising of planets, eclipses of Jupiter's satellites, maxima and minima of variable stars, *etc.* (also by the editor), and 'The Ephemeris for Physical Observations of Jupiter', and the same for the Moon, including times when the Sun would be on the horizon as seen from specific craters, both supplied by Marth.

Albert Marth studied astronomy at Königsberg before moving to England in 1853 to work at George Bishop's observatory in Regent's Park. After a period at

Durham University Observatory, he worked as Lassell's assistant in Malta in the 1860s, using the 48-inch telescope (at the time the second largest in the world) to observe nebulae, eventually becoming director of the Markree Observatory in Sligo from 1883. By coincidence, Lassell described the dismantling and destruction of the 48-inch (after failing to find anyone who would take it on) later in *The Observatory*'s first volume[8].

The *Magazine* had evidently found a successful niche and continued through the year to the same basic plan, with a total of 165 articles in Volume 1 (even if counting each month's Notes section as just one contribution) and with 49 authors listed in the Index, as well as Christie. As Turner[3] later pointed out, "The first volume was fortunate enough to appear at a time when it could announce the discovery of the satellites of Mars" by Asaph Hall in Washington[9,10]. Other Notes covered the 'British Transit-of-Venus Results'[11], prospects for observing the upcoming transit of Mercury in 1878 May[12], and the discovery of oxygen in the Sun by Henry Draper in New York[13,14] (even if this did turn out later to have been spurious), amongst many other things. There were five more parts of Gill's article on the solar parallax and a letter from the only female contributor, Mary Ashley, on naked-eye and telescopic observations of an eclipse of the Moon[15]. Miss Ashley, a resident of Bath (living in the same street as the Herschels), was a member of the Liverpool Astronomical Society and of the Selenographical Society. The first of what would become regular reports from observatories, in this case the new one at Oxford University, was supplied by Pritchard[16], and there were a number of obituaries (starting with that by Edward Dunkin[4] for Professor Giovanni Santini[17] of Padua who had been an RAS Associate since 1825). There was also a string of somewhat acrimonious communications from Christie, Brett, and Lindsay on the process for altering the RAS bye-laws, and the controversial council election which had led to the proposed changes[18]. Finally, towards the end of Volume 1, we find the first appearance of another long-standing feature of the *Magazine*, the book reviews[19], Christie starting it off with a decidedly mixed review of Camille Flammarion's *Les Terres du Ciel*, said to be written in a "light and pleasant style to which the author has accustomed the public as a substitute for the severe language of science".

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(16) C. Pritchard, *The Observatory*, **1**, 109, 1877.
(17) E. Dunkin, *The Observatory*, **1**, 113, 1877.
(18) J. Brett, *The Observatory*, **1**, 142, 1877.
(19) W. Christie, *The Observatory*, **1**, 355, 1878.

REDISCUSSION OF ECLIPSING BINARIES. PAPER 15: THE B-TYPE SUPERGIANT SYSTEM V1765 CYGNI

By John Southworth

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V1765 Cyg is a detached eclipsing binary containing a B0·5 supergiant and a B1 main-sequence star, with an orbital period of 13·37 d and an eccentricity of 0·310. The system shows apsidal motion and the supergiant exhibits strong stochastic variability. V1765 Cyg was observed by the *Transiting Exoplanet Survey Satellite* over four sectors. We analyse these data to obtain the first determinate light-curve model for the system. To this we add published spectroscopic orbits to infer masses of 23 ± 2 and 11·9 ± 0·7 $M_{\odot}$, and radii of 20·6 ± 0·8 and 6·2 ± 0·3 $R_{\odot}$. These properties are in good agreement with theoretical predictions for a solar chemical composition and an age around 7 Myr. We also present two epochs of blue–optical spectroscopy that confirm the luminosity classification of the primary star and appear to show absorption lines from the secondary star. Extensive spectroscopy and further analysis of the system is recommended.

Introduction

Detached eclipsing binaries (dEBs) are a vital source of empirical measurements of the properties of stars[1–3]. Such measurements typically show a good agreement with theoretical predictions except for stars of very low or very high mass. At lower masses, M-dwarfs are known to show a *radius discrepancy* which remains unsolved[4–6]. At higher masses, there is a *mass discrepancy* whereby stellar masses inferred from the stars' positions in the Hertzsprung–Russell diagram are systematically greater than those measured directly from orbital motion in binary systems[7]. Tkachenko *et al.*[8] have investigated this in detail using dEBs and concluded that it is stronger at lower surface gravities, and is partially caused by overestimation of the effective temperatures ($T_{\rm eff}$s) of massive stars from their optical spectra.

Massive stars are typically found in multiple systems[9,10] and most also show brightness variability due to a range of phenomena. Massive stars in dEBs have been found to show intrinsic variations due to stochastic low-frequency (SLF) variability[11,12] and β Cephei pulsations[13–15]. At lower masses, A- and F-stars in dEBs can show variability due to δ Scuti[16–19] and γ Doradus pulsations[20–22]. In all cases the pulsations can be perturbed or excited by tidal effects in close binary systems[23,24,18,22].

In this work we present the first analysis of extensive space-based photometry for the bright B-type supergiant system V1765 Cyg (see Table 1), which has a long observational history. The new photometric data also exhibit a strong signature of SLF variability. See ref. 25 for a detailed description of our project and ref. 26 for a review of the impact of space-based photometry on binary-star science.

TABLE I

Basic information on V1765 Cyg.

Property	*Value*	*Reference*
Right ascension (J2000)	$19^h48^m50^s\cdot60$	27
Declination (J2000)	$+33^{\circ}26'14''\cdot2$	27
Bright Star Catalogue	HR 7551	28
Henry Draper designation	HD 187459	29
Gaia DR3 designation	2034968875123889536	27
Gaia DR3 parallax	0·6895 ± 0·0250 mas	27
TESS Input Catalog designation	TIC 59632148	30
B magnitude	6·578 ± 0·014	31
V magnitude	6·463 ± 0·010	31
J magnitude	6·027 ± 0·019	32
H magnitude	6·034 ± 0·018	32
K_s magnitude	6·030 ± 0·020	32
Spectral type	B0·5 Ib + B1 V	33, This work

V1765 Cygni

V1765 Cyg was announced as a spectroscopic binary by Plaskett & Pearce[34]. The primary component (hereafter star A) is a B0·5 supergiant and is the source of the observed SLF variability. The secondary component (star B) is of similar $T_{\rm eff}$ but is much smaller than the supergiant component. For clarity, star A is eclipsed (*i.e.*, is at superior conjunction) by star B at primary eclipse.

Mayer & Chochol[35] discovered the eclipses and also commented on the presence of "irregular fluctuations in the range of about 0·06 mag". They also obtained radial velocities (RV) of star A and asserted the presence of apsidal motion. However, they did not attempt a solution of the light-curve. Percy & Welch[36] confirmed the presence of "pronounced intrinsic variability".

The spectral type of the much brighter component of the system has been given as either B0·5 Ib[33,37,38] or B0·5 II[39,40]. A classification of B0·5 Ib + B2 V was given by Hill & Fisher[41] (hereafter HF84).

HF84 presented the most detailed analysis of the system thus far, based on photographic spectra subsequently converted to electronic format for analysis. They found star B to show up reasonably well in He I lines and determined RVs *via* cross-correlation. The plotted cross-correlation functions (HF84's Fig. 1) show that the two components are never resolved, so the RVs were obtained by fitting double overlapping Gaussian functions. Apsidal motion was detected but at a level below that required for confirmation. HF84 presented mass and radius estimates for both components but relied on a calibration of radius *versus* spectral type for star A since the solution of the light-curves from Mayer & Chochol[35] was indeterminate.

Mayer *et al.*[42] obtained new photometry and spectroscopy and estimated the masses and radii of the components, giving values similar to those found by HF84. However, they preferred an earlier spectral type for star B of of B1 V or even B0 V. Raja[43] presented further photographic spectroscopy in which they were not able to find a sign of star B, but found an apsidal motion of $7\cdot3 \times 10^{-4}$ deg d^{-1}, in agreement with previous results.

Popper[44] presented a small number of high-quality spectra of V1765 Cyg. He obtained a much larger rotational velocity of ~200 km s^{-1} for star A, *versus* the value of 135 ± 10 km s^{-1} measured by HF84. He was also not able to find clear evidence of spectral lines of star B despite being sensitive to much smaller lines than expected based on the light ratio of the system inferred by HF84. He concluded that the system was unfavourable for further analysis due to the difficulties it poses for both spectroscopy and photometry.

Percy & Khaja[45] presented further photometry of the system from which they measured the eclipse depths and found a possible slow increase in brightness. Since then, V1765 Cyg has mostly been left well alone save for appearances in large sky surveys. The *MASCARA* cameras[46] have observed V1765 Cyg extensively and obtained 12 057 photometry measurements of the system[47] which show the eclipses and intrinsic variability.

In the current work we use extensive new light-curves to investigate the photometric properties of the system, infer its physical properties, examine two new spectra, and draw attention to the similarity between V1765 Cyg and V380 Cyg. We conclude with a discussion on the future prospects for analysis of this important but challenging binary system.

Photometric observations

V1765 Cyg has been observed four times by the NASA *Transiting Exoplanet Survey Satellite*[48] (*TESS*). The data from sector 14 (2019/07/18 to 2019/08/15) were obtained at a cadence of 1800 s, and the data from sector 41 (2021/07/23 to 2021/08/23) and sectors 54 and 55 (2022/07/09 to 2022/09/01) had an observing cadence of 600 s. We used the LIGHTKURVE package[49] to download the data and reject points flagged as bad. We adopted the simple aperture photometry (SAP) data[50] for consistency with previous papers in this series.

We converted the data to differential magnitude and subtracted the median magnitude for further analysis. The numbers of data points are 1237, 3505, 3571, and 3645, for sectors 14, 41, 54, and 55, respectively. Data with a 120-s cadence are available for all but the first sector, but were not used in our analysis because the system does not vary on a time-scale fast enough to require the higher sampling rate.

The data are shown in Fig. 1. The light-curves clearly show the existence of annular primary eclipses, total secondary eclipses, orbital eccentricity, and SLF variability.

Spectroscopic observations

We obtained spectroscopy of V1765 Cyg on the nights of 2023/07/02 and 2023/07/04 in order to investigate the suitability of the system for detailed analysis. Our observing run lasted seven nights and covered only half of the orbit of V1765 Cyg, so we made no attempt to obtain sufficient data for measuring the spectroscopic orbits of the stars. Instead we obtained two spectra on the first night at a time when the two stars had approximately the same RV, and three spectra on the second night when the stars were close to their largest RV separation.

We used the *Isaac Newton Telescope* (*INT*), *Intermediate Dispersion Spectrograph* (*IDS*) with the 235-mm camera, the EEV10 CCD, the H2400B grating, a central wavelength of 420 nm, and a 1″ slit. This gave spectra with a reciprocal dispersion of 0·24 Å mm^{-1}, a resolution of 0·5 Å as measured from the Cu+Ar lamps used for wavelength calibration, and a spectral coverage of 410–465 nm. The data were reduced using a pipeline currently under construction (see ref. 51).

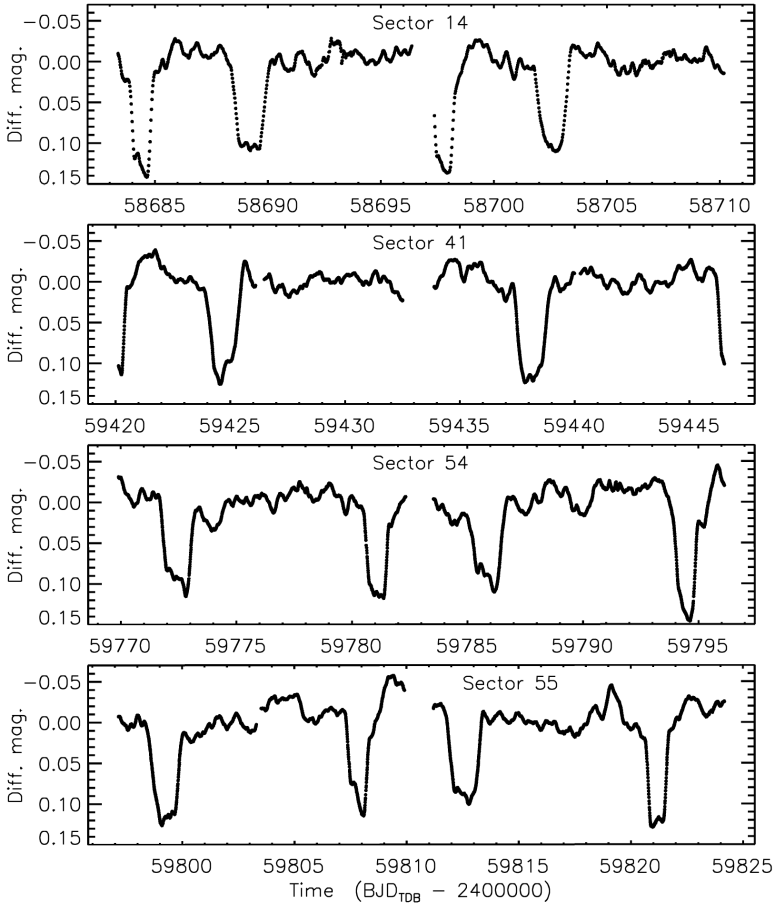

Fig. 1

TESS short-cadence SAP photometry of V1765 Cyg. The flux measurements have been converted to magnitude units then rectified to zero magnitude by subtraction of the median. The individual sectors are labelled.

The spectra from each night were taken at the same time so were summed to give two overall spectra. The total exposure time was 240 s on the first night and 720 s on the second night, with the latter being significantly longer to compensate for the presence of moderate cloud.

Light-curve analysis

We modelled the light-curve of V1765 Cyg from *TESS* using version 43 of the JKTEBOP* code[52,53]. Star A is formally too deformed to be suitable for JKTEBOP,

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

but the intrinsic variability of the system is much more important than the expected bias in the parameters and we were keen to utilise the error estimation algorithms available in the code. We analysed the data with a cadence of 600 s from sectors 41, 54, and 55 simultaneously. Sector 14 was not used due to the lower sampling rate. Conversely, the data with a higher cadence of 120 s available in the last three sectors were not used because it greatly oversamples the changes in brightness due to both eclipses and pulsations.

We fitted for the sum ($r_A + r_B$) and ratio ($k = r_B/r_A$) of the fractional radii of the stars (r_A and r_B), and their central-surface-brightness ratio in the *TESS* passband ($\mathcal{J}$). We fitted for the orbital period (P), reference time of primary minimum (T_0), and the eccentricity (e) and argument of periastron (ω) in terms of their Poincaré elements ($e\cos\omega$ and $e\sin\omega$). A set of straight lines *versus* time were included for the baseline brightness of the system, one for each half-sector of *TESS* data, and the coefficients of the lines were included as fitted parameters. We included limb darkening using the simple linear law[54] with the coefficients of both stars fixed to 0·2. More sophisticated laws are not justified due to the strong SLF variability in the light-curve, and attempts to fit for the coefficients were unsuccessful for the same reason. We also found that third light was not estimable from the data, so fixed it at zero.

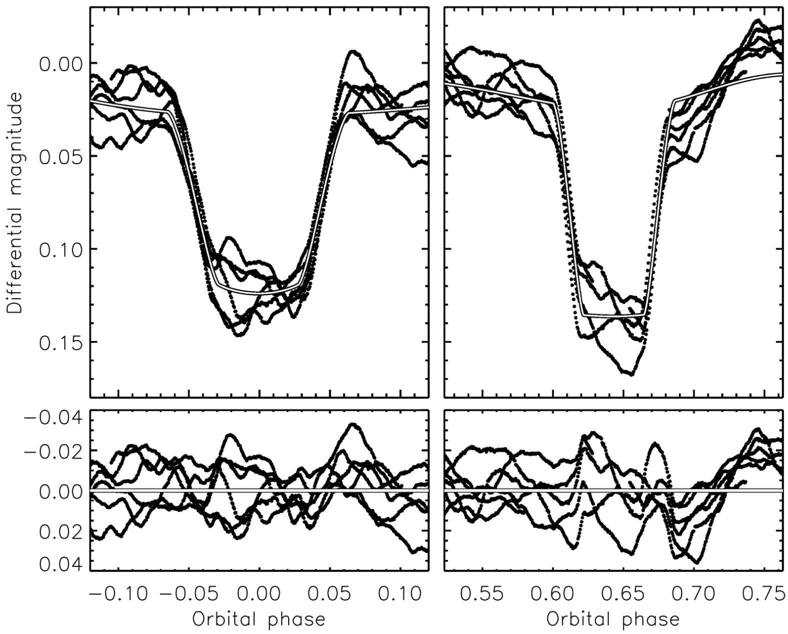

FIG. 2

The *TESS* light-curves of V1765 Cyg from sectors 41, 54, and 55, with 600-s cadence (filled circles) *versus* the best fit from JKTEBOP (white-on-black line) as a function of orbital phase. The primary eclipse is shown on the left and the secondary eclipse on the right. The residuals are shown on an enlarged scale in the lower panel.

The first result of the analysis above is that the secondary eclipse is deeper than the primary (Fig. 2). This conflicts with the standard definition of which is primary and which is secondary, but we have chosen to retain our labelling of the stars so the dominant component remains star A. From this it can be deduced that star B has a higher surface brightness, and thus T_{eff}, than the supergiant star A. Our results are otherwise very much as expected, and are given in Table II. The values of e and ω agree well with previous spectroscopic results.

For the record, we were able to obtain an almost identical fit for the inverse of k (*i.e.*, 3·0 *versus* 0·3). We rejected this solution as being inconsistent with the the model of the system developed by HF84.

TABLE II

Adopted parameters of V1765 Cyg measured from the TESS light-curves using the JKTEBOP code. The uncertainties are 1σ and were determined using residual-permutation simulations.

Parameter	*Value*
Fitted parameters:	
Primary-eclipse time (BJD_{TDB})	2459438·122 ± 0·021
Orbital period (d)	13·37441 ± 0·00075
Orbital inclination (°)	84·3 ± 1·0
Sum of the fractional radii	0·344 ± 0·011
Ratio of the radii	0·3006 ± 0·0090
Central surface brightness ratio	1·30 ± 0·13
$e \cos \omega$	0·2211 ± 0·0027
$e \sin \omega$	−0·217 ± 0·021
Derived parameters:	
Fractional radius of star A	0·2643 ± 0·0074
Fractional radius of star B	0·0794 ± 0·0038
Light ratio ℓ_B/ℓ_A	0·117 ± 0·010
Orbital eccentricity	0·310 ± 0·014
Argument of periastron (°)	315·5 ± 2·9

Light-curve uncertainties

The light-curve is dominated by the SLF variability, which is essentially red noise from the point of view of eclipse modelling. We therefore used only residual-permutation (RP) simulations[55] to determine the uncertainties in the fitted parameters.

These results are also given in Table II. Although the data in hand fully cover six orbits of the system, the strong deformation of the eclipses by the SLF signature complicates any attempts to model them. Our error bars account for this but may still be underestimates.

To further illustrate the effect of the SLF variations on the parameters measured from the eclipses, in Fig. 3 we plot the variation of the best-fitting values of four selected parameters through the RP simulation run. The residuals *versus* the best JKTEBOP fit are shifted by one data point between each successive iteration, and the gradual progression of red noise through the light-curve causes systematic changes in the fitted parameter values. The most-affected parameter is J, which depends primarily on the relative depths of the primary and secondary eclipses. The eclipse depths are significantly changed by the SLF noise, causing a large uncertainty in J and thus the ratios of the T_{eff}s of the two stars. A similar signature is seen in the ratio of their radii. The variation for $r_A + r_B$ and i

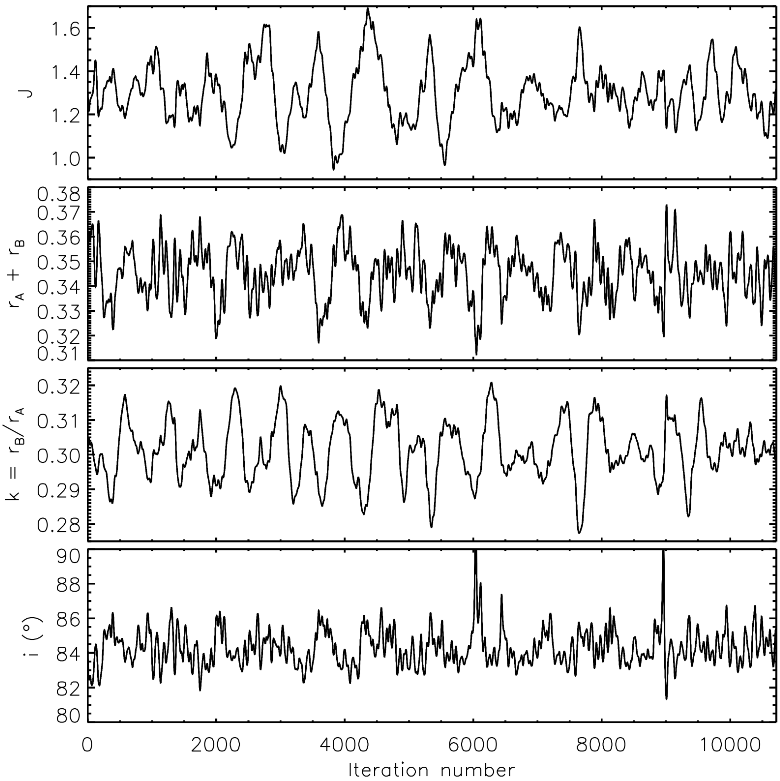

FIG. 3

Variation in the best-fitting values of four of the photometric parameters during the RP simulations, as the residuals are cyclically shifted through the light-curve.

is much faster: these parameters depend on the shapes and durations of the ascending and descending branches of the eclipses, which in turn are shorter than the total eclipse durations. The properties of V1765 Cyg mean it allows a beautiful demonstration of these effects.

Fig. 4 shows the variations between pairs of parameters over the RP simulations. The first panel shows r_B *versus* r_A and a clear correlation can be seen. The second panel shows the light ratio *versus* the radius ratio: it has a satisfying child's-scribble appearance but the correlation is small. The inference from this panel is that a spectroscopic light ratio would not be useful in improving the precision of the radius measurements. The remaining two panels show the orbital shape parameters in two forms: the poor determinacy of $e \sin \omega$ (which depends on the ratio of the eclipse durations) is obvious. The much greater correlation between e and ω, *versus* $e \cos \omega$ and $e \sin \omega$, is also clear: this reiterates the advantage of fitting for the Poincaré elements rather than e and ω directly.

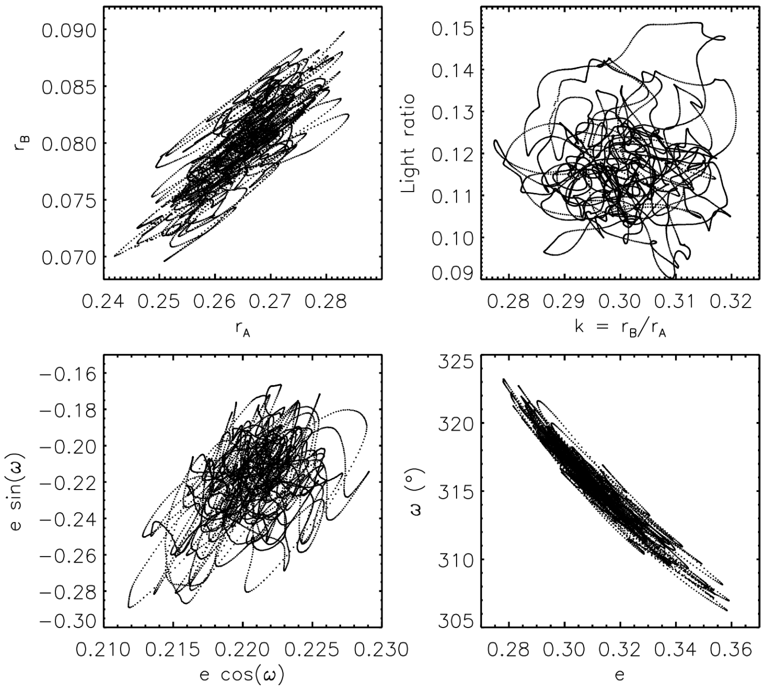

Fig. 4

Comparison plots for the best-fitting values of pairs of parameters during the RP simulations.

Stochastic low-frequency variability

The intrinsic variability in the light-curves of V1765 Cyg is obvious and can safely be assumed to arise from the supergiant star A. To investigate it further we used the best fit from JKTEBOP found above, restricted it to sectors 54 and 55 as these data are semi-continuous, selected the residuals of the best fit, and calculated a periodogram using the PERIOD04 code[56]. The result is shown in Fig. 5. A periodogram of the 120-s cadence data from sector 55 shows no significant signal at higher frequencies, up to the Nyquist limit for these data of 350 d^{-1}.

Fig. 5 shows excess power at frequencies below 5 d^{-1} with a large number of peaks with significant amplitude. This is characteristic of SLF variability[11,57], has been seen before in dEBs[58,12], and is attributable to internal gravity waves excited at the boundary of a convective region within the star[59,60]. The two highest peaks occur at 0·19 and 0·38 d^{-1} and have amplitudes of 5·6 mmag.

Spectroscopic properties

V1765 Cyg is spectroscopically difficult due to the large line broadening and SLF-induced line-profile variability of star A. HF84 identified faint peaks in the cross-correlation functions arising from star B which was found to be approximately ten times fainter than star A at blue-optical wavelengths. This was questioned by Popper[44], who was not able confidently to identify lines of

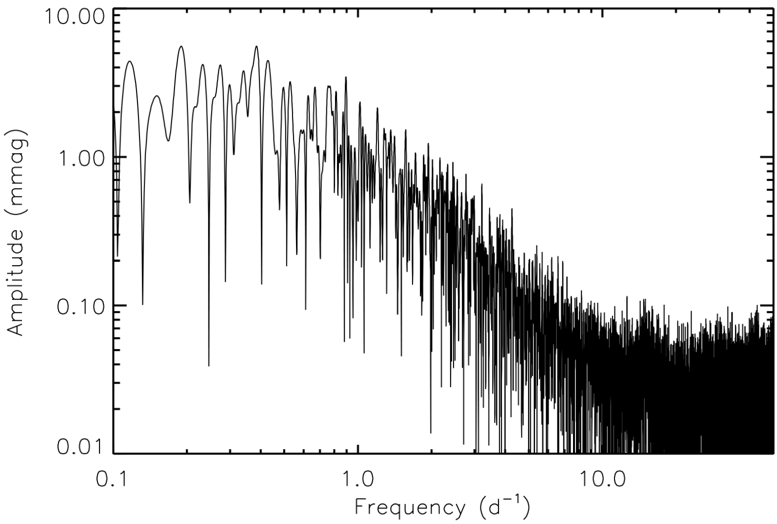

FIG. 5

Periodogram of the residuals of the best fit for *TESS* sectors 54, and 55, calculated using the PERIOD04 code.

star B despite having spectra of much better quality. A relevant point here is that the light ratio we found from the *TESS* light-curve matches that inferred by HF84 from the relative areas of the cross-correlation-function peaks.

As described above, we obtained two *INT/IDS* spectra in order to investigate this further. These are shown in Fig. 6, where the spectrum from the second night has been offset by +0·1 from that for the first night, and also shifted by –0·20 nm to remove the RV variation of star A relative to the first spectrum. The first spectrum was taken at orbital phase 0·617 — at the beginning of totality during secondary eclipse — so contains light from star A only. The second spectrum was taken at phase 0·768 so includes light from both stars, with a velocity separation of 376 km s^{-1}.

In both cases the spectra are corrected for the barycentric velocity. The spectra show strong H, He, and O absorption, plus C, N, Si, and Mg lines and a diffuse interstellar band centred at approximately 443 nm. The strong O II lines at 4348 and 4416 Å confirm the supergiant classification, and are strong enough to support a luminosity class of Ia rather than the typically-quoted Ib.

A careful comparison of the two spectra reveals the appearance of three faint absorption lines to the left of the main lines on the second night (see Fig. 7). These are exactly where we would expect to find lines from star B, and similar features are *not* seen where they should not be (*e.g.*, for the O II lines). This suggests that V1765 Cyg may well be double-lined and thus suitable for direct measurement of its masses and radii. This work will be helped by obtaining extensive new high-quality spectroscopy and analysing them using methods not available to previous workers such as two-dimensional cross-correlation[61], broadening functions[62], and spectral disentangling[63]. The last method is most promising (*e.g.*, ref. 64) but may be affected by the line-profile variations from the stochastic variability. We defer further analysis until suitable spectra are available.

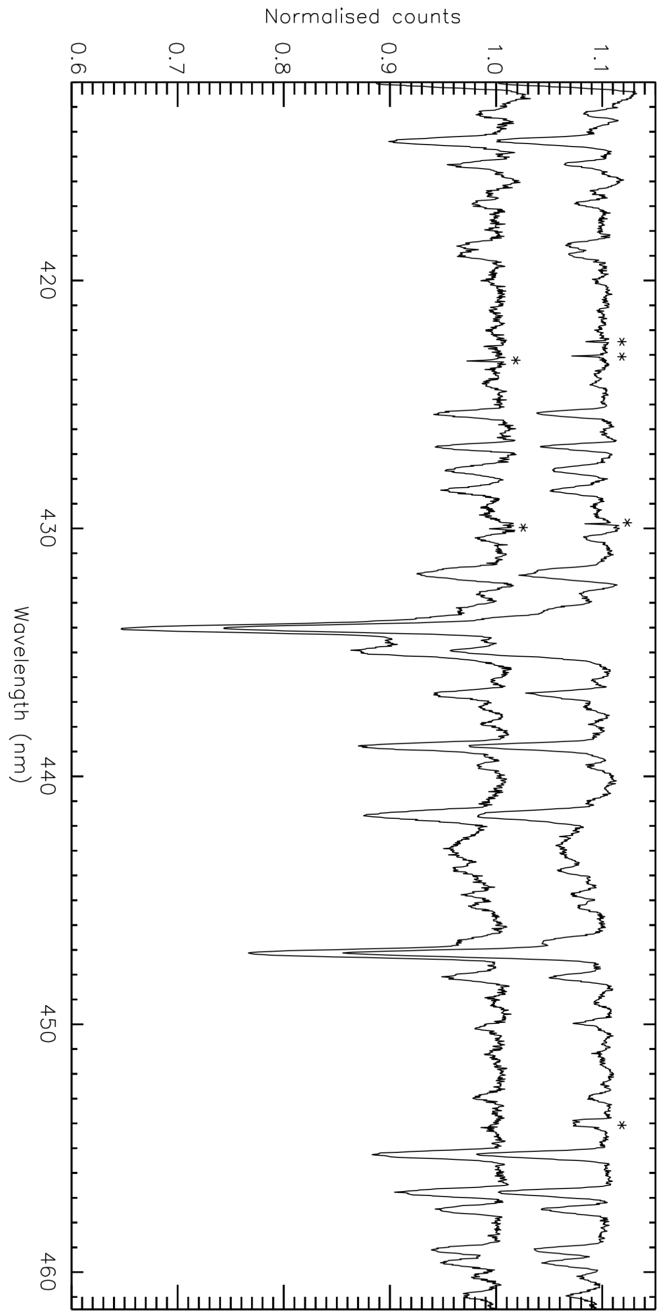

Fig. 6

The two combined spectra of V1765 Cyg taken when the RVs of the two stars were the same (normalized to 1·0) and when they show their greatest separation (offset by +0·1). The second spectrum has been shifted by −0·2 nm to align the spectral lines of star A. CCD cosmetics are indicated with asterisks.

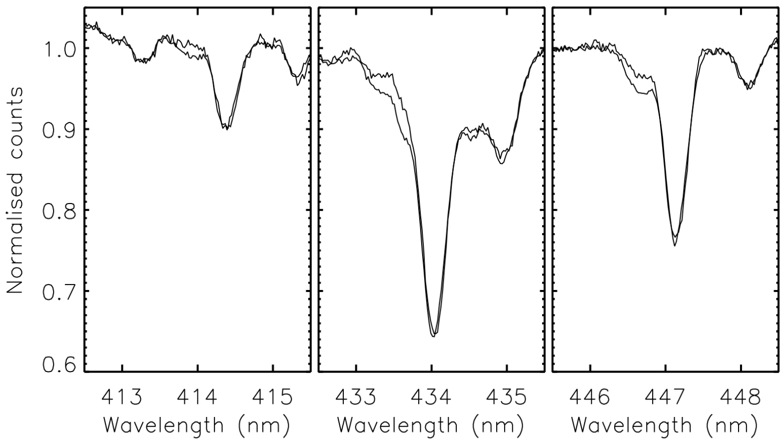

Fig. 7

Comparison between the two combined spectra of V1765 Cyg in the region of the He I 4143 Å, Hγ 4340 Å, and He I 4471 Å lines. The two spectra were aligned in wavelength to make the strong lines from star A overlap.

Physical properties of V1765 Cyg

This work presents the first determinate solution of the light-curve of V1765 Cyg and thus enables a more direct estimation of the properties of the system. For this the velocity amplitudes of the stars' spectroscopic orbits are needed. There is only one source available in the literature, HF84, and their results were questioned by Popper[44]. We chose to adopt (approximately) the values from HF84 but with increased error bars to account for the conflicting results: $K_A = 103 \pm 2$ km s^{-1} and $K_B = 206 \pm 10$ km s^{-1}.

HF84 adopted a $T_{\rm eff}$ of 25000 K for star A from a calibration *versus* spectral type by Underhill *et al.*[65], to which we add a plausible error bar of 2000 K. The surface-brightness ratio from the light-curve analysis (Table II) then gives a $T_{\rm eff}$ of 26500 ± 2500 K for star B, which implies a spectral type of B1 V using the calibration of Pecaut & Mamajek[66]. Wu *et al.*[67] gave a higher $T_{\rm eff}$ of 26556 ± 1934 K for the system (analysed as if it were a single star) but we did not use this value as it yielded a distance to the system significantly longer than that from the *Gaia* parallax (see below). More precise and accurate $T_{\rm eff}$ values could be obtained from spectroscopy of the system in future.

Armed with these numbers, we calculated the expected physical properties of V1765 Cyg using using the JKTABSDIM code[69] in our usual way for this series of papers. However, in this case, the numbers should not be taken as definitive due to the disagreement over whether the RVs of star B are reliable. The inferred properties are given in Table III.

To determine the distance to the system we used the *Tycho-2 B* and *V* magnitudes[31] which are averages of 14 measurements each, the 2MASS JHK_s magnitudes[32] which are single measurements taken at orbital phase 0·78 (*i.e.*, outside eclipse), and bolometric corrections from Girardi *et al.*[70]. An interstellar reddening of $E(B-V) = 0{\cdot}43 \pm 0{\cdot}10$ mag is needed to bring the BV and JHK_s distances into agreement, giving a final K-band distance of 1520 ± 110 pc which

TABLE III

Plausible physical properties of V1765 Cyg defined using the nominal solar units given by IAU 2015 Resolution B3 (ref. 68).

Parameter	*Star A*	*Star B*
Mass ratio M_B/M_A	0·50 ± 0·02	
Semi-major axis of relative orbit ($R^N_\odot$)	78 ± 2	
Mass ($M^N_\odot$)	23 ± 2	11·9 ± 0·7
Radius ($R^N_\odot$)	20·6 ± 0·8	6·2 ± 0·3
Surface gravity (log[cgs])	3·19 ± 0·03	3·93 ± 0·04
Effective temperature (K)	25000 ± 2000	26500 ± 2500
Luminosity $\log(L/L^N_\odot)$	5·18 ± 0·14	4·23 ± 0·17
M_{bol} (mag)	−8·2 ± 0·11	−5·8 ± 0·4
Distance (pc)	1520 ± 110	

is concordant with the distance of 1450 ± 53 pc from the *Gaia* DR3 parallax. This agreement supports the reliability of the approximate system parameters put forward in Table III.

The similarity of V1765 Cyg and V380 Cyg

One object stands out as being rather similar to V1765 Cyg. V380 Cyg is a dEB containing B1 III and B2 V components with an orbital period of 12·4 d, an eccentricity of 0·222, and an extensive observational history[71–73,54,74,58]. In Fig. 8 we show light-curves of the two systems with the same axis scales.

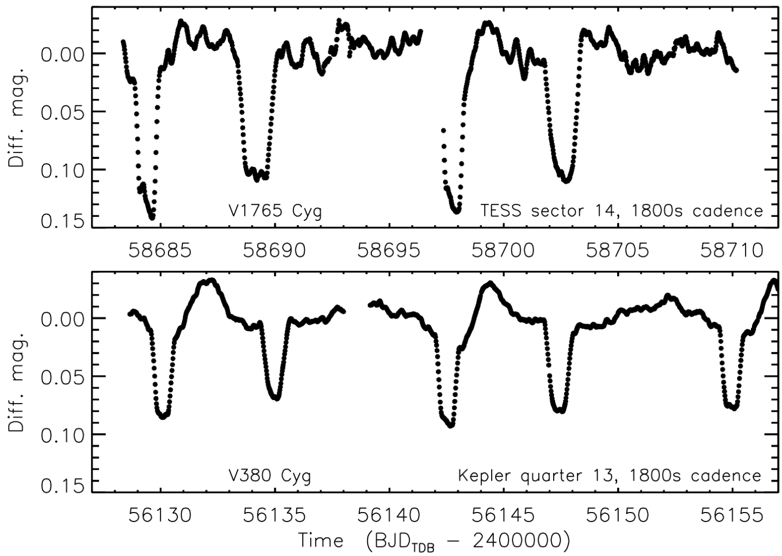

FIG. 8

Comparison between the *TESS* light-curve of V1765 Cyg (top) and the *Kepler* light-curve of V380 Cyg (bottom). The *y*-axes are the same, and the *x*-axes are of the same duration, in the two panels.

We chose *TESS* sector 14 for V1765 Cyg and *Kepler*[75] quarter 13 for V380 Cyg, in both cases with a sampling rate of 1800 s. It can be seen that the eclipses are slightly deeper and longer in V1765 Cyg, and in particular the SLF variability is much stronger. Although the more evolved components in the two systems have almost the same fractional radii, V380 Cyg has a much more pronounced 'orbital hump' at periastron passage shortly after primary eclipse.

Tkachenko *et al.*[58] found these masses and radii for the components of V380 Cyg: $M_A = 11{\cdot}43 \pm 0{\cdot}19\ M_\odot$, $R_A = 15{\cdot}71 \pm 0{\cdot}13\ R_\odot$, $M_B = 7{\cdot}00 \pm 0{\cdot}14\ M_\odot$, and $R_B = 3{\cdot}82 \pm 0{\cdot}05\ R_\odot$. V1765 Cyg is therefore a more extreme version of V380 Cyg. Tkachenko *et al.* used 406 spectra in their investigation — V1765 Cyg would probably need a similar amount because the larger light ratio (so star B is relatively brighter) will be offset by the stronger variability of star A. Whilst this is a *lot* of spectra, the brightness of the system means such a number is achievable.

Comparison with theoretical models

Although the properties in Table III are not definitive, a brief check against theoretical predictions could be illuminating. For this we adopted the PARSEC 1·2S models from Chen *et al.*[76]. A reasonable agreement is found in plots of mass *versus* radius and T_{eff} (not shown) for a metal abundance of $Z = 0{\cdot}02$ and an age of 7 ± 1 Myr. This supports the lower of the two T_{eff} measurements discussed above. The radius of star B is approximately 3σ larger than predicted, but the two T_{eff} values sit perfectly on the predictions.

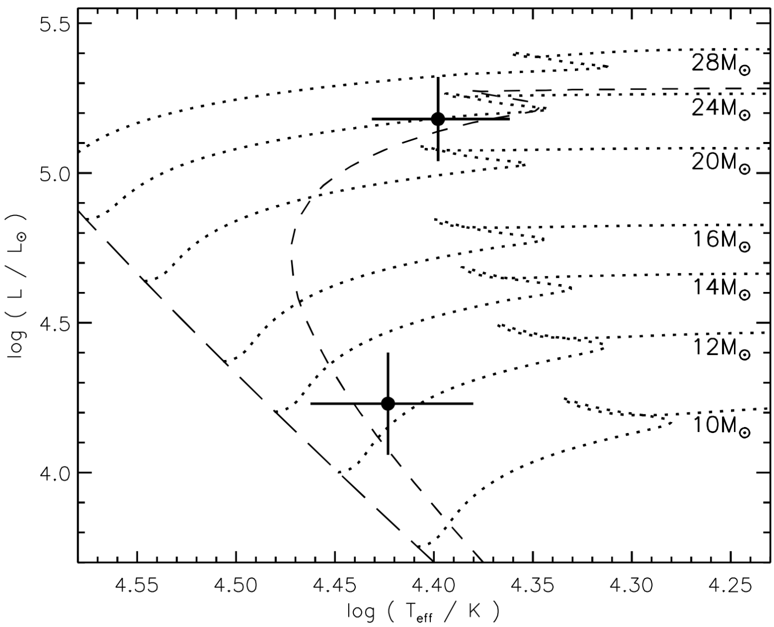

Fig. 9

Hertzsprung–Russell diagram for the components of V1765 Cyg (filled circles with error bars) and the predictions of the PARSEC 1·2S models[76] for selected masses (dotted lines with masses labelled). The zero-age main sequence is indicated with a long-dashed line, and a 7-Myr isochrone with a short-dashed line.

Fig. 9 shows a Hertzsprung–Russell diagram with the components of V1765 Cyg and predictions from the PARSEC models for a range of masses. The figure includes the zero-age main sequence and an isochrone for an age of 7 Myr. The agreement between observation and theory is good. More precise properties of V1765 Cyg are needed to provide a useful test of the models.

Summary and conclusions

V1765 Cyg is a very interesting, totally-eclipsing binary containing a B0·5 supergiant and a B1 main-sequence star on a 13·37-d orbit with an eccentricity of 0·310. Extensive previous work has yielded a reliable spectroscopic orbit for star A and a less reliable one for star B. Whilst the reality of the detection of star B in the spectra has been questioned, the resulting RVs lead us to a plausible set of properties for the system.

In this work we analysed four sectors of observations from the *TESS* mission, allowing us to determine the radii of the stars from the eclipse profiles. Previous radius estimates were based only on calibrations *versus* spectral type. We arrive at physical properties in agreement with published values but on a more solid empirical basis. These properties can be matched by the PARSEC models for a solar chemical composition and an age in the region of 7 Myr.

Star A shows strong stochastic brightness variations of the SLF type, which distort the eclipse shapes and complicate both photometric and spectroscopic analyses. More extensive photometry, should the opportunity arise, may allow specific pulsation modes to be identified. V1765 Cyg is similar to but a more extreme version of the well-studied V380 Cyg system.

Apsidal motion has been detected in this system[43,43], although the detection has been questioned (HF84). The value of ω we deduced from the light-curve supports the existence of apsidal motion, as it is significantly greater than the values found in the old spectroscopic studies. A more detailed analysis of this phenomenon would be rewarding.

We also presented two epochs of medium-resolution spectroscopy which confirm the spectral classification of star A. Star B produces approximately 10% of the light of the system and our spectra show evidence of its absorption lines which encourages further study. We strongly recommend that a large set of high-quality spectra are obtained for this system to confirm the detection of star B and for measurement of the atmospheric parameters and spectroscopic orbits of both stars. Such work will be difficult, but will be helped by the development of new analysis tools since the last detailed spectroscopic study of this system.

Finally, we note that *TESS* is scheduled to observe V1765 Cyg in four further sectors (74, 75, 81, and 82) during 2024. The addition of these data to the analysis should significantly improve the measurements of the radii of the stars, which are currently limited by the pulsations interfering with the eclipse shapes. The nature of the V1765 Cyg system makes such work well worth pursuing.

Acknowledgements

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CORRESPONDENCE

To the Editors of 'The Observatory'

Identifying Polophylax — a 430-year Mystery Solved?

During the history of celestial mapping various newly invented constellations have appeared on star charts from time to time, only to drop out of sight again as they were ignored by other astronomers or were replaced with competing innovations. One of the oddest and shortest-lived of these new constellations was an enigmatic figure called Polophylax, introduced by the great Dutch celestial cartographer Petrus Plancius (1552–1622) in 1592 but then dropped by its own inventor within a few years and never seen again. Where did the idea for this figure come from and why did it disappear so rapidly?

Polophylax made its debut on a small planisphere of the southern sky tucked into the margin of Plancius's world map of 1592 (Fig. 1; ref. 1). At that stage, knowledge of the far southern sky was limited to sketchy reports from explorers and navigators, much of it kept under wraps for commercial reasons by the trading companies who had opened up sea routes to lucrative markets in the East. Plancius himself never travelled on any such voyages of exploration so had to rely on the word of others.

In this case, as Plancius explained in his text on the 1592 chart, his source for the far southern stars was a sketch by the Italian explorer Andrea Corsali (1487–15??) made in 1515 and sent in a letter to his patron, Giuliano de Medici.* This letter and the accompanying diagram were first privately published in 1516 and later reprinted for wider circulation[2].

*Thomas Blundeville, the English scholar, published a translation of Plancius's Latin text in 1594 as follows: "I haue taken these Southerne starres out of the obseruations of Andreas Corsalius Florentine". See T. Blundeville, *His Exercises*, 1594.

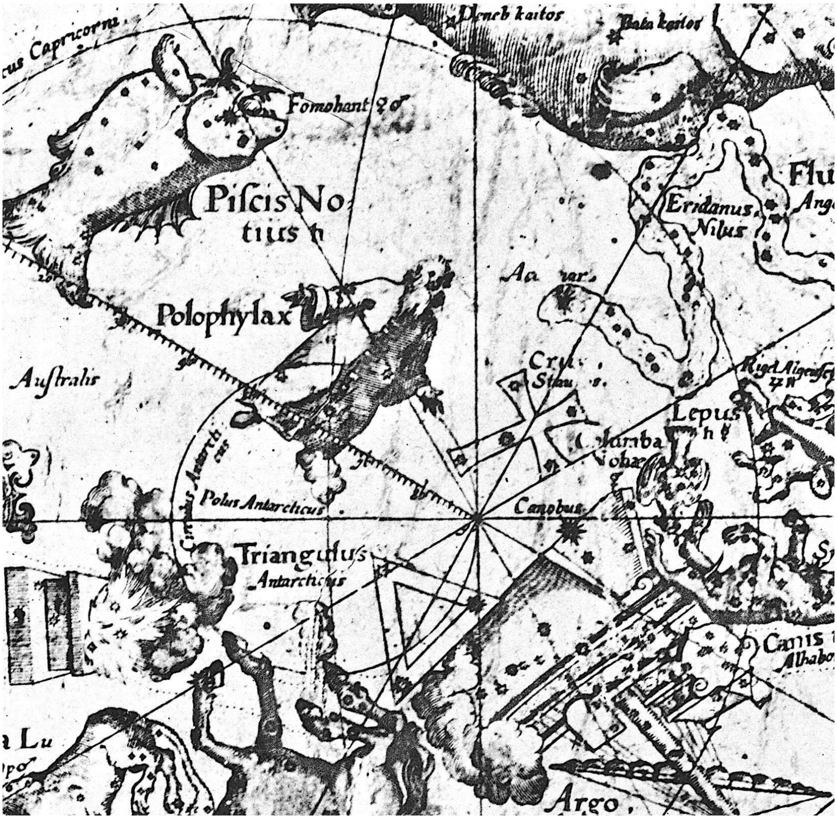

FIG. 1

Polophylax seen on a southern celestial planisphere that was part of Petrus Plancius's world map of 1592. To the right of Polophylax is an imaginary Southern Cross, and below centre is an equally imaginary southern triangle. This reproduction comes from a photographic facsimile of the one surviving copy of the map. (National Library of Australia)

Corsali's diagram showed the southern cross, some surrounding stars, and the two Magellanic Clouds (Fig. 2). However, Corsali was not an astronomer and gave no positional measurements or magnitudes. Hence Plancius was left guessing the orientation of the drawing, and got it wrong. He placed its stars almost 180° from their true positions, where they at least served the purpose of filling an otherwise empty space.

Assuming that the seven stars in the tower-like group to the left of the cross in Corsali's diagram were previously unrecorded, Plancius created a new constellation out of them in the form of a bearded man in a long gown he called Polophylax. Plancius did not explain why he chose such a figure but it is generally thought to represent a pole watcher or pole guard, a southern counterpart of Boötes, the bear watcher or bear guard of northern skies, who was also known in Greek as Arctophylax.

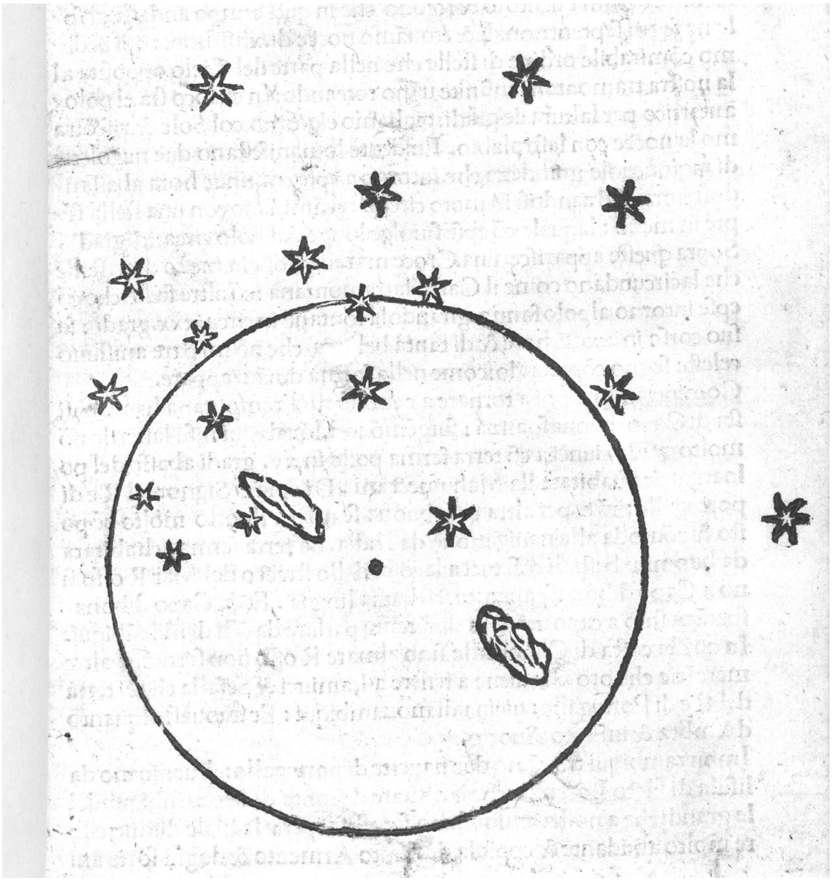

FIG. 2

Andrea Corsali's sketch of the south polar region of the sky, printed in 1516. The Southern Cross is above centre. The stars from which Petrus Plancius created Polophylax are to the left, and the Magellanic Clouds below. To the right of the drawing are the two pointers to the Cross, Alpha and Beta Centauri. The drawing, which contains distortions of scale, shows the sky from an external viewpoint, as on a globe. (State Library of New South Wales)

This mysterious southern pole-watcher appeared again on another Plancius map two years later, with the spelling of his name slightly amended to Polophilax[3]. Only one copy of the 1592 map still survives, in the Colegio del Corpus Christi, Valencia, but well-preserved examples of the later version are more common*.

Plancius recognized that better observations of the southern sky were sorely needed, and he saw his chance to obtain them in the form of the first Dutch trading expedition to the East Indies, known as the *Eerste Schipvaart*. During preparations for that voyage, Plancius instructed the chief navigator, Peter Dirkszoon Keyser (*c.*1540–96), to make accurate observations for him. Keyser

*Unfortunately, the engravings of the constellation figures on the second map are not as detailed as on the 1592 original and the labelling is sparser. See, for example, https://exhibits.stanford.edu/ruderman/catalog/fb595jz5474

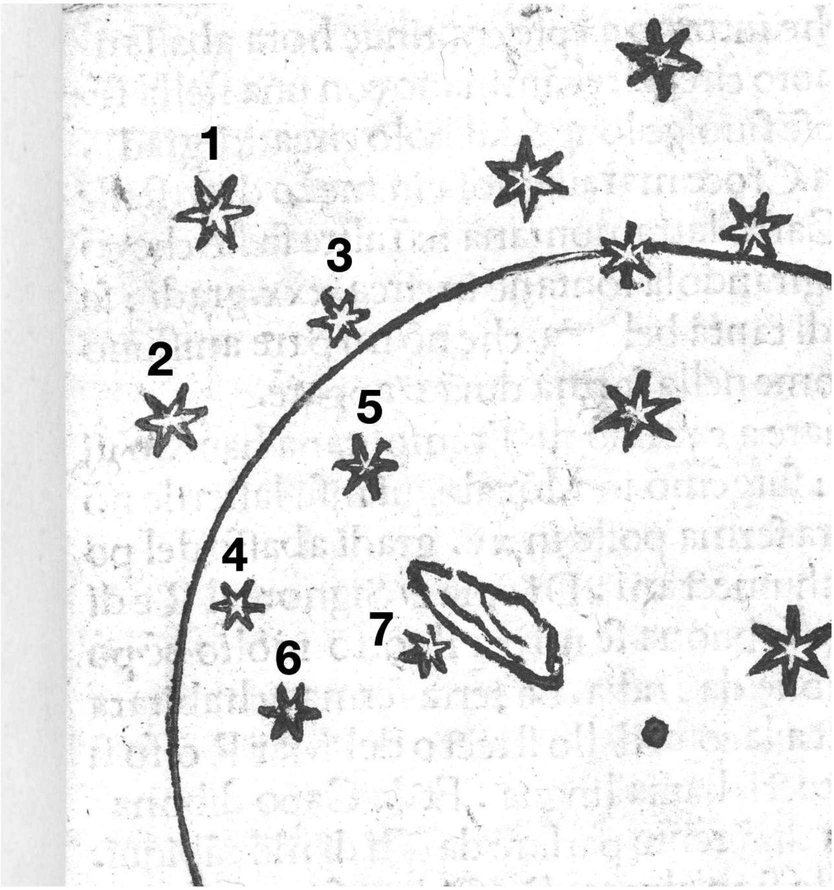

Fig. 3

The seven stars on Corsali's sketch from which Plancius formed Polophylax. See Table 1 for proposed identifications.

died during the mission but his pioneering catalogue of around 130 southern stars was duly delivered to Plancius on the fleet's return to Holland in 1597. (The catalogue was never published and the original observations are long lost.)

Keyser's stars appeared on a Plancius globe the following year, 1598, arranged into 12 new constellations representing some of the wonderful things the sailors had seen on their voyage, such as a bird of paradise, a dorado chasing a flying fish, a toucan, a chameleon eating a fly, a peacock with an opulent tail, and a water snake. But of Polophylax there was no sign. What happened to it, and can traces of it still be found?

The first question is easy enough to answer. Once Plancius had received Keyser's observations he would have quickly realized that the stars of the southern cross actually lay in the hind legs of Centaurus, the centaur, and had been catalogued by the Greek astronomer Ptolemy in the *Almagest* in the second century AD, although they were not at that time identified as a cross*.

If Corsali's sketch is rotated so that Crux is in its correct position over the hind legs of Centaurus, and Polophylax is rotated with it, then we find that the stars of Polophylax fall in Argo Navis, the ship. In other words, this was not an uncharted area of sky after all, but had been known to the ancient Greeks until precession took it below their horizon. That, in answer to our first question, is why Plancius dropped Polophylax.

So, coming to the second question, what were the stars of Polophylax? All previous attempts to identify them have failed because the investigators have been looking in the wrong place. Given the realization that they were actually part of Argo we can make a fresh attempt, although even then the task is not straightforward.

As noted by Dekker[4], Corsali's chart showed the sky as on a globe, not as it appears from Earth. However, she also noted that the map contains errors such as the enlarged scale of the Cross and the misplacing of the Magellanic Clouds with respect to the pole which she attributed to "the confusion of different sets of data by some other author".

Further evidence of this confusion emerges when trying to match up the stars of Polophylax with the real sky. A reasonable match can be obtained only if we assume that the seven stars of Polophylax were not reversed as on a globe like the rest of the map but are in fact positioned as they appear in the sky (Fig. 3). If that is indeed the case, the identifications of the seven stars in Fig. 3 are as in Table I.

TABLE I

Identification of the stars of Polophylax, as numbered in Fig. 3.

1 = Lambda Vel (mag. 2·2)
2 = Kappa Vel (2·5)
3 = Delta Vel (1·9)
4 = Iota Car (2·2)
5 = Epsilon Car (1·9)
6 = Beta Car (1·7)
7 = NGC 2070.

The stars numbered 2, 3, 4, and 5 are the False Cross. Hence, if these identifications are correct, Corsali's diagram contains not one but two southern crosses. It seems reasonable that Corsali would include both the real cross and its look-alike on his diagram.

And, no matter which way you flip the drawing, number 7 can only be the first recorded observation of the Tarantula Nebula (NGC 2070, or 30 Doradus), which is bright enough to have been catalogued by Keyser and appeared as a star on Johann Bayer's chart of the southern sky in his *Uranometria* atlas of 1603[5].

Yours faithfully,
IAN RIDPATH

* This, incidentally, had already been pointed out by the English mathematician Thomas Hood in his book *The Use of the Celestial Globe in Plano* of 1590 in which he wrote that the stars of the Southern Cross "are none other then [sic] those which are in the hinder feete of the Centaure". The source of Hood's information was probably the English explorer Robert Hues who had returned from circumnavigating the globe two years earlier.

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2023 June 14

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REVIEWS

For the Love of Mars. A Human History of the Red Planet, by Matthew Shindell (University of Chicago Press), 2023. Pp. 248, 23·5 × 16 cm. Price £22/$27·5 (hardbound; ISBN 978 0 226 82189 4).

Writing this book during the Covid lockdown, author and Smithsonian curator Matthew Shindell wanted to go beyond the few sentences other Mars books had devoted to ancient beliefs about the planet. Who cared about Mars in the past? Who cares about it today? The result is a well-crafted narrative, rich in human history and literature, and a book that addresses questions such as why we continue to visit the Red Planet.

A great deal of patient research must have been needed to prepare the earlier chapters, which range from the era of the Mayans to the invention of the telescope. Included are visions of Mars imagined by Dante and Kircher, explored in scholarly but always accessible detail. From Chapter 4 we are on to the time of telescopic observers, and scientific popularizers like Proctor, and it is clear that Shindell knows the literature well. It's not generally true to write (page 102) that telescopic sketches of Mars might only show one or two details, but this is a tiny point. I enjoyed the way in which he explores Martian science fiction, which even by the late 19th Century had become voluminous. Shindell spends some time describing the campy film *Total Recall*, based upon a clever story by Philip K. Dick. Kim Stanley Robinson's rather turgid Mars trilogy is also discussed, though in your reviewer's opinion the same author's *Icehenge* is a more finely crafted work that also discusses ecosystems, longevity, and aspects of human memory, and a future Martian rebellion, and which I commend to those interested. John Carter of Mars gets a mention in the text but fails to reach the index. Chapter 5 takes us into the Cold War period, and we are soon with the latest robotic rovers crawling over the surface of the planet. A Conclusion considers the human future of Mars. Shindell's final comment is that the most important question we can ask now is not "How will we get to Mars?" but "Who do we want to be when we become Martians?"

Historically insightful in chronicling human engagement with the Red Planet, and complete with a pseudo-dog-eared retro dust jacket, *For the Love of Mars* is likely to have a wide appeal. — Richard McKim.

Star Noise. Discovering the Radio Universe, by Kenneth I. Kellermann & Ellen N. Bouton (Cambridge University Press), 2023. Pp. 396, 25 × 18 cm. Price £39·99/$49·99 (hardbound; ISBN 978 1 316 51935 6).

A comprehensive history of the early days of radio astronomy has been written by W. T. Sullivan (*Cosmic Noise*, 2009, Cambridge University Press) but covering only up to the early 1950s. The explosive expansion of the subject since then makes it practically impossible to write the same comprehensive review to cover the next seven decades. Ken Kellerman and Ellen Bouton have nevertheless produced a useful and entertaining history of radio astronomy from the earliest days up to the present by concentrating on the main discoveries and particularly on the circumstances and the individual participants involved. What was the background of those who built the first radio telescopes and the students who joined them? How did the subject become international and expand into the present-day huge project of the *Square Kilometre Array*? The result is full of colourful detail, often including anecdotes which have not been told before and do not appear in the scientific journals.

Kellerman's research career coincides with the life of the National Radio Astronomy Observatory in the USA, including some time in Australia. Bouton is the Historical Archivist at the NRAO; they are well placed to tell these stories, although of course from their standpoint they are bound to concentrate on the USA and Australia, and cannot spread much to the other main participants or to the development of radio telescopes in other countries round the world. They might, for example, have traced the separate early developments in the UK of big dishes and interferometers at Jodrell Bank and at Cambridge back to the different wartime experiences of Bernard Lovell, who developed big scanners for aircraft radar, and Martin Ryle, who installed pairs of aerials in fighter aircraft; similarly the Australian radio astronomers Joe Pawsey and John Bolton built on their wartime experience for their sea-reflection interferometers.

The book is organized into chapters on the main subjects within the discipline, such as the Sun and stars, radio galaxies and quasars, pulsars, cosmology and the cosmic microwave background. Within each we have a history of the main developments, and for some we have a comprehensive story such as the history of the discovery of large redshifts in radio sources leading to the discovery of quasars. There are prime examples of serendipity; for example, the discovery of radio noise from Jupiter was made with a *Mills Cross* antenna (incidentally an × configuration rather than a +), which was designed for a sky survey that was never carried out but which was ideally suited for the Jupiter discovery; and of course the prime example of the antenna built for measuring diameters of quasars through their scintillation, which led Jocelyn Bell to the discovery of pulsars. Other discoveries had been predicted by theorists but not noticed by the observing community; there is an interesting account of the predictions of the cosmic microwave background which was detected using an antenna designed for measuring the limitations of satellite communications. Fortune indeed favours those who are prepared. In contrast the existence of the 21-centimetre hydrogen line was predicted and led directly to its discovery, although the prediction by van der Hulst was rather discouraging.

With such a rich palette there is no need for the authors to dig further into the astrophysical or cosmological significance of the discoveries. Similarly, a chapter on the design of radio telescopes cannot be exhaustive, although the main lines leading to the huge arrays of *LOFAR* (for metre wavelengths) through to *ALMA* (for millimetre wavelengths) are clearly set out. There are, however, comprehensive pages of notes and references which allow the reader to dig deeper. A final chapter on the sociology of research groups and the individuals who emerged as Nobel Prize winners is thoughtful and salutary for those responsible for funding new science.

Altogether a fascinating and enjoyable book especially for one who has been involved or a spectator in the whole subject. — Francis Graham-Smith.

China's Space Programme, by S. Chandrasekhar (Springer), 2022. Pp. 320, 23 × 15 cm. Price $39·99 (about £33) (hardbound; ISBN 978 981 19 1503 1).

This book and the Chinese space programme both begin with the 1955 return of long-term US resident, Caltech PhD recipient, and former WWII US Army colonel Quian Xuesen* to the land of his birth.

The book ends with Annexure 16.4, a table of "Procured satellites launched by China end 2020", from which you can gather that the author is not a native speaker of English. But nor is he Chinese. Rather he is J. R. D. Tata Chair Professor at the National Institute of Advanced Studies (NAIS) in Bengaluru, India. Whether he is related to the S. Chandrasekhar you might have expected to find as an author of astronomical volumes I have not attempted to find out.

What do we find between Quian's arrival in China and the Annexures? Many tables of Chinese launches — a long list of 677 up to 2020 December 28; subsets of communications, weather, remote sensing, navigation, human space flight, and military satellites. Among the military purposes have been gathering of electronic intelligence "SIG" — intelligence, missile detection, and anti-satellite and situational awareness.

As to priorities, Chapter 14 informs readers that "all of China's current stable of operational launchers have their origins in its military missile programme." Of course you can aim a rocket more or less up to launch something into space or more or less sideways to deliver something to your foe's territory, and, although Quian was appointed to a position of considerable power and authority within months of his return, the decision from Mao Zedong, Zhou Enlai, and others was to focus first on missiles. Thus, although Dr. Quian/Tsien was inspired by the Soviet launch of *Sputnik* in late 1957, the first Chinese launch is dated to 1970 April 24. It was the 'East is Red' or Dong Fang Hong.

The pillars of the space-missile network were, according to Chapter 2, Prime Minister Zhou Enlai, Long March veteran General Nie Rongshen, and the technical leadership provided by Quian Xuesen. Launch vehicles carrying the Long March name have continued in use down to the present. Also on-going has been close connection between the satellite and the missile programmes, with (Chapter 13) what seem to be clear responses to anti-ballistic missile and other activities of the United States.

My copy of *China's Space Programme: From the Era of Mao Zedong to Xi Jinping* was sent for review to 'Another Journal' which decided against having it reviewed. I asked for the stray copy because I expect to teach space science

*In the Chinese transcriptional spelling of the day, he was Tsien Hsue-shen (1911–2009). The PhD was in aeronautics, under Theodore van Karman, but it was also a good year for Caltech PhD physicists, including degrees to Tommy Lauritsen, Frank Oppenheimer, and Charles H. Townes. The Tsien thesis was 'Problems in motion of incompressible fluids and reactive propulsion', which already begins to sound a bit like rocketry (yes, he was also involved in the founding of Jet Propulsion Laboratory), and in 2005 the Caltech alumni association knew he was to be found as chairman of the National Academy of Sciences at the Institute of Mechanics, Beijing, Peoples Republic of China. Tsien had come initially to the Massachusetts Institute of Technology on a Boxer Indemnity Scholarship, earning an MS there in 1936 before moving on to Caltech. The miserable details of his departure from the US were featured in his Wiki, at least in the last week of June, 2023.

in the fall. The book is, however, not an easy read. An index would have helped. The list of abbreviations is very nearly complete, one is told that CZ is Chang Zheng, DF is Dong Feng, and FB is Feng Bao. Now, if only I knew, what a Chang and a Dong and a Bao were … . If there are a few native speakers of Chinese in that fall class, one of their homework choices will be to provide some insight on those matters.

It was a remarkable insight on the part of Tom Lehrer, long before that 1970 first launch, to recognize the enormous potential of the Chinese space programme, though he chose to credit it to a mythical version of the founding genius of the US space programme:

"In English and German I know how to count down,
And I'm learning Chinese", said Wernher von Braun.

— Virginia Trimble.

New Windows on the Universe. Advances in multimessenger astronomy, by Saeqa Dil Vrtilek (IoP Publishing), 2022. Pp. 179, 26 × 18·5 cm. Price £120/$190 (hardbound; ISBN 978 0 7503 3729 8).

This book is an introduction and overview of astrophysics as it is practised today, aimed especially at students with some background who want to learn their way into the subject. In the first chapter the author goes directly to the multimessenger nature of astrophysical research, and uses angular resolution to show how observational techniques have improved and are improving. There is a quick treatment of a variety of these techniques, from optical imaging to gravitational waves, which includes many of the standard ranges of electromagnetic radiation, and takes in cosmic rays and neutrinos.

The rest of the chapters are organized in terms of specific astronomical themes, and how the different techniques are applied to each. Starbirth gives rise naturally to discussion of infrared and millimetre-wave astronomy, and is illustrated by combining images from infrared satellites with optical counterparts from the *Hubble Space Telescope*. The author cannot be blamed for writing the book before the launch of the *James Webb Space Telescope*, which would clearly have enhanced this section (and will have to be included if there is a new edition). In the same chapter the deaths of stars point the reader at planetary nebulae and supernova remnants, and the techniques move on to include radio and X-ray images. This use of specific cases to allow the author to show where the different techniques are being applied is a strong point.

Another positive point is the chapter on planet formation and exoplanets. Starting with the historical question, verging on the philosophical, of whether the Solar System is unique, we can see the need to study exoplanets and their formation in order to understand better the formation of our own planetary system (much as the comparative meteorology of other Solar System planets has given us a better framework to study the Earth's meteorology and climate). We are told about the two basic methods for detecting exoplanets: planetary transits and periodic spectral shifts, described with brief physical detail, and given a description of specific exoplanet detections. The chapter concludes by explaining what we will need to do in order to detect Earth-like planets.

A chapter with the title 'New Characters on the Cosmic Stage' allows the author to show how high-energy electromagnetic radiation, above all X-rays and gamma-rays, are letting us see how the highest-energy objects and processes work. Here we find pulsars, both individual and binary, magnetars, gammaray bursters and their host galaxies, collapsars, hypernovae, and kilonovae, a veritable zoo of phenomena. In this *pot pourri* I will pick out one interesting case, the observation of the gravitational-wave event involving merging neutron stars by observers using the full range of electromagnetic radiation. This enabled a missing piece of the nucleosynthesis puzzle, the *r* process (which among other elements produces gold), to be put into its context: the merging of neutron stars, which will be a fruitful field as gravitational-wave observations become routine.

The author uses energy production to link, in a single chapter, solar physics and the processes which produce X-rays in binaries, and in the zones around the supermassive black holes at the centres of galaxies, which we most often observe as quasars. She has a neat description and explanation of superluminal motion in some of these types of objects. The chapter also includes the analogy between stellar binary X-ray sources and quasars, and tells us of the detection of a high-energy neutrino from a blazar with the *IceCube* neutrino telescope in the Antarctic ice. The question of what sources produce the highest-energy cosmic rays is asked, to close this discussion of high-energy phenomena.

Cosmology is given its place, with a historic look at how our horizons have expanded. The story of the discovery of the expanding Universe in the early 20th Century leads on to the essentially optical observations of distant galaxies, reaching the point where dark matter and dark energy have been introduced, and showing how the cosmic microwave background now underpins the commonly accepted ΛCDM cosmological scenario. As this is pre-*JWST* we are shown only questions about the first stars and galaxies which should lead the reader towards a Google search for the latest imagery and spectroscopy of these objects. The general topic of how the Universe may end is briefly noted under the umbrella of General Relativistic scenarios. We are also given an explanation of why it is a mistake to consider that the Universe is in expansion from a specific central point.

The final chapter is devoted to upcoming instruments and the impact they are likely to have on astronomy as whole. These include the two telescope arrays making up the *Square Kilometre Array*, for radioastronomy, the *JWST* in the infrared, the *Vera Rubin* optical survey telescope, and the *Cherenkov Telescope Array* for gamma rays and high-energy cosmic rays. This latter instrument is already partly constructed and one of the four major dishes in its northern observatory is already producing data. Future upgrades to existing gravitational-wave detectors and neutrino detectors are explained, as are coming developments in time-domain astronomy. The author might have mentioned the *E-ELT*, which will be the largest optical/infrared telescope in the world when it is completed before the end of this decade.

I found the book easy to read, but this may not be a fully relevant remark, since I am a practising professional astronomer. As a supplementary text for general courses in physics it should work well. There may be other ways to organize the material but the way the author has picked individual cases to illustrate general principles, rather than in the other direction, may well be easier to assimilate for a reader with little previous knowlege. The contents are quite comprehensive, and the only sub-field which is not touched on is that of the contribution of meteorite, lunar-sample, and cometary-sample science to chronology of the Solar System and beyond. I also missed a little more use of spectroscopic results to describe and explain the astronomy. The extension of the term multimessenger astronomy to the whole gamut of electromagnetic radiation as well as to neutrino and gravitational-wave astronomy is clearly justified.

The book is well produced, the text is clear, and the illustrations are appropriate. The book would be a good choice for libraries. But the single negative point about it is the price. It is true that the edition I have reviewed is in hardback, but I have recently seen texts which cover a similar range of topics at less than one third of the price of this book. I do not understand the pricing policy of the IoP in this case. — John Beckman.

The Large Scale Structure of Space-Time. 50th Anniversary Edition, by Stephen W. Hawking & George F. R. Ellis (Cambridge University Press), 2023. Pp. 391, 25 × 18 cm. Price £27·99 (hardbound; ISBN 978 100 925315 4).

This is a 50th anniversary re-issue of the classic book on General Relativity from 1973, with a new foreword by Abhay Ashtekar and a new preface by George Ellis, which delightfully recalls the historical context, as well as giving some personal recollections. Partly inspired by the ground-breaking work of Roger Penrose, for which he was subsequently awarded the Nobel Prize, the book focussed on the global structure of space-time, and in proving singularity theorems, which went beyond the special symmetries that were considered might be necessary. Equally important was its influence in changing the direction of thinking of many relativists to contemplating geometrical terms, away from local formulations of General Relativity in terms of partial differential equations. What is particularly interesting is the coverage of the collision and merging of black holes, especially prescient in the light of their subsequent discovery, but curiously there is nothing on gravitational waves. In terms of what has changed in the intervening years, in the new preface George Ellis notes that the introduction of inflation theory affected the singularity theorems in that the required energy conditions don't necessarily hold. Interestingly, the book discusses de Sitter and anti-de Sitter space-times when they were presumably rather niche, but now of course are mainstream in the light of inflation and the accelerating Universe on the one hand, and AdS-CFT correspondence on the other, advancing our understanding of string theory and quantum gravity. Amusingly, the notion of de Sitter space-time as due to a fluid was not considered reasonable in 1973 since the pressure would be negative. It is a book well worth reading today — its clarity and mathematical rigour ensure its longevity, and notwithstanding the topics that it does not cover, it is as much a classic in the physics literature now as it was 50 years ago. — Alan Heavens.

ASTRONOMICAL CENTENARIES FOR 2024

Compiled by Kenelm England

The following is a list of astronomical events, whose centenaries fall in 2024. For events before 1600 the main source has been Barry Hetherington's *A Chronicle of Pre-Telescopic Astronomy* (Wiley, 1996). For the 17th to 20th Centuries lists of astronomical events came from wikipedia and other on-line sources, supplemented by astronomical texts made available through the NASA Astrophysics Data System. Discoveries of comets, asteroids, novae, and other objects for 1924 appeared in the February issue of *Monthly Notices of the Royal*

Astronomical Society in the following year. There were also references from *Popular Astronomy*, *Journal of the British Astronomical Association*, and *Publications of the Astronomical Society of the Pacific*. Professional discoveries and observations were followed up in *Astronomische Nachrichten*, *Astronomical Journal*, and *Monthly Notices of the Royal Astronomical Society*. Details of individual astronomers were supplemented by articles published in *Biographical Encyclopedia of Astronomers* (Springer, 2007). Gary Kronk's *Cometography* Volumes 1–3 (Cambridge, 1999–2007) provided details on all the comets. Finally, NASA's Five Millennium Canons of Eclipses and planetary tables were consulted for information on eclipses and planetary events.

1924

January 10: Karl Wilhelm Reinmuth (Heidelberg Observatory) discovered a suspected supernova (mag. 15) in the barred spiral galaxy NGC 2535. On January 18 it had brightened to mag. 13·3 [The object was not confirmed].

January 30: Death of Margaretta Palmer. Born in 1862, she was an American astronomer at Yale University, calculating orbits of asteroid (7) Iris, comet C/1847 T1 (Mitchell) [her university tutor] and the satellites of Jupiter; worked on the Yale Index to Star Catalogues.

February 4: A meteorite was found at Lake Labyrinth, South Australia, which was not witnessed but very recent. It weighed 25·85 kg and is an LL6 ordinary chondrite [Lake Labyrinth Meteorite].

February 5: The Royal Observatory at Greenwich began transmitting hourly time signals.

February 14: Aldebaran was occulted by the Moon in daylight, which was widely observed from the United States.

February 20: A total lunar eclipse was visible from North America, Asia, Europe, and Africa [Saros 122].

February 28: Death of Edward Prentice. Born in 1864, he was a British businessman in the paper-making industry and an amateur astronomer, observing Mira variable stars; member of the BAA; FRAS 1919.

March 5: A partial solar eclipse was visible from the Cape of Good Hope and Antarctica [Saros 148].

March 7: Paul-Henri Stroobant (Uccle Observatory, Belgium) discovered an 11th-magnitude object, which was later identified as asteroid (177) Irma.

March 8: Samuel Cramer (Worcester, Massachusetts) observed 15 to 40 meteors in about 15 seconds.

March 19: Death of William Henry Maw. Born in 1838, he was a British railway engineer and amateur astronomer, observing double stars; FRAS 1888 and founder member of the BAA 1890; President of BAA (1898–1900) and RAS (1905–7).

March 25: William Reid (Rondebosch, South Africa) discovered a 10th-magnitude comet in Fornax, just after it reached perihelion on March 13 (q = 1·7557 AU). Over the next month it was observed from South Africa and Chile, as it slowly faded, until it was lost in the Sun's glare on May 31. The comet was recovered in the Northern Hemisphere from September 28 to October 7 [Comet C/1924 F1 (Reid)].

April 8: Aldebaran was occulted by the Moon, which was widely observed from the United States.

April 13: Death of Hugh Walsham. Born in 1853, he was a British doctor involved in the pioneering use of X-rays, and an amateur astronomer; FRAS 1914.

April 29: Death of Ernest Fox Nichols. Born in 1869, he was an American Professor of Physics who demonstrated experimentally that light exerts pressure.

May 1: While riding home from Ness City to Burdett, Kansas, at 11·45 pm, Clyde William Tombaugh saw a brilliant fireball in the southeast "as bright as at noonday".

May 7: The Transit of Mercury was widely observed from Europe and the United States.

May 11: Birth of Antony Hewish, a British radio astronomer at Cambridge University, developing equipment to study high time resolution in radio sources, leading to the discovery of pulsars; FRAS 1957; FRS 1968; Nobel Prize for Physics 1974; Professor of Radio Astronomy at the Cavendish Laboratory (1971–89); died 2021.

May 20: Birth of Uco van Wijk, a Dutch–American astronomer at Harvard, Princeton, and the University of Maryland, studying the dynamics of star clusters and stars in the Large Magellanic Cloud; FRAS 1964; died 1966.

May 31: Harlow Shapley (Harvard Observatory) published the results of a study of the Small Magellanic Cloud. He found that it was 2 kiloparsecs in diameter and 31 kiloparsecs away.

May: Arthur Stanley Eddington published 'On the Masses and Luminosities of the Stars' in *Monthly Notices*, where the position of stars on the main sequence depends on the star's mass, ending the idea that stars evolved along the main sequence.

June 14: Harlow Shapley (Harvard Observatory) announced the completion of the *Henry Draper Catalogue* of the positions, brightnesses, and spectra of 225 300 stars, the work of the women astronomers at Harvard led by Williamina Paton Stevens Fleming and Annie Jump Cannon.

June 19: A moving white cloud appeared in the sky over Spain, and after several detonations five large stones fell near the town of Olivenza and broke apart. About 150 kg of material was collected from this LL5 ordinary chondrite [Olivenza Meteorite].

June 21: S. D. Tscherny (Kiev Observatory) observed Mars occult the magnitude 7·6 star BD –15° 6169.

June 24: Birth of Archibald Edmiston Roy, Professor of Astronomy at Glasgow University; FRAS 1951; took part in Project Moonwatch during the International Geophysical Year; studied and wrote on celestial dynamics; interested in megalithic stone alignments in Scotland; died 2012.

June 27: Witnesses saw a meteorite fall near the village of Béréba in Upper Volta [now Burkina Faso]. It is a eucrite weighing 18 kg, probably originating from Vesta [Béréba Meteorite].

July 6: Local people saw a meteorite fall into the Elwell Cemetery during a funeral procession in Johnstown, Colorado. The meteorite is a diogenite weighing 40·3 kg, which may have originated from Vesta. The local townspeople are making a collection to purchase a fragment of the meteorite for the centenary [Johnstown Meteorite].

July 8: Periodic comet Spitaler returned to perihelion ($q = 2{\cdot}0887$ AU). The comet was discovered in 1890 but was not recovered at the next few returns. After 1910 no searches were made, and the comet remained lost until it was accidentally recovered by James Vernon Scotti (Spacewatch) in 1993 [Comet 113P/Spitaler].

July 31: A partial solar eclipse was visible only from the Southern Ocean [Saros 115].

August 1: Orbital calculations predicted that Encke's comet would return to perihelion on November 1. It was recovered by George van Biesbroeck (Yerkes Observatory) and later found on a photograph taken on July 29. The comet brightened from magnitude 15 to 7, when it was last observed on October 27. It reached perihelion on October 31 ($q = 0{\cdot}3411$ AU) but was not recovered after passing in front of the Sun [Comet 2P/Encke].

August 14: A total lunar eclipse was visible from Asia, Europe, Africa, and South America [Saros 127].

August 23: Mars was at a very favourable opposition near perihelion, better than in 1909 and comparable to the close opposition of 1877. Its apparent diameter reached 25·1 arcseconds, which allowed detailed visual observations of the planet's surface. Some observers still thought they saw canals, although the better telescopes under the best conditions showed no sign. There was a large number of photographs taken. Edison Pettit and Seth Barnes Nicholson (Mount Wilson) used a thermocouple on the 100-inch reflector to measure the surface temperature of Mars. They found that the average temperature was 250 K, with 280 K at the equator and 205 K at the pole.

August 25: Birth of Harlan James Smith, an American professional astronomer, who studied variable stars and discovered the δ Scuti class of variables; Co-Editor of the *Astronomical Journal* (1958–63), Director of the McDonald Observatory, Texas (1963–89); FRAS 1964; died 1991.

August 31: A partial solar eclipse was visible from the Arctic, Siberia, and Northern China [Saros 153].

September 15: Paul Finsler (Bonn, Germany) discovered a 4th-magnitude comet in the west after sunset. It was widely observed over the next few nights as a naked-eye object with a tail 1 degree long. At the end of September the comet began to fade rapidly and was last seen on October 19. It had been at perihelion on September 4 ($q = 0{\cdot}4060$ AU) [Comet C/1924 R1 (Finsler)].

September 17: Death of Johann Martin Schaeberle. Born in Germany in 1853 and emigrating to the United States in 1856, he discovered comets C/1880 G1 (Schaeberle) and C/1881 N1 (Schaeberle). He worked at the University of Michigan Observatory in Ann Arbor and then the Lick Observatory, where he observed the total solar eclipse of 1889; discovered Procyon B in 1896.

September 24: Venus occulted by the Moon.

October 7: Death of Thomas Frederick Furber. Born in England in 1955, he was an Australian government surveyor of New South Wales; observed the Transit of Venus 1882 from Lord Howe Island; FRAS 1896.

October 23: Wilhelm Heinrich Walter Baade (Bergedorf Observatory, Hamburg) discovered a new asteroid (mag. 9·2), which was a new Amor object with an orbital period of 4·35 years. It could approach close to Mars, as it will do in 2050, and was named (1036) Ganymed [Asteroid 1924 TD = A924 UB].

November 5: Birth of John Grant Davies, a British radio astronomer at Jodrell Bank, studying meteors and artificial satellites; FRAS 1953; developed the *MERLIN* network of radio telescopes; Professor of Radio Astronomy at Manchester University (1966–88); died 1988.

November 12: Birth of Audouin Charles Dollfus, a French astronomer at the Meudon and Pic du Midi Observatories; observed Mars in polarized light in 1956 to conclude that the surface was composed of iron oxide; drew features on Mercury 1959; discovered Saturn's tenth moon, Janus, in 1966; Honorary FRAS 1975; died 2010.

November 23: Edwin Powell Hubble (Mount Wilson Observatory) announced in the *New York Times* the discovery of Cepheid variables in the Andromeda Galaxy, which proved that it lay well beyond the Milky Way.

December 2: Death of Hugo von Seeliger. Born in 1849, he was a German professional astronomer who observed the Transit of Venus in 1874. He worked at the Bonn, Gotha, and Munich Observatories on the distribution of stars in the Milky Way. He was particularly hostile to Einstein's theory of relativity.

December 7: Death of William Henry Finlay. Born in 1849, he was a British astronomer at the Cape Observatory; FRAS 1873; discovered the Great Comet C/1882 R1 and Periodic Comet 15P/1886 S1 (Finlay), which he recovered in 1893; observed the Transit of Venus 1882.

December 8: Peter van de Kamp (Lick Observatory) saw a very bright fireball (mag. –5).

December 9: Periodic comet Tempel 1 returned to perihelion (q = 2·0941 AU). Discovered in 1867 and observed in 1873 and 1879, the comet's orbit was severely perturbed by Jupiter in 1881, and the comet remained too faint until the next observation in 1967 [Comet 9P/Tempel 1].

December 22: Maximilian Franz Josef Cornelius Wolf (Heidelberg Observatory) discovered a faint comet in Taurus on a photograph. It was only magnitude 16 and observed from professional observatories until 1925 February 14. This was a new periodic comet, designated P/Wolf (2), which reached perihelion on 1925 January 11 (q = 2·4283 AU). The comet became lost and was accidentally rediscovered by Robert George Harrington in 1951 [Comet 43P/1924 Y1 (Wolf–Harrington)].

Edwin Powell Hubble (Mount Wilson Observatory) discovered 58 novae in the Andromeda Galaxy during the year.

The Einstein Tower, in Potsdam, Germany, began operating as an astrophysical observatory.

The Commonwealth Solar Observatory near Canberra, Australia, was established [now Mount Stromlo Observatory].

Formation of the Edinburgh Astronomical Association (now the Astronomical Society of Edinburgh).

James Lane, a labourer in the Weekeroo Station, South Australia, discovered a IIe iron meteorite, weighing 94·2 kg. The largest piece (47 kg) is in the Australia Museum [Weekeroo Station Meteorite].

A farmer bumped into a meteorite while ploughing near the town of Coldwater, Kansas. It is an H5 chondrite, weighing 16 kg [Coldwater (stone) Meteorite].

Herbert Basedow was exploring the geology of central Northern Territory, Australia, when he came across a rare pallasite meteorite of about 1 kg, 17 km north of Alice Springs [Alice Springs Meteorite]. In July 1937 Cecil Thomas Madigan found the main mass of 1·4 tons at Huckitta and the meteorite was renamed [Huckitta Meteorite].

A meteorite was ploughed up at the Caster Farm just outside Beeler, Kansas. It is an LL6 ordinary chondrite, considerably weathered and weighing 11·62 kg. It may be related to the Kausala meteorite found in 1894 [Beeler Meteorite].

Erick Holmdale discovered a meteorite 6 km north of the town of Achilles, Kansas. The rock was poking out of the soil but was not recognized as a meteorite until 1950. It is an H5 ordinary chondrite, weighing 16 kg [Achilles Meteorite].

E. Keller, a meteorite collector, found a knobbly lump of iron on his property near Dermbach, Germany. It is a Ni-rich ataxite iron meteorite, weighing 1·5 kg [Dermbach Meteorite].

1824

January 1: An annular solar eclipse was only visible from Australia and Antarctica [Saros 119].

January 4: Birth of William Coleman, a British landowner and amateur astronomer, measuring double stars; FRAS 1884; died 1911.

January 15: A meteorite was seen to descend over the village of Renazzo, near Ferrara in Central Italy, which broke up into three main pieces plus many fragments. The meteorite was scattered over an area 1·5 km in diameter. It is a CR2 carbonaceous chondrite, weighing 10 kg, although only 1 kg remains in museums [Renazzo Meteorite].

January 16: A partial lunar eclipse was visible from Europe, West Africa, the Americas, and Asia [Saros 131].

February 7: Birth of Sir William Huggins, the British astronomer who developed spectroscopy for astronomy; FRAS 1854; found emission lines in certain nebulae and the nova T Coronae Borealis; FRS 1865; married Margaret Lindsay Murray in 1875 and together worked on the *Atlas of Representative Stellar Spectra*; RAS Gold Medal (1867 & 1885) and RS Copley Medal (1898); President of RAS (1876–8) and RS (1900–5); knighted 1897; Order of Merit 1902; died 1910.

February 18: A meteorite was seen to fall amid loud detonations in Tounkin [now Tunkinsky District], 140 km WSW of Irkutsk, Siberia. It is an ordinary chondrite, weighing 2 kg [Tounkin Meteorite].

February 22: Birth of Pierre Jules César Janssen, a French astronomer who travelled widely to observe the Sun including eclipses, and developed spectrohelioscopes to image solar prominences; claimed detection of vapour in the spectrum of Mars' atmosphere (later disproved); set up the Meudon Observatory; died 1907.

March 12: Birth of Gustav Robert Kirchhoff, a German experimental physicist and chemist who developed spectroscopic analysis of minerals with Robert Wilhelm Eberhard Bunsen; produced a detailed map of the solar spectrum and the concept of a perfect blackbody; FRS 1875; died 1887.

June 21: Death of Martin Wall. Born in 1747, he was a British doctor and chemist who in 1783 wrote *Antiquity and Use of Symbols in Astronomy and Chemistry*; FRS 1788.

June 26: Birth of Sir William Thomson, Baron Kelvin, a British mathematician and physicist, Professor of Natural History at Glasgow University. He studied thermodynamics and electromagnetism, estimating the ages of the Earth and the Sun; knighted 1866; died 1907.

June 26: A total solar eclipse was visible from Japan and China [Saros 124].

July 11: A partial lunar eclipse was visible from Europe, Africa, and the Americas [Saros 136].

July 14: Christian Karl Ludwig Rümker (Pinton, New South Wales) discovered a comet with a faint tail in Sextans. He informed Thomas Macdougall Brisbane (Parramatta, New South Wales), and the two observed the comet until August 11. It had reached perihelion on July 12 (q = 0·5917 AU) [Comet C/1824 N1 (Rümker)].

July 23: Christian Friedrich Scheithauer (Chemnitz, Germany) discovered a comet in Ophiuchus, when it was closest to the Earth. It was also discovered by Jean Louis Pons (La Marlia, Italy) on July 24, Jean Félix Adolphe Gambart (Marseilles, France) on July 27, and Karl Ludwig Harding (Göttingen, Germany) on August 2. The comet was just too faint to be seen with the naked eye but was widely seen in August and September. It reached perihelion on September 29 (q = 1·0498 AU). Then the comet began to fade slowly and was last seen on December 25 [Comet C/1824 O1 (Scheithauer)].

August 24: Birth of John William Aldridge, a British amateur astronomer, who observed Halley's comet in 1835; FRAS 1890; died 1897.

September 27: Birth of John Welsh, a British meteorologist, observer at observatories at Makerstoun, Roxburghshire, and Kew; made four balloon flights to make meteorological observations in 1852; FRS 1857; died 1859.

September 27: Birth of Benjamin Apthorp Gould, an American astronomer who worked at Greenwich and Berlin Observatories; founding editor of the *Astronomical Journal* (1849–61); worked at the US Coast Survey (1852–67); founded the Cordoba Observatory, Argentina, and laid the basis for the *Cordoba Durchmusterung* star catalogue; died 1896.

October 7: Birth of Lorenzo Respighi, an Italian professional astronomer at Bologna and Rome Universities, cataloguing star positions and spectra. He discovered comets C/1862 W1 (Respighi), C/1863 (Respighi), and C/1863 Y1 (Respighi); extensively studied the Sun; died 1889.

October 14: A meteorite was seen to fall near Zebrak, Bohemia, 37 km southwest of Prague. Two pieces of this H5 ordinary chondrite were found, weighing 2 kg [Zebrak Meteorite].

October 20: Franz von Gruithuisen (Munich, Bavaria) reported observing intermittently flashing light appearing on the dark part of the Moon, while observing it with his telescope.

October 22: Birth of Francis Henry Samuel Orpen, a British imperial administrator in South Africa, involved in land surveys; interested in astronomy and geology, observing the transit of Venus 1882; FRAS 1889; died 1893.

December 20: An annular solar eclipse was visible from the Cape of Good Hope and the coast of Brazil [Saros 129].

Franz von Gruithuisen explained the formation of craters on the Moon as a result of meteorite impacts.

William Pearson published *An Introduction to Practical Astronomy*.

Joseph Fourier calculated that the Earth would be far colder if it lacked an atmosphere.

1724

April 22: Birth of Immanuel Kant, a highly-influential German philosopher, Professor at the University of Königsberg. He wrote on the 1755 Lisbon earthquake, geography as a subject, and in his *Universal Natural History* proposed the nebular hypothesis for the formation of the Solar System, the Milky Way as a large disc of stars, and other nebulae might be distant galaxies; died 1804.

May 8: A partial lunar eclipse, visible from the Americas [Saros 107].

May 22: A total solar eclipse was observed from the Royal Observatory, Paris, by the cousins Giacomo Filippo Maraldi and Jacques Cassini and the brothers Guillaume and Joseph-Nicolas de l'Isle. Maraldi concluded that the corona was part of the Sun, not the Moon. In England most of the country was cloudy, although the inhabitants of London could see darkness during near totality, as predicted by Edmond Halley. King George I and other members of the royal family were at Kensington palace for the spectacle. The only visual observation of totality was made by Doctor William Stukeley and his companions at Haraden Hill, near Salisbury, Wiltshire, who described the darkness "drop upon us . . . like a dark mantle". The eclipse was total across France, the British Isles, and North America [Saros 133].

June 16: William Burnet FRS, Governor of New York, observed the eclipse of Jupiter's moon Io to calculate the longitude of New York.

July 1: Death of Johann Baptist Homann. Born in 1664, he was a German geographer and cartographer, published *Grosser Atlas ueber die ganze Welt* (*Grand Atlas of all the World*).

September 14: Birth of Edmé-Sébastien Jeaurat, a French astronomer, who set up observatories at the Military School, Paris, and observed the transit of Venus in 1769; editor of the *Connaissance des Temps* (1772–87); died 1803.

October 29: Death of Jean de Hautefeuille. Born in 1647, he was a French priest, physicist, and inventor, designing a spiral spring to control pendulum clocks; elected FRS 1687.

November 1: Giovanni Poleni (Padua) observed a lunar eclipse. It was also observed by William Saunderson (Gomroon, Persia). The eclipse was partial and visible from West Asia, Europe, Africa, and the Americas [Saros 112].

November 15: An annular solar eclipse, visible only from Australia and Antarctica [Saros 138].

November 27: Death of James Pound. Born in 1669, he was a British clergyman and astronomer, elected FRS 1699; observed the total solar eclipse of 1715, the Moon and planets; inspired his nephew, the Astronomer Royal James Bradley.

Death of Joken Nishikawa. Born in 1648, he was a Japanese astronomer who attempted to reconcile Chinese and Western astronomy, relying on observation.

An IVA iron meteorite was found near Steinbach, Saxony, weighing 96 kg. Fragments of the meteorite have had extensive analysis [Steinbach Meteorite].

1624

February 7: Death of Cort Aslaksson. Born in 1564, he was a Norwegian astronomer and philosopher, Professor at the University of Copenhagen.

May 27: Death of Diego Ramirez de Avellano. Born in about 1580, he was a Spanish navigator and cosmographer, pilot of Garcia de Nodal's expedition to the Pacific (1618–9).

July 22: Death of Garcia de Silva Figueroa. Born in 1550, he was a Spanish diplomat and traveller, who wrote on the geography of Persia; observed the two bright comets of 1618 (C/1618 V1 & C/1618 W1) from Isfahan, Persia.

July–August: The Chinese saw a 'large star', which passed behind the Moon, recorded in *Ku chin t'un shu chu ch'eng*. It was also observed in the south by the Japanese, according to *Shiryo Sohran*.

December 26: Death of Simon Marius. Born in 1573, he was a German astronomer, early user of telescopes to observe the moons of Jupiter, the Andromeda Galaxy, and Kepler's Supernova of 1604.

Death of Giuseppe Biancani. Born in 1566, he was an Italian Jesuit priest, astronomer and mathematician, working with Christopher Clavius at the Roman College. Although he supported the Capellan–Tychonic model of the Solar System, he was a friend of Galileo, wrote on astronomy and mathematics, and taught mathematics at the Jesuit College, Parma.

Jakob Bartsch published *Usus astronomicus planisphaerii stellate*, a star atlas which included six new constellations created by Petrus Plancius: Camelopardalis, Gallus (now the northern part of Puppis), Jordanus (the river flowing through Canes Venatici, Leo Minor, Lynx, and Camelopardalis), Monoceros, Tigris (the river flowing through Ophiuchus, Vulpecula, Cygnus-Aquila, and Pegasus), and Vespa (in Aries).

Michael Maestlin published the last edition of his *Epitome astronomiae* (*Summary of Astronomy*), which maintained the Ptolemaic system but included the latest telescopic discoveries. He used this as the basic textbook in his teaching at the University of Tübingen.

The French Parliament passed a decree banning criticism of Aristotle on penalty of death, making the Copernican Model of the Solar System technically illegal.

1524

July 8: Birth of Cyprian Leowitz, a German astrologer and astronomer, who wrote on the Great Comet of 1556, author of *Accurate Description and Picture of All Eclipses from 1554 to 1606 AD, Computed for the Meridian of Augsburg*; issued ephemerides for 1556 to 1606; died 1574.

Birth of John Hooker. He was an English astronomer who observed the Great Comet of 1577 and published *The Events of Comets or Blazing Stars made upon the Sight of the Comet Pagania; Which Appeared in November and December 1577*; died 1601.

Petrus Apianus published *Cosmographicus liber* on navigation.

(about) Death of Muhammad ibn al-Katib Sinan al-Qunawi. He was a Turkish astronomer and timekeeper at Istanbul, writer on astronomy, and part of a circle of Ottoman astronomers.

1424

June 26: There was a solar eclipse visible from Europe. At Wittenberg the eclipse was total. The total eclipse was visible across Eastern and Northern Europe, while the partial phase could be seen from Europe, North Africa, and the Middle East [Saros 127].

1224

July 11: The Chinese discovered a nova in Scorpius, recorded in *Sung Shih*.

1124

February 1: There was an eclipse of the Moon seen in Northern Germany, recorded in *Annales Hildesheimenses*. The eclipse was partial and visible across Europe, Africa, and Asia [Saros 90].

August 11: A solar eclipse was seen in Russia, recorded in the *Chronicle of Novgorod*. Fulcher of Chartres wrote in France that "the sun appeared to us for almost an hour with a colourful light, changed into a new hyacinth form or into a kind of horned eclipsed moon . . . as the 9th hour was passing". In England "on the 11th day of August before evening service the sun began to decrease and it totally perished; oh, there was great terror and darkness! There were stars and the moon; then it began to reappear and came out quickly in full; then all the city rejoices". The eclipse was total from Russia and Scandinavia and partial across Europe, North Africa, and West and North Asia [Saros 121].

1024

There is a vague report from Poland that a comet was seen a year before the death of King Boleslav I on 1025 June 17. This may have been a very bright fireball.

924

July 21 & 23: Chinese astronomers saw many stars fly, crossing each other, recorded in *Ssu-tien-k'ao*.

824

March 18: A total eclipse of the Moon was seen shortly after the death of Pope Paschal I on February 11. The eclipse was total across Europe, Africa, and Asia [Saros 84].

May–June: The Chinese saw many stars fall in the north, a bright meteor shower recorded in *T'ien-wên-chih*.

724

Nangong Shuo, Head of the Imperial Astronomical Bureau, organized the measurements of noon shadow-lengths at the midwinter solstice and the spring equinox from a series of stations at Huazhou, Biazhou, Xuzhou, and Yuzhou. He measured the distances between the locations. Yi Xing calculated the length corresponding to one degree of latitude. His result was 351·3 li (113·47 km), so the circumference of the Earth would be 40850 km [actually 40008 km].

Yi Xing was a Chinese astronomer who constructed shadow-poles, quadrants, and armillas. He built a water-powered celestial globe.

The Tang emperor Xuanzong sent a naval expedition to the South Seas to observe Canopus and other bright southern stars. These were charted within 20 degrees of the South Pole, recorded in *Chiu Thang Shu*.

The Chinese *Da Yen* almanac gave the year length as 365·2444 days.

Gautama Siddha and his colleagues completed *Kaiyuan Zhanjing* (*Kaiyuan Star Observations*), an encyclopedia of Chinese astrology.

Death of George, Syriac Orthodox Bishop of the Arabs, who wrote a poem on the calendar and mentioned astronomy in his letters.

624

June 21: The Welsh historical texts *Annales Cambriae* recorded that "the sun was obscured". There was an annular solar eclipse visible from North Africa, but the partial phase could be seen from Europe [Saros 95].

524

There is a report that a comet appeared for 26 days. This may have been a misdated account of Halley's comet in 530.

424

November 22: Transit of Venus.

324

August 6: A solar eclipse was observed from Italy in a list compiled by Sethus Calvisius. The eclipse was annular from North Africa and partial across Europe [Saros 89].

77 BC

October–November: The Chinese observed a ‘guest star’ in Ursa Major, recorded in *Han Shu*. This was more likely a tailless comet than a nova.

(about) The Greek astronomer Geminus of Rhodes wrote *Isagoge eis ta Phaenomena* (*Introduction to the Phenomena*) on the astronomical theories of Euctemon, Calippus, and the Chaldeans (Babylonians). He placed the stars at different distances, not on the surface of a sphere. He also wrote on mathematics and a commentary on Poseidonius’ work *On Meteorology*.

577 BC

(about) A Babylonian tablet gave the approximate synodic periods of the planets.

Here and There

NOT LIKE THE ASTRONOMERS WE KNOW

Being mostly rocky or metallic and primarily found in the main belt between the orbits of Mars and Jupiter, astronomers long thought that asteroids orbit too close to the Sun to carry the ice that powers sublimation-fueled outbursts. — *Sky and Telescope*, 2023 June, page 12.