The Jeety Starn*

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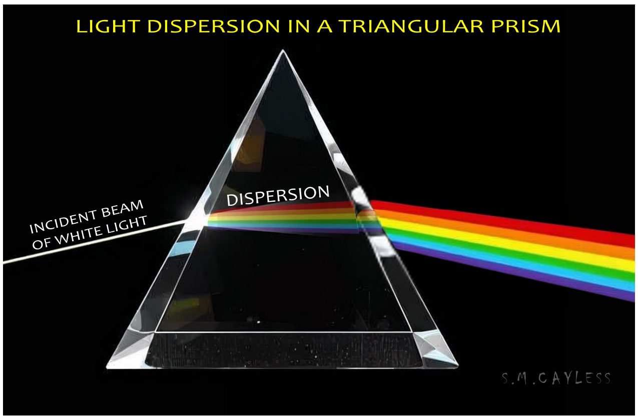
Welcome to Issue 9 of *The Jeety Starn*, the quarterly newsletter of Stirling Astronomical Society. Included in this issue are articles on Arizona's Meteor Crater, the Sharpless Catalogue of Emission Nebulae, the Herschel Wedge for solar observing, the binary asteroid system Didymos, our Observatory Report for 2024-2025, comets, and our usual allowance of literary bits and pieces.

Solar Observing: using the Herschel Wedge

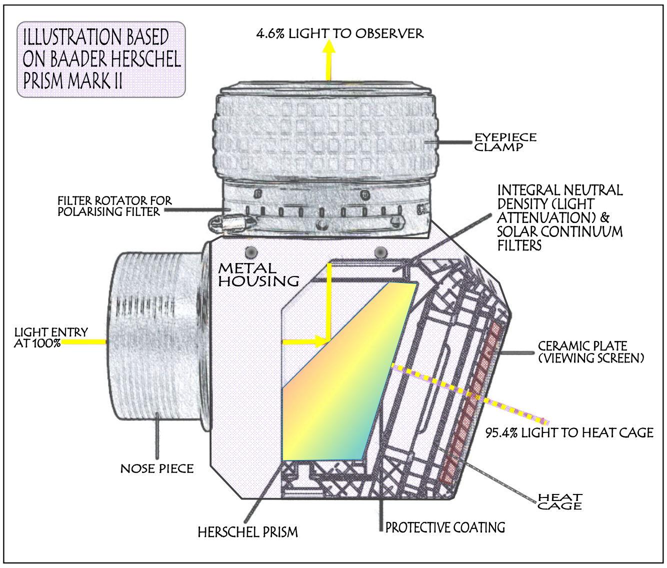
By Sandi Cayless

Never look directly (or obliquely) at the Sun! A safer way of solar observing and photography is by using a Herschel wedge, also known as a Herschel prism, attached to a suitable refracting (***not*** reflecting*) telescope. This optical aid to reduce light entering the observer's eye was first suggested by the astronomer John F. W. Herschel (son of William Herschel), an enthusiast of physical optics (Cannon 1961), who used it in comparable light measurements of stars. John Herschel had advocated the daily observation and recording of sunspots on return from the Cape of Good Hope in 1838 (Herschel 1861, Rothermel 1993). The Herschel wedge is an optical prism and works by refracting most of the light out of the optical path. In modern devices, around 95.4% of the light is deflected and 4.6% reaches the observer (e.g. the Baader Herschel Prism, see Baader 2025).

An optical prism is a section of accurately cut transparent material (usually glass) whose angles and plane faces reflect and refract light. The familiar triangular prism separates a beam of white light into its constituent wavelengths, or spectrum of colours (see illustration). Each apparent colour is refracted (bent) by a different amount. Shorter wavelengths (toward the violet) are bent most, while longer wavelengths (toward the red end) are bent least. Optical prisms are useful for identifying and working out the composition of materials that emit or absorb light.



Prisms can also reverse light direction by internal reflection. The prism in a Herschel wedge is *trapezoidal* in cross section (see Math Monks 2025), with the surface facing the light working as an oblique mirror to reflect a small part of the light entering the wedge at 90 degrees into the eyepiece (see illustration). The trapezoidal form refracts the rest of the collected light from the telescope's objective off at an angle.

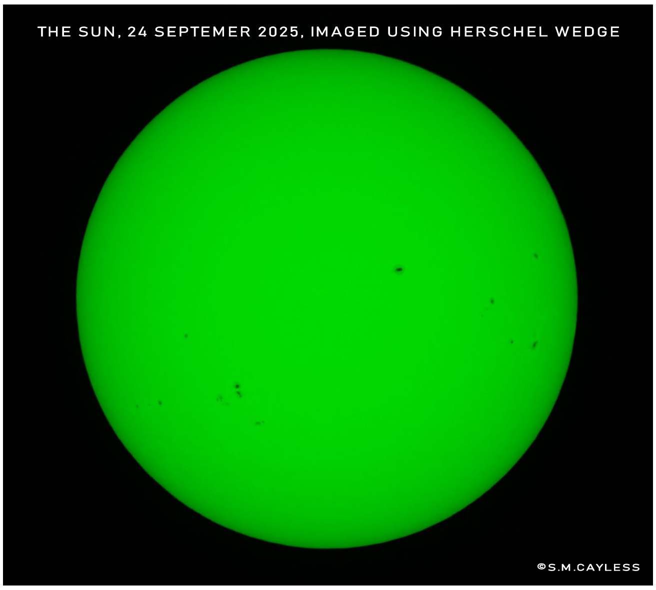


In a modern Herschel prism such as the Baader Mark II (Baader 2025), the bright light and energy of the sun are dissipated, preventing equipment overheat and unwanted thermal effects on the image. A multi-layered perforated steel light trap (heat cage) and a ceramic end plate (to absorb radiant heat) safely deals with heat and light escape from the housing, thus avoiding risk of damage to equipment and helping with image stability. The heat cage connects to the prism housing at four points, meaning that there is practically no heat transfer to the actual prism. The ceramic plate also doubles as a viewing screen, and the sun can thus be placed at the centre of the field of view.

The protective anti-reflective coating of the prism cuts light-scatter and blocks dangerous ultraviolet and infrared light. This means that high-contrast views of details such as sunspots and surface granulation can be observed. Inbuilt filters not only safeguard the observer from exposure to unfiltered light (neutral density (ND) filter), but allow various solar features to be observed more clearly (the narrow-band Solar Continuum filter maximises contrast and minimises air turbulence). These can be removed for astrophotography and replaced by others. Other ND and polarising filters can be installed in the rotatable filter holder for astrophotography and viewing in different lights.

The Herschel wedge can be attached directly to a telescope's focuser (visual observing) or connected to a suitable camera (astrophotography) using an adapter. In the photographic arrangement shown here, a Baader Mark II Herschel wedge is attached directly to the focuser of a William Optics GT102 refracting telescope (102mm lens), and a Fuji XT30 camera is attached to the clamp of the Herschel wedge. The image can be centred and focused using the ceramic plate as a viewing screen.

The solar continuum filter gives the resultant image the green colour seen in the image here, which shows the very spotty Sun of 24 September 2025.



*A reflecting telescope is dangerous to use with a Herschel wedge as its optical path is inadequately restricted and misuse can result in blinding. Light is focused to a plane in front of the telescope by a reflector's primary mirror. Correction and redirection of this light by added lenses or reflective optics only move a small part of the focal plane to another area in the telescope, and most stays in free space.

References

Baader (2025) *Baader 2" Cool-Ceramic Safety Herschel prism Mark II, Visual and photographic Instruction Manual*. https://www.baader-planetarium.com/en/downloads/dl/file/id/1864/instruction-manual-and-application-examples.pdf.

Cannon W.F. (1961) John Herschel and the Idea of Science. *Journal of the History of Ideas Vol. 22, No. 2 (Apr. - Jun., 1961), pp. 215-239* (25 pages) https://www.jstor.org/stable/2707834.

Herschel, J.F.W. (1861) *Outlines of Astronomy, 4th Edition*. Blanchard & Lea, Philadelphia 1861. 573pp. https://books.google.co.uk/books?hl=en&lr=&id=VMwzxRtbU2IC&oi=fnd&pg=PR7&dq=john+herschel+shadow+of+the+telescope&ots=46SrvwEQTq&sig=gr5SMW_tQwpwoCVObUw615fiRE8&redir_esc=y#v=onepage&q&f=false.

Math Monks (2025) *Trapezoidal prism*. https://mathmonks.com/prism/trapezoidal-prism. Accessed 26 Sep 2025.

Rothermel, H. (1993) Images of the Sun: Warren De la Rue, George Biddell Airy and Celestial Photography. *The British Journal for the History of Science 26 (2) 137-169*. https://www.jstor.org/stable/4027095.

The Sharpless Catalogue of Emission Nebulae

By Alan Cayless FRS

Astronomers have always aimed to organise and classify objects in the night sky. The ancients of different civilisations organised the stars into constellations, each according to their own culture, and wondered at the movements of the planets and the structure of the Universe. For centuries the stars and planets, along with the Sun and the Moon and the occasional comet, were the only known celestial objects (with the possible inclusion of the Andromeda Galaxy), until the development of the telescope revealed a whole new universe of fainter and more distant objects not visible to the naked eye. Astronomers soon began to organise these new and interesting objects into lists and catalogues, with one of the earliest and perhaps most well-known being the Messier Catalogue of 110 galaxies, nebulae and star clusters. Other well-known lists such as the NGC and IC catalogues also contain a wide range of different types of object, with distant galaxies listed alongside nebulae and clusters within our own Galaxy.

While the Messier catalogue with its selection of bright objects makes a good starting point for general astronomical observing and imaging with a small telescope, other more specialist catalogues concentrate on specific types of more challenging objects. One of these, the Sharpless Catalogue of emission nebulae, has recently taken on a new significance with the development of narrowband imaging.

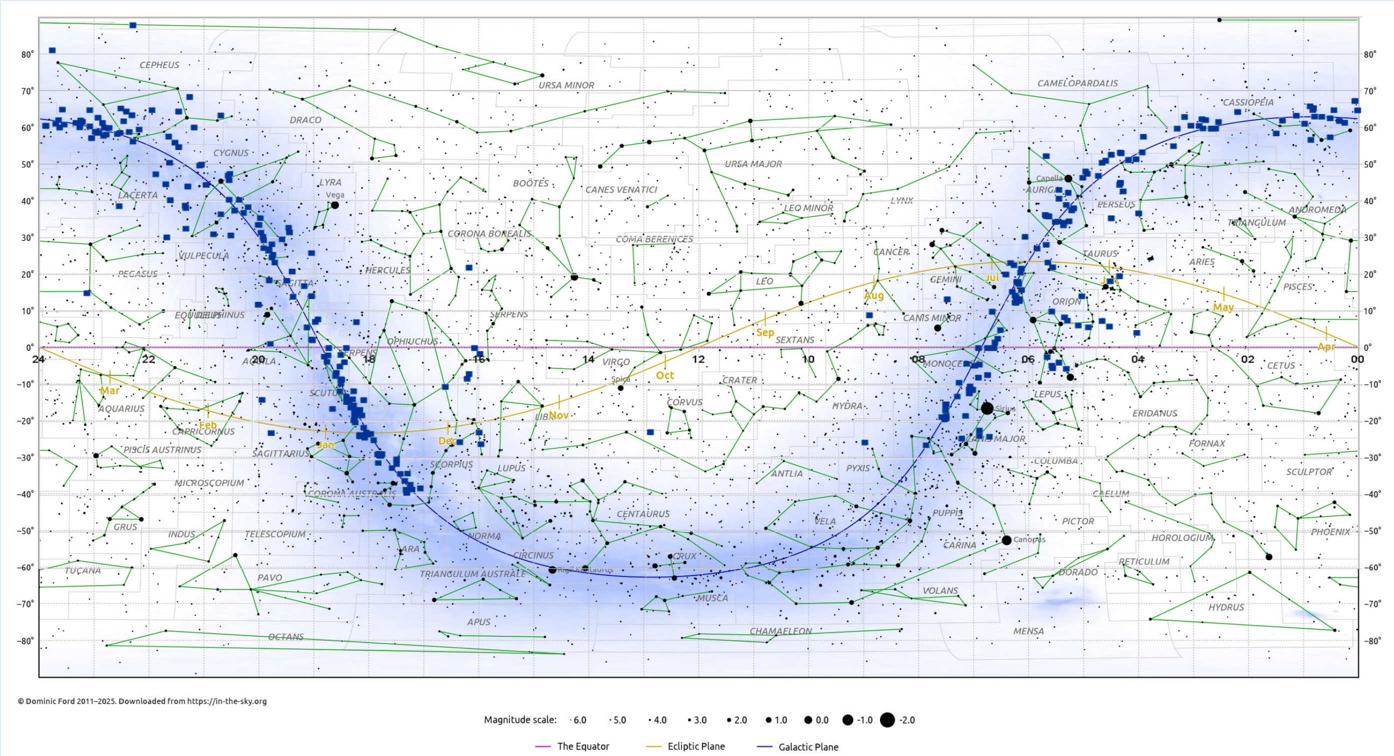
Stewart Sharpless (1926 – 2013) began his astronomy career at the age of 19, working as a graduate student at Yerkes Observatory (Van Horn & Pipher 2020). While there he helped to develop the Johnson-Morgan UBV photometric system, a system of Ultraviolet, Blue and Visual (yellow/green) filters which is still in use today for determining the spectral types of stars (Johnson & Morgan 1951, 1953). He also developed an interest in studying HII emission regions, which are often associated with young, hot O and B type stars. Sharpless realised that measuring the distances to these embedded stars gave a means of determining the distances to the HII regions themselves and, working with fellow student Donald Osterbrock (1924–2007), used this technique to map out two of the nearby spiral arms of the Milky Way Galaxy (Morgan, Sharpless & Osterbrock 1952).

Sharpless subsequently worked with Walter Baade and Rudolf Minkowski at the Mount Wilson and Palomar observatories before taking up a position at the U.S. Naval Observatory (USNO) in Flagstaff, Arizona, a few miles away from the more famous Lowell Observatory. There he continued in his interest in HII emission nebulae. In 1953 he published a catalogue of 142 HII regions – the first Sharpless Catalogue – and followed this up in 1959 with a more extensive second catalogue containing 313 objects (Sharpless 1959). Objects in this second catalogue are designated with SH2 (Sharpless 2) numbers.

HII regions are vast interstellar clouds of ionised atomic Hydrogen, anything up to hundreds of light years across. Being associated with star formation they are generally found in the plane of the Milky Way, and specifically in the spiral arms. When excited by radiation from nearby stars the atoms emit light of very specific wavelengths, predominantly the Hydrogen-alpha (Hα) line at 656.3 nm, giving these emission nebulae their characteristic deep red colour. The image below shows SH2-112, a typical HII emission nebula in Cygnus.

SH2-112 emission nebula in Cygnus. At a distance of approximately 5600 light years from Earth, SH2-112 is between 50 and 100 light years in diameter. The ionised atomic Hydrogen in the nebula is energised by the star BD +45 3216 (the bright star near the centre), causing the Hydrogen-alpha emissions that give the nebula its deep red colour. Image credit: Alan Cayless

From its position in the northern hemisphere, the USNO telescopes were able to observe objects north of Declination -27 degrees. The list of objects in the Sharpless-2 catalogue shows some interesting patterns, with objects between 0h and 4h Right Ascension, and between 21h and 24h, being at high declinations of up to +60 degrees, and those between RA 7h and RA 19h being predominantly below the celestial equator. There are very few SH2 objects between RA 8h and RA 17 h. These patterns all make sense when the distribution of SH2 objects is plotted on an all-sky map:



Distribution of SH2 objects. The blue squares show the positions of the 313 HII emission nebulae in the 1959 Sharpless 2 catalogue. The blue shading indicates the Milky Way with the blue line denoting the centreline of the galactic plane. Based on an original chart © Dominic Ford with overlay by Alan Cayless.

other listings, making the Sharpless catalogue a valuable resource for emission nebula hunters.

Stewart Sharpless died in 2013 but in recent years his catalogue has taken on a new relevance with the advent of narrowband imaging. Narrowband filters isolate spectral lines such as Hα, making imaging possible even from light-polluted urban locations by excluding background light and skyglow and only letting through the specific wavelengths emitted by the nebulae themselves. This makes the Sharpless objects ideal targets for narrowband imaging.

Because HII regions are associated with star formation they all lie within the plane of the Galaxy and therefore the majority of the SH2 objects appear close to the galactic centreline on the star chart. Only a few are at any distance from the centreline – these tend to be the more nearby objects with their apparent displacement from the galactic plane being simply a result of perspective.

There is some overlap between the Sharpless 2 catalogue and the other well-known catalogues. For example, SH2-162 (the Bubble Nebula in Cassiopeia) is listed in the New General Catalogue as NGC 7635, and SH2-224 is also the first and one of the most distinctive objects in the Messier catalogue – the Crab Nebula (M1) in Taurus. However, many of the SH2 objects do not appear as prominently in the

In December and January, the Sharpless objects best placed for observing will be those located between RA 4h and RA 7h. These include some familiar objects such as the Great Orion Nebula (SH2-281), the Running Man (SH2-279) and the Flame Nebula (SH2-277) and also some lesser-known targets such as SH2-261 (Lower's Nebula in Orion), SH2-240 (The Spaghetti Nebula in Taurus) and SH2-290 (a planetary nebula in Cancer). From March onwards we are into the gap between RA 8h and RA 17 h, but the Sharpless objects will be back as the skies start to darken again in late summer!

References

Morgan, W.W., Sharpless, S., & Osterbrock, D. (1952) Some features of galactic structure in the

neighborhood of the Sun. *The Astronomical Journal 57, 3–3*. https://doi.org/10.1086/106673.
Sharpless, S. (1959) A Catalogue of H II Regions. *Astrophysical Journal Supplement Series 41, pp 257-280*. https://ui.adsabs.harvard.edu/abs/1959ApJS....4..257S/abstract. doi:10.1086/190049.
Johnson, H.L., Morgan, W.W. (1951) On the Color-Magnitude Diagram of the Pleiades. *The Astrophysical Journal 114: 543*. doi:10.1086/145496.
Johnson, H.L., Morgan, W.W. (1953) Fundamental stellar photometry for standards of spectral type on the Revised System of the Yerkes Spectral Atlas. *The Astrophysical Journal 117: 313*. doi:10.1086/145697
Van Horn, H.M., Pipher, J.L. (2020) Stewart L. Sharpless (1926–2013). *Bulletin of the American Astronomical Society 52 (2)*. https://baas.aas.org/pub/2020i0326/release/1. doi:10.3847/25c2cfeb.b841062b.

Observatory Report to 31 August 2025

By Bert Mackenzie, Observatory Guide

The total number of visitors to the Observatory was 1356, a new record (last year 1276). Visitors came from all parts of the UK. There were also people from nine countries in Europe, eleven USA states, three in Canada, and the West Indies, Bermuda, South Africa, China, New Zealand, and Australia.

Nine adult groups included Swiss Rotary, Netherland Post Office, and Scottish Tourist Board. Eighteen youth groups such as Brownies, Guides, Scouts, Cubs and Squirrels also made up the numbers, along with pupils from Riverside School and students from Heriot Watt University.

We opened up for public viewing on two nights for Doors Open Days in September 2024 and for the Stirling Science Festival in October.

The Astronomical Society continues to carry out maintenance on the Observatory, keeping the 136 year old telescope in full working order, and permitting visitors to view the night sky and appreciate the Victorian engineering involved. We had the mirror re-silvered in May.

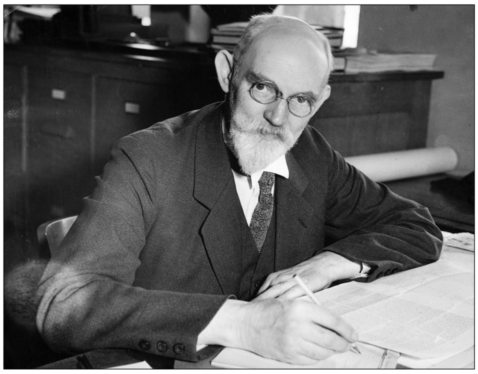
The **Old High School Observatory** was the gift in 1889 of Henry Campbell-Bannerman (1836-1908), Liberal MP for Stirling Burghs. Born in Glasgow as Henry Campbell, he was a son of Glasgow's Lord Provost, and was educated at Glasgow High School, Glasgow University and Trinity College, Cambridge. He took the name Bannerman in 1871 in line with the will of his uncle, from whom he inherited. He was knighted in 1895 and held the positions of Financial Secretary at the War Office, and Secretary of State for War, and then served as Prime Minister from 1905 to 1908. He was the first person to use the official title *Prime Minister*, and held strong views on subjects such as free trade, Irish Home Rule, and social reform. During his time in office, his government *inter alia* ruled that trade unions were not liable for damages during strikes, brought in free school meals, and instigated the modern Probation Service (Probation Act 1907). A statue of Sir Henry Campbell-Bannerman (erected 1913) stands on the Back Walk, Stirling.

Dutch Astronomers 3

By Sandi Cayless

The third in a series on a selection of astronomers from the Netherlands, a small country that has produced a notable number of talented individuals that have made remarkable contributions to the science of astronomy. Part three of the series deals with contemporaries Willem de Sitter and Anton Pannekoek.

Willem de Sitter (1872-1934)



Willem de Sitter was born in 1872 in Sneek, in Friesland, where his father was a judge (van Berkel *et al.* 1999a). The family moved to Arnhem when his father became the presiding judge of the court there, and Willem attended grammar school, after which he went to Groningen University to study mathematics. There, he carried out experimental physics work at the astronomical laboratory of Jacobus C. Kapteyn (Anon 1934). At that time Kapteyn, in a collaboration with Scottish astronomer Sir David Gill, was measuring photographic plates from the Cape Observatory in South Africa, to chart the southern skies (Cayless 2025). While visiting Groningen, Gill invited the young de Sitter to Cape Town. The invitation was accepted, de Sitter switched his studies to astronomy and left for South Africa in August 1897.

At Cape Town, he and others worked on measuring Jupiter's four Galilean satellites, and he was the first to use electric light (as opposed to an oil lamp) in stellar photometry (de Sitter 1899). It was there that he also met his wife, Elanora Suermondt (Anon 1934). De Sitter was Jacobus Kapteyn's first PhD student, and at the end of 1899 he returned to Groningen to complete his Ph.D., which he did in 1901 (van der Kruit 2014). The title of his dissertation was: *Discussion of Heliometer Observations of Jupiter's Satellites* (Anon 1934). This work, and his expansion of it using new approaches and mathematical tools, led to improved estimations of the orbits of the Galilean satellites, correcting for the mutual gravitational influences on each other's orbits.

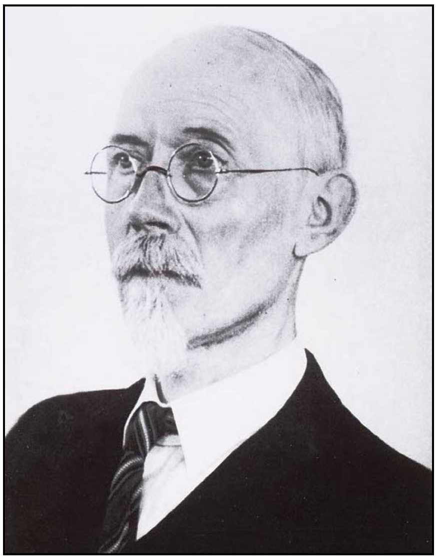
De Sitter was appointed to the Chair of Astronomy at Leiden University in 1908, his inaugural lecture being: *The New Methods in Celestial Mechanics*. He was later (1919) also appointed as director of Leiden Observatory, where he completely reorganised the study of astronomy into three disciplines: fundamental astrometry; astrophysics; and, theoretical astronomy, moving the work there forward to place Leiden as a world-leading astronomical centre (Anon 1934, Oort 1935, Blaauw 2004, O'Connor & Robertson 2009). Despite pressing administrative duties and serious illness, his scientific work was not compromised. He had worked for some years on the general structure of the galactic system, but began to concentrate on celestial mechanics. Much of his life had been and was spent investigating the system of Jovian satellites, and he published around 30 key papers (e.g. De Sitter 1906, 1910, 1915a, 1916a,b, 1918, 1919a, 1919b, 1925, 1929, 1931). He was still working on tables of the motions of the satellites when he died in 1934 (Oort 1935).

Alongside this major work, he carried out other significant investigations (O'Connor & Robertson 2009). In 1913 he formulated a case based on double star system observations to prove that the velocity of light was not dependent on the velocity of the source (De Sitter 1913); in 1915 he published a first paper on improving Simon Newcomb's values for the fundamental constants of astronomy re the Earth, with a second (in 1927) on the constants associated with lunar astronomy; in 1916, in correspondence with mathematician Paul Ehrenfest, they suggested that a 4-dimensional space-time would fit cosmological models based on general relativity (Longair 2004); in 1916-17 he published several papers on the cosmological effects of Einstein's general theory of relativity (De Sitter 1916c,d; 1917a,b,c,d), finding solutions to Einstein's field equations where matter did not exist (a De Sitter Universe). This work led to Arthur Eddington's eclipse-observing 1919 expedition to Principe, to measure the deflection of light by the Sun's gravitational field (Dyson *et al. 1920*). De Sitter, as opposed to Einstein, held that relativity implied an expanding universe; Einstein only accepted his theoretical results later, when they were verified by observation (Einstein had introduced the cosmological constant in 1917 to solve the problem of why the universe did not collapse under gravitational attraction).

De Sitter was the first to provide a cosmological model of an expanding universe and in 1932, he and Einstein jointly published a paper based on De Sitter's solution of Einstein's field equation (Einstein & de Sitter 1932) proposing the Einstein-de Sitter model (van der Kruit 2014). It gave a simple solution for the field equations of general relativity for an expanding universe, and included the argument that there might be large amounts of undetected matter that did not emit light, i.e. *dark matter*, which has now been detected by observing its gravitational effects, although its nature is still a mystery (O'Connor & Robertson 2009).

De Sitter, often unwell, died suddenly of pneumonia in November 1934 at the age of 62 (Blaauw 2004). During his relatively short life, he received many honours for his remarkable contributions to astronomy. These included the James Craig Watson Medal (1929), the Bruce Medal of the Astronomical Society of the Pacific (1931), the Gold Medal of the Royal Astronomical Society (1931) and the Prix Jules Janssen of the Société Astronomique de France (1934). He was also president of the International Astronomical Union from 1925 to 1928. As well as the De Sitter universe and Einstein-de Sitter universe, De Sitter space, anti-De Sitter space, De Sitter invariant special relativity, the De Sitter double star experiment, De Sitter precession and the De Sitter–Schwarzschild metric all bear his name. The crater De Sitter on the Moon was named for him, as was asteroid 1686 De Sitter (MPC 2025a).

Anton Pannekoek (1873-1960)



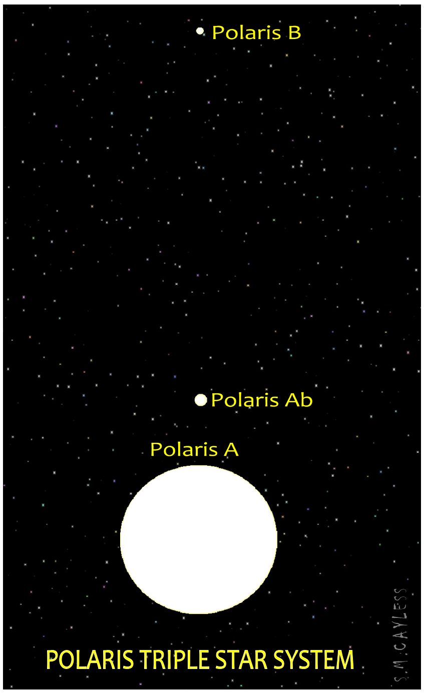
Anton Pannekoek was born in 1873 in Vaassen, Gelderland province, into the rural middle class. He was the younger son of Johannes Pannekoek, the manager of a metal foundry, and Wilhelmina Dorothea Beins, a midwife, and had a brother and two sisters (Anon 2025; van Berkel *et al.* 1999b; van den Heuvel 2019; Zanstra 1960). He attended the Hoogere Burger School (HBS) in Appeldoorn, where the curriculum included astronomy, the result of the Dutch colonial empire's need for a large merchant fleet. A fast learner, Pannekoek completed his schooling two years earlier than most, at 15, and left with an abiding interest in astronomy and biology (van den Heuvel 2019). At twelve years old he had used star charts from his elder brother's schoolbook and a German atlas to study Gemini, and seeing an extra star, deduced it was a planet (it was Saturn). He learned more astronomy from his physics teacher, Dr J.M. Smit, who was later fired for his socialist views. Pannekoek's diaries, begun at age 15, consisted of astronomical observations and biology notes. Two observations in particular involved a gap in the Milky Way between the stars alpha (α) and gamma (γ) Cygni, and an oval island of light he saw between beta (β) and gamma (γ) Cygni. The Milky Way remained a fascination and he was later to apply much of his time to resolving its structure.

Pannekoek had planned to teach as a career, but his teachers persuaded his parents to send him to university, despite his school certificate being inadequate (van den Heuvel 2019). He spent three years studying the fluent Latin and Greek required for entrance and in studying astronomy and biology, using the second-hand books he had begun to collect at the prompting of his teacher, Smit. Using an observation guide for amateurs by German astronomer F.W Argelander, he taught himself to precisely estimate a star's brightness by naked eye, by interpolating between its brightness and those of nearby stars of known luminosity. He documented his observations assiduously and at 17 years old, in the very cold December nights of 1890, he discovered that the brightness of α Ursae Minoris (Polaris) varied minutely over about 4 days. He continued to observe and document Polaris' variation until March 1891 and was still observing the star in 1900 when he was a professional astronomer. Finding that Campbell at Lick Observatory had reported in 1898 that the radial velocity of Polaris was variable, with a period of 3968 days, Pannekoek published *his* results as a footnote in a 1908 article about luminosities of stars of differing spectral types (Pannekoek 1906, p148).

Pannekoek entered Leiden University in 1891 and one year later obtained a Bachelor's degree in physics and mathematics and began publishing his research findings – his first (in more than 100 peer-reviewed scientific works) examined the light variations of Algol (β Persei), an eclipsing binary (Pannekoek 1892). He completed his graduate studies in 1895, majoring in astronomy, and spent two years as a geodetic engineer in triangulating the Netherlands. After this, the offer of an assistantship at Leiden University allowed him to begin his PhD, on the light variations of the eclipsing binary Algol, which he successfully defended in 1902 (van den Heuvel 2019). He married Johanna Maria Nassau Noordewier in 1903. He continued with his enduring interest in the Milky Way, publishing a succession of articles in 1898 on how to observe the Milky Way, using means such as photography, visual observations and combinations of realistic sketches and verbal descriptions, numerical tables, and isophotic diagrams (an isophote is a curve on an illuminated surface connecting points of equal brightness).

While working at Leiden Observatory, Pannekoek was converted to socialism, joining the Dutch Social Democratic Workers' Party (SDAP) in 1899, helping found its Leiden chapter, reading Karl Marx and actively teaching and talking on Marxism in the Netherlands and Germany. During his political years, he was increasingly frustrated with how astronomy was undertaken at Leiden, with individuals having to carry out their research with no help and no use of the latest instruments and methodology. His highly precise and painstaking observations accrued over long nights of work were never published, which made him depressed and unequal to his post, so much so that he decided to leave the Observatory and astronomy (van den Heuvel 2019). He had begun to apply for a teaching post in physics and mathematics when he was asked by Karl Kautsky of the German Social Democratic Party (SDP) to teach Marxism at a new Party School in Berlin (Baneke 2010). Pannekoek accepted and left Leiden in 1906, but in 1907 the German authorities barred non-nationals from working at the Party School. He thus ran a weekly column for socialist newspapers and lectured in Germany, Switzerland and Austria until 1910, when the Bremen SDP asked him to lecture at its party school, Bremen being a Free City where the German government had no authority.

Between 1906 and 1914, Pannekoek wrote widely on Marxism and socialism, but in 1909, he had a surprising visitor: Ejnar Hertzsprung of the Imperial Observatory, Potsdam (van den Heuvel 2019). Hertzsprung had come to tell him that from numerous photographic observations, he had validated Pannekoek's earlier discovery of the variability of Polaris. The star had a period of about four days, varying in brightness by 0.17 magnitudes, i.e. a maximum change of 16%. This suggests that Pannekoek had exceptional eyesight and very good technique to detect it in 1890/91. From his results, Hertzsprung concluded that Polaris was a Cepheid variable. Pannekoek accepted an invitation from Hertzsprung to visit Potsdam Observatory, as he was keen to renew his acquaintance with director Karl Schwarzschild. The latter had studied in München and as students, he and Pannekoek had regularly corresponded. The meetings with Hertzsprung and Schwarzschild revived his interest in astronomy, and shortly afterwards, he re-examined his original 1890-1900 observations of Polaris to confirm that the regular period of four days found by Hertzsprung was present. He published his findings years later (Pannekoek 1913). (Polaris is now known to be a triple star system.)



Pannekoek also returned to his obsession with the Milky Way and renewed an early interest in Babylonian astronomy. With his wife he daily tracked the motions of the sun, moon, planets and constellations to understand how Babylonian astrologers had made naked-eye observations (van den Heuvel 2019). This encouraged him to resume writing a book on popular astronomy (in German) which he had begun in 1903 in Leiden. He finished the book in 1914, a few months before the start of World War I, but it was never published in German: the government seized all the country's lead and copper, including the book's typesetting, for munitions. Pannekoek was in the Netherlands at the outbreak of war and, unable to return to Germany, he translated his book into Dutch and it was published as *De Wonderbouw der Wereld* (Pannekoek 1920a), to wide acclaim (Baneke 2010). It impressed both Jacobus Kapteyn and Willem de Sitter, to the extent that the latter offered Pannekoek an unpaid post at the state-funded Leiden University, which he accepted. Meanwhile Pannekoek took up teaching at various secondary schools whilst continuing his political work, until he obtained a post as lecturer of Mathematics and Astronomy in 1918 at Amsterdam University. His politics resulted in his nomination for vice-director of the Leiden Observatory in 1920 to be vetoed by state interests (director De Sitter had wished to appoint him and Ejnar Hertzsprung as vice-directors to improve the poor conditions at the Observatory; Kapteyn accepted the second post on a one day per week basis and held it until his death in 1922).

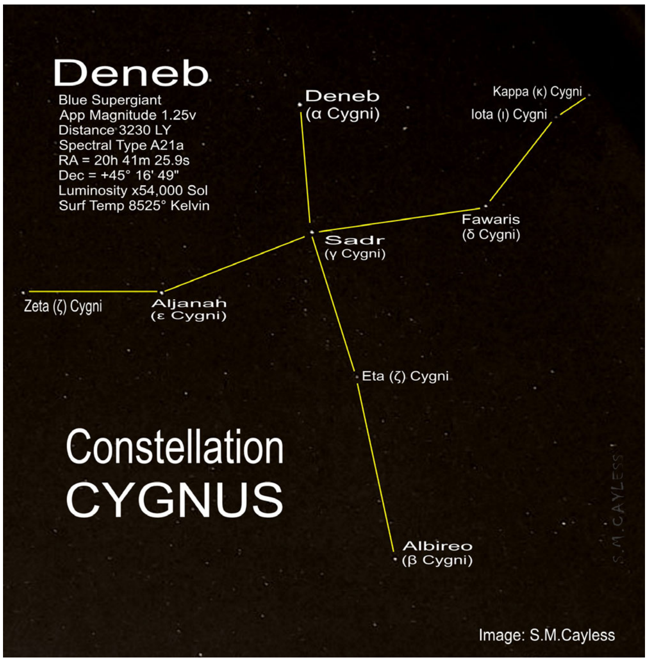
The city-funded University of Amsterdam was noted for its tolerance of 'red' lecturers and Pannekoek was made extraordinary professor in 1925 and full professor in 1932 (van den Heuvel 2019). In 1921, he founded the Astronomical Institute, with a strong grounding in astrophysics. Tai (2023) describes it as: "exemplary for a new type of institution that emerged in astronomy in the late nineteenth and early twentieth century due to the growing professional implementation of astrophotography". Instead of a telescope, Pannekoek equipped the Institute with instruments to measure photographic plates brought in from other observatories, and hired two 15-year-old human computers (*rekenaars*) to operate them and do calculations. In this way he could investigate the structure of the Milky Way photometrically, and he did so, using the plates to work out the Milky Way's surface brightness and to measure the absorption lines of stellar spectra (Tai 2019). Pannekoek published his drawings, isophotic diagrams and descriptions of the northern Milky Way (Pannekoek 1920b). He argued that the Milky Way was an optical illusion created by the brain from signals received by the human eye when hit by the light of myriad stars, yet he still considered it valuable to accurately represent it visually, to show its overall distribution of stars and allow that distribution to be followed over time.

Pannekoek knew that capturing the form of the Milky Way photographically was very difficult because its make-up of countless faint stars could not allow its large-scale structure to be determined (Pannekoek 1961); in the faint areas, the galactic light was concentrated into individual stars, while in dense areas, the coalescence produced an inflated and overexposed effect (Pannekoek & Koelbloed 1949). His answer at first was to use his own linked to others' drawings and diagrams made via naked-eye observations to provide a composite, but realising that the representations were subjective, he filtered out observer variation by combining the drawings and calculating the average surface brightness for each part of the Milky Way. This resulted in what he termed the 'mean subjective image', represented by numerical tables and isophotic diagrams (Tai 2019, 2023). These were successful, but, still seeking a photographic method of imaging the Milky Way, he chose to use *extrafocal* photometry, in which photographic plates are exposed out of focus. The light of individual stars are thus not concentrated as sharp points of light but diffused into small circles, the overlapping circles giving the illusion of Milky Way clouds (Pannekoek 1923). More than a hundred plates taken at various observatories over different sites

were needed to portray the full Milky Way, and for the northern hemisphere, these were taken in line with Pannekoek's directions by Max Wolf in Heidelberg, Germany between 1921 and 1928. For the southern hemisphere, plates by Voute in Lembang (1933 to 1939) and by Paraskevopoulous in Maselspoort, S. Africa, in 1942 and 1946 were taken. Several batches were needed as many plates turned out to be flawed when checked in Amsterdam (Pannekoek & Koelbloed 1949, Tai 2023). Every plate had to be measured precisely with a microphotometer to quantify the dark areas on given parts of the plate. Calibration was done by comparing these with measurements from parts of other plates where specific areas overlapped. This gruelling work was done by *rekenaar* David Koelbloed. The calibrated data were duplicated onto glass slides and projected onto big sheets of paper, thus combining the numbers in one diagram. Pannekoek then drew contours on the sheets to define the shape of Milky Way clouds. From the sheets, he produced numerical tables and isophotic diagrams to quantify the surface brightness of the Milky Way, and made drawings to show how the photographic Milky Way would look as seen by the human eye.

Van der Kruit (2024) compared Pannekoek's painstaking photographic work with the much later in-depth photographic surface photometry of the southern Milky Way by the group from the Astronomical Institute of the University of Bochum (see Hoffmann *et al*. 1998) and to the near whole-sky mapping by Pioneer 10 from beyond the asteroid belt (see Matsuoka *et al.* 2011), and concluded that Pannekoek's visual and photographic maps were remarkably accurate. His work on the appearance of the Milky Way linked directly to his research on galactic structure and he adapted Kapteyn's statistical methods to study individual star clusters; his most important was measuring the distance to the star clusters leading to the Milky Way clouds in Cygnus and Aquila. He worked out that these were about 40000-60000 parsecs from the sun, more distant than generally believed to be the diameter of the galactic system itself and early support for Shapley's expanded galaxy theory (Tai 2017).

Pannekoek pushed the Astronomical Institute further, and began a programme on the astrophysics of stellar atmospheres, whereby he aimed to develop Meghnad Saha's ionisation formula and uncover the physical conditions and processes in the outer layers of stars, using spectroscopy (Tai 2021). A key deduction was that the narrow spectral lines in c-type stars that Antonia Maury discovered were probably caused by lower pressure in the stars' atmospheres. Specialised instruments were used to accurately measure the photographic spectra of stars and calibrate the results. The latter required much time and painstaking effort and was mostly carried out by human computers, not necessarily trained in astronomy. Even so, the number of observatories generating more photographic spectra than they could use resulted in a surplus of plates, and led to an international collaboration of astronomical institutions, of which Amsterdam was one. Pannekoek also borrowed plates from other observatories, travelled on eclipse expeditions to record the spectra of the solar corona, and asked for custom-made plates from observatories that had the observation time. The Dominion Astrophysical Observatory (DAO) in Victoria, BC, Canada, provided most of the customised plates. Such distance collaboration was problematical, and Pannekoek was invited to the DAO to make his own plates. He spent six months there, taking about 50 spectrographs. Using the combined collection, he, with his students, published catalogues of the wavelength and strength of every single spectral line in numerous photographic spectra. This often meant measuring over a thousand lines in fine detail, but he considered that this level of precision was Amsterdam's unique strength. The physical properties of the outer layers of stars and the processes occurring within could be determined by examining the presence, strength and width of certain lines, and by comparing observed spectra with the output of complex theoretical stellar models (Pannekoek 1931, 1935, 1950). Pannekoek's theoretical models for stellar atmospheres aimed to replicate an entire stellar spectrum, but no one model was totally satisfactory because he had underestimated the impact of negative hydrogen ions as a cause of optical opacity, as Rupert Wildt was to show in 1935 (Tai 2021; Wildt 1939).



Nevertheless, he constructed the growth curve of Deneb in 1931, the first for a star other than the sun, took part in expeditions to observe solar eclipses in Sumatra and Lapland and wrote a book, *A History of Astronomy* (Pannekoek 1961), that is counted a standard reference. His untiring work in this field led him to be regarded as the founder of astrophysics as a separate discipline in the Netherlands (Tai 2021).

Anton Pannekoek became a member of the Royal Netherlands Academy of Arts and Sciences in 1925 (Anon 2025) and his researches earned him an honorary degree from Harvard University in 1936 and the Gold Medal of the Royal Astronomical Society in 1951 (Anon 2025, van den Heuvel 2019). The crater Pannekoek on the Moon and the asteroid 2378 Pannekoek (MPC 2025b) are named for him. The Institute that he founded at the University of Amsterdam was named after him in 1982, and is now the Anton Pannekoek Institute for Astronomy.

References

Anon (1934) In memoriam Willem de Sitter, in: *KNAW, Proc. 37, Amsterdam, 1934, pp. 734-737.* https://dwc.knaw.nl/DL/levensberichten/PE00003004.pdf (in Dutch).
Anon (2025) Anton Pannekoek. *Digitaal Wetenschapshistorich Centrum, KNAW* (Royal

Netherlands Academy of Arts and Sciences), https://dwc.knaw.nl/?pagina=0&s=Pannekoek&gender=all&type=persons&personen.
Baneke, D.M. (2010) Teach and travel: Leiden Observatory and the renaissance of Dutch astronomy in the Interwar years. *J. for the History of Astronomy 41 (2) 167-198*. https://dspace.library.uu.nl/handle/1874/379806.
Baneke, D. (2019) *Pannekoek's One Revolution: Anton Pannekoek and the Modernization of the Dutch Astronomical Community*. In: Tai, C., van der Steen, B., & van Dongen, J. (eds.), *Anton Pannekoek: Ways of Viewing Science and Society*, Amsterdam University Press (2019), pp. 87–108. https://doi.org/10.2307/j.ctvp7d57c.7.
Blaauw, A. (2004) My Cruise Through the World of Astronomy. *Ann. Rev. Astron. & Astrophysics 42, 1-37*. https://www.annualreviews.org/content/journals/10.1146/annurev.astro.42.053102.134020.
Cayless, S. (2025) Dutch Astronomers 2. *The Jeety Starn 8, 3-8*.
De Sitter, W. (1899) On the use of the electric light for the artificial star of a Zöllner photometer. *Monthly Notices of the Royal Astronomical Society* 59 (6) 341–345, https://doi.org/10.1093/mnras/59.6.341.]
De Sitter, W. (1906) On the orbital planes of Jupiter's satellites, in: *KNAW, Proc. 8 (II) 1905-1906, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1906, pp. 767-780*. https://dwc.knaw.nl/DL/publications/PU00013914.pdf.
De Sitter, W. (1910) On the formulæ for the comparison of observed phenomena of Jupiter's satellites with theory. *Monthly Notices of the Royal Astronomical Society 71 (1) 85–101*, https://doi.org/10.1093/mnras/71.1.85.
De Sitter, W. (1911) On the bearing of the Principle of Relativity on gravitational astronomy, *Monthly Notices of the Royal Astronomical Society 71 (5) 388–415*, https://doi.org/10.1093/mnras/71.5.388.
De Sitter, W. (1913) A proof of the constancy of the velocity of light. *Proc. of the Royal Netherlands Academy of Arts and Sciences 15 (II) 1297-1298*. https://en.wikisource.org/wiki/A_proof_of_the_constancy_of_the_velocity_of_light.
De Sitter, W. (1915a) On the figure of the planet Jupiter, in: *KNAW, Proc. 17 (III) 1914-1915, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1915, pp. 1047-1050*. https://dwc.knaw.nl/DL/publications/PU00012740.pdf.
De Sitter, W. (1915b) Proposal for a new method of determining the constant of aberration. *Monthly Notices of the Royal Astronomical Society 75 (6) 458-465*. https://doi.org/10.1093/mnras/75.6.458.
De Sitter, W. (1916a) On the orbital planes of Jupiter's satellites, as derived from measurements made at Berlin, in: *KNAW, Proc. 18 (II) 1916, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1916, pp. 1012-1017*. https://dwc.knaw.nl/DL/publications/PU00012565.pdf.
De Sitter, W. (1916b) The longitudes of Jupiter's satellites, derived from photographic plates taken at the Cape Observatory in the year 1913. *Monthly Notices of the Royal Astronomical Society 76 (6) 448–469*, https://doi.org/10.1093/mnras/76.6.448.
De Sitter, W. (1916c) On Einstein's theory of gravitation and its astronomical consequences. First Paper. *Monthly Notices of the Royal Astronomical Society 76 (9) 699–728*, https://doi.org/10.1093/mnras/76.9.699.
De Sitter, W. (1916d) On Einstein's theory of gravitation and its astronomical consequences. Second Paper. *Monthly Notices of the Royal Astronomical Society 77 (2) 155–184*, https://doi.org/10.1093/mnras/77.2.155.
De Sitter, W. (1917a) Planetary motion and the motion of the moon according to Einstein's theory, in: *KNAW, Proc. 19 (I) 1917, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1917, pp. 367-381*. https://dwc.knaw.nl/DL/publications/PU00012364.pdf.
De Sitter, W. (1917b) On the relativity of rotation in Einstein's theory, in: *KNAW, Proc. 19 (I) 1917, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1917, pp. 527-532*. https://dwc.knaw.nl/DL/publications/PU00012379.pdf.
De Sitter, W. (1917c) On Einstein's theory of gravitation and its astronomical consequences. Third Paper. *Monthly Notices of the Royal Astronomical Society 78 (1) 3–28*, https://doi.org/10.1093/mnras/78.1.3.
De Sitter, W. (1917d) On the curvature of space. *Proc. Akad. Amsterdam. 1917 Jun 30, vol. Xx, 1217-1225*. (Original in Dutch, reprinted in English in: *KNAW, Proc. 20 (I) 229-243, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1918*. https://dwc.knaw.nl/DL/publications/PU00012216.pdf
De Sitter, W. (1918) Outlines of a new theory of Jupiter's satellites, in: *KNAW, Proceedings, 20 (II) 1918, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1918, pp. 1289-1308*. https://dwc.knaw.nl/DL/publications/PU00012321.pdf /https://dwc.knaw.nl/DL/publications/PU00012322.pdf.
De Sitter, W. (1919a) Theory of Jupiter's satellites. I. The intermediary orbit, in: *KNAW, Proc. 21 II, 1919,*

Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1919, pp. 1156-1163. https://dwc.knaw.nl/DL/publications/PU00012173.pdf
De Sitter, W. (1919b) Theory of Jupiter's satellites. II. The variations, in: *KNAW, Proc. 22 I, 1919-1920, Royal Netherlands Academy of Arts and Sciences, Amsterdam, 1919, pp. 236-241.* https://dwc.knaw.nl/DL/publications/PU00011958.pdf.
De Sitter, W. (1925) Outlines of a new mathematical theory of Jupiter's satellites. *Annalen van de Sterrewacht te Leiden 12, A1-A55.* https://ui.adsabs.harvard.edu/abs/1925AnLei..12A...1D/abstract.
De Sitter, W. (1929) Discussion of old eclipses of Jupiter's satellites. *Annalen van de Sterrewacht te Leiden 16, pp. D1-D80*. https://adsabs.harvard.edu/full/1929AnLei..16D...1D.
De Sitter, W. (1931) Jupiter's Galilean satellites. (George Darwin Lecture, delivered by Professor W. de Sitter, Assoc. R.A.S., on 1931 May 8). *Monthly Notices of the Royal Astronomical Society 91 (7) 706–738*. https://doi.org/10.1093/mnras/91.7.706.
De Sitter, W. (1933) On the expanding universe and the time-scale, *Monthly Notices of the Royal Astronomical Society 93 (8) 628–634*, https://doi.org/10.1093/mnras/93.8.628.
Dyson, F.W., Eddington, A.S., Davidson, C. (1920). A determination of the deflection of light by the Sun's gravitational field, from observations made at the total eclipse of May 29, 1919. *Phil. Trans. of the Royal Society A: Mathematical, Physical and Engineering Sciences 220 (571–581) 291–333.* https://ui.adsabs.harvard.edu/abs/1920RSPTA.220..291D/abstract.
Einstein, A. and de Sitter, W. (1932) On the relation between the expansion and the mean density of the universe. *Proceedings of the National Academy of Sciences of the United States of America, 18, 213-214.* https://doi.org/10.1073/pnas.18.3.213.
Hertzsprung, E. (1911) Nachweis der Veranderlichkeit von *a* Ursae minoris. *Astronomische Nachrichten 189(6): 89-104.* https://ui.adsabs.harvard.edu/abs/1911AN....189...89H/abstract.
Hoffmann, B., Tappert, C., Schlosser, W., Schmidt-Kaler, Th., *et al.* (1998) Photographic surface photometry of the Southern Milky Way VIII. High-resolution U, V and R surface photometries of the Southern Milky Way. *Astron. Astrophys. Suppl. Ser. 128, 417-422.* https://aas.aanda.org/articles/aas/pdf/1998/06/ds1394.pdf.
Longair, M.S. (2004) *A Brief History of Cosmology*. In: Carnegie Observatories Astrophysics Series, Vol. 2: Measuring and Modeling the Universe, 2004 ed. W. L. Freedman, pp1-18. Cambridge Univ. Press. https://sites.astro.caltech.edu/~george/ay21/readings/longair.pdf.
MPC (2025a) (1686) De Sitter = 1929 RK1 = 1933 GF. IAU Minor Planet Center [Ref: M.P. Circ. 2822] https://www.minorplanetcenter.net/db_search/show_object?object_id=1686.
MPC (2025b) (2378) Pannekoek = 1918 RE = 1935 CY, IAU Minor Planet Center. [Ref: M.P. Circ. 18135] https://www.minorplanetcenter.net/db_search/show_object?object_id=2378.
Matsuoka, Y., Ienaka, N., Kawara, K. and Oyabu, S. (2011) Cosmic optical background: The view from Pioneer 10/11. *The Astrophysical J. 736 (2) 119-132.* https://ui.adsabs.harvard.edu/abs/2011ApJ...736..119M/abstract.
O'Connor, J.J. and Robertson, E.F. (2009) *Willem de Sitter*. MacTutor History of Mathematics Archive, University of St Andrews. https://mathshistory.st-andrews.ac.uk/Biographies/Sitter/.
Oort, J.H. (1935) *Obituary: Willem de Sitter. The Observatory 58, 22-27.* https://adsabs.harvard.edu/full/1935Obs....58...22O.
Pannekoek, A. (1892) Minima von Algol am 2. und 5.Nov.1891. *Astronomische Nachrichten 130 (28) 436.* https://ui.adsabs.harvard.edu/abs/1892AN....130..435P/abstract.
Pannekoek, A. (1906) The luminosity of stars of different types of spectrum. *Proceedings of the Section of Sciences, Koninklijke Akademie van Wetenschappen te Amsterdam 9 (1) 134-148.* https://dwc.knaw.nl/DL/publications/PU00013731.pdf
Pannekoek, A. (1913) The variability of the Pole-Star. *Proceedings of the Section of Sciences, Koninklijke Akademie van Wetenschappen te Amsterdam 15 (2) 1192-1199.* https://dwc.knaw.nl/DL/publications/PU00013052.pdf.
Pannekoek, A. (1920a) *De Wonderbouw Der Wereld*. S. L. Van Looy, Amsterdam, 1920. https://www.gutenberg.org/files/59744/59744-h/59744-h.htm.
Pannekoek, A. (1920b) *Die Nördliche Milchstrasse*, Annalen van de Sterrewacht te Leiden, 11:3 (Haarlem: Joh. Enschedé en Zonen, 1920), 15–16. Cited by Tai, (2023).
Pannekoek, A. (1923) Photographic photometry of the Milky Way and the colour of the Scutum Cloud. *Bulletin of the Astronomical Institutes of the Netherlands 2 (44) 19–24.* https://ui.adsabs.harvard.edu/abs/1923BAN.....2...19P/abstract.
Pannekoek, A. (1931) The influence of collisions on the formation of the Fraunhofer lines. *Proceedings*

of the Section of Sciences, Koninklijke Akademie van Wetenschappen Te Amsterdam 34 (6): 755-763. https://archive.org/details/proceedings-knaw-series-b_1931_34_6.
Pannekoek, A. (1935) The theoretical intensities of absorption lines in stellar spectra. *Publications of the Astronomical Institute of the University of Amsterdam 4, pp4-74.* https://adsabs.harvard.edu/full/1935PUAms...4....4P.
Pannekoek, A. (1950) Line intensities in spectra of advanced type. *Publications of the Dominion Astrophysical Observatory VIII (5) 141-223.* https://adsabs.harvard.edu/full/1946PDAO....8..141P.
Pannekoek, A. (1961) *A History of Astronomy*. New York: Interscience. 521pp. https://archive.org/details/a-history-of-astronomy-anton-pannekoek_202207.
Pannekoek, A. and de Sitter, W. (1919a) The distance of the Milky Way. *Monthly Notices of the Royal Astronomical Society 79 (7) 500–507.* https://doi.org/10.1093/mnras/79.7.500.
Pannekoek, A. and de Sitter, W. (1919b) On the distribution of the stars of the 11th magnitude, *Monthly Notices of the Royal Astronomical Society 79 (5) 333–343*, https://doi.org/10.1093/mnras/79.5.333.
Pannekoek, A. and Koelbloed, D. (1949) *Photographic Photometry of the Southern Milky Way*. Publications of the Astronomical Institute of the University of Amsterdam 9 (Amsterdam: Stadsdrukkerij, 1949), 50pp. https://articles.adsabs.harvard.edu/pdf/1949PUAms...9....1P.
Tai, C. (2017) Left radicalism and the Milky Way: Connecting the scientific and socialist virtues of Anton Pannekoek. *Studies in the Natural Sciences, 47 (2) 200-254.* https://works.hcommons.org/records/dx42h-aqd30.
Tai, C. (2019) *The Milky Way as optical phenomenon: perception and photography in the drawings of Anton Pannekoek*. In Tai, Chaokang; van der Streen, Bart; van Dongen, Jeroen (eds.). Anton Pannekoek: Ways of Viewing Science and Society. Amsterdam: Amsterdam University Press. pp. 219–247. https://pure.uva.nl/ws/files/47043080/1005802.pdf.
Tai, C. (2021) *Anton Pannekoek, Marxist astronomer: Photography, epistemic virtues, and political philosophy in early twentieth-century astronomy*. PhD Thesis, University of Amsterdam, 2021, Chap. 3. https://dare.uva.nl/search?identifier=ffd11908-9018-492c-8805-952387d964fc.
Tai, C. (2023) *Astrophotography and the Founding of the Astronomical Institute in Amsterdam*. Shells and Pebbles,https://www.shellsandpebbles.com/2023/09/11/astrophotography-and-the-founding-of-the-astronomical-institute-in-amsterdam/. Accessed 11 Sep 2025.
van Berkel, K., van Helden, A., and Palm, L. (Eds) (1999a) *A History of Science in The Netherlands. Survey, Themes and Reference, pp 558-560.* Leiden/Boston/Köln: Brill, 1999. https://dwc.knaw.nl/wp-content/berkelbio/48.desitter.pdf.
van Berkel, K., van Helden, A., and Palm, L. (Eds) (1999b) *A History of Science in The Netherlands. Survey, Themes and Reference, pp 552-555.* Leiden/Boston/Köln: Brill, 1999. https://dwc.knaw.nl/wp-content/berkelbio/46.pannekoek.pdf.
van den Heuvel, E.P.J. (2019) *Anton Pannekoek's astronomy in relation to his political activities, and the founding of the Astronomical Institute of the University of Amsterdam*. In: Tai, C., van der Steen, B., & van Dongen, J. (eds.), Anton Pannekoek: Ways of Viewing Science and Society, Amsterdam University Press (2019), pp. 25-50. https://www.jstor.org/stable/j.ctvp7d57c.4?seq=1.
van der Kruit, P.C. (2014) English Translation of *Kapteyn, zijn Leven en Werken*, 1928, biography of Kapteyn by his daughter Henrietta Herzsprung-Kapteyn. Preface (i). Available at: https://www.astro.rug.nl/JCKapteyn/.
van der Kruit, P.C. (2024) Pannekoek's galaxy. *J. Astronomical History and Heritage 27 (1) 135-199.* https://dds.sciengine.com/cfs/files/pdfs/view/1440-2807/C4A24E891EF4443D9DE77DAA8853EFE1.pdf.
Wildt, R. (1939) Negative ions of hydrogen and the opacity of stellar atmospheres. *Astrophysical Journal 90, 611-620.* https://ui.adsabs.harvard.edu/abs/1939ApJ....90..611W/abstract.
Zanstra, H. (1960) *Levensbericht A. Pannekoek*, in: Jaarboek, 1959-1960, Proc. Royal Netherlands Academy of Arts and Sciences (KNAW), Amsterdam, pp. 328-330. (In Dutch) https://dwc.knaw.nl/DL/levensberichten/PE00002227.pdf.

Image References

Willem de Sitter, 1930s, Author Unknown, Wide World Photos, University of Chicago Photographic Archive [apf6-04310], Hanna Holborn Gray Special Collections Research Center, Univ. Chicago Library.
Anton Pannekoek: Photo of Pannekoek before 1960, Unknown photographer; source: The Dutch labour movement until 1918, International Institute of Social History, Amsterdam. Public domain.
Polaris Triple System, Milky Way and Constellation Cygnus: © S.M. Cayless.

A Quote or Two...

Kelvin, Lord (1824-1907)
In science there is only physics; all the rest is stamp collecting.

Hoyle, Sir Fred (1915-2001)
Space isn't remote at all. It's only an hour's drive away if your car could go straight upwards.

There is a coherent plan in the universe, though I don't know what it's a plan for.

Herzen, Aleksandr Ivanovich (1812-1870)
Man and science are two concave mirrors continually reflecting each other...

Hoffer, Eric (1902-1983)
Our passionate preoccupation with the sky, the stars, and a God somewhere in outer space is a homing impulse. We are drawn back to where we came from.

Hubble, Edwin (1889-1953)
The history of astronomy is a history of receding horizons.

The explorations of space end on a note of uncertainty... we measure shadows... we search among ghostly errors of measurement.

The great spirals, with their enormous radial velocities and insensible proper motions, apparently lie outside our Solar system.

Huygens, Christiaan (1629-1695)
I do not believe everything very certainly, but everything very probably.

It is surrounded by a thin flat ring, inclined to the ecliptic, and nowhere touches the body of the planet. (In reference to Saturn)

We shall be less apt to admire what this World calls Great, shall nobly despise those Trifles the generality of Men set their Affections on, when we know that there are a multitude of such Earths inhabited and adorned as Well as our own.

Jeans, Sir James (1877-1946)
The universe begins to look more like a great thought than a machine.

Life exists in the universe only because the carbon atom possesses certain exceptional properties.

Put three grains of sand inside a vast cathedral, and the cathedral will be more closely packed with sand than space is with stars.

Kaku, Michio (1947-)
Chances are, when we meet intelligent life forms in outer space, they're going to be descended from predators.

Kepler, Johannes (1571-1630)
The treasures hidden in the heavens are so rich that the human mind shall never be lacking in fresh nourishment.

I demonstrate by means of philosophy that the earth is round, and is inhabited on all sides; that it is insignificantly small, and is borne through the stars.

I much prefer the sharpest criticism of a single intelligent man to the thoughtless approval of the masses.

Where there is matter there is geometry.

Without proper experiments I conclude nothing.

Truth is the daughter of time, and I feel no shame in being her midwife.

Oh telescope, instrument of much knowledge, more precious that any sceptre!

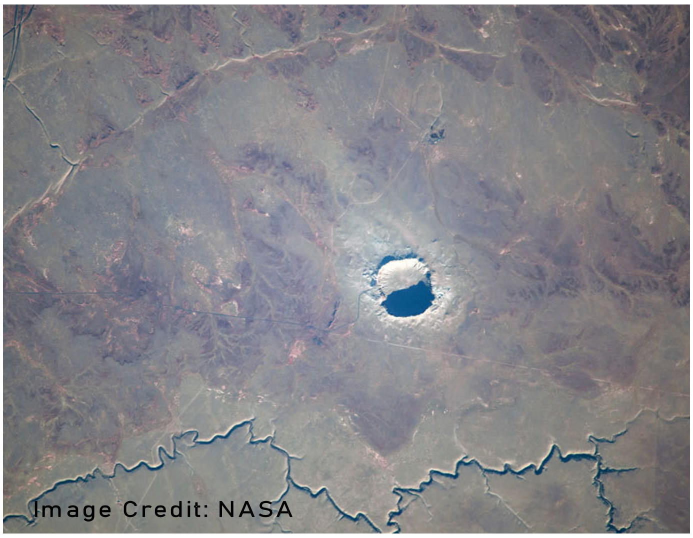
When ships set to sail the void between the stars have been built, there will step forth men to sail these ships.

And women, Mr Kepler!

Arizona's Meteor Crater

By Cairenn Farland

The Barringer Meteor Crater – History



The Barringer Meteor Crater in Arizona, USA, was the first crater on Earth recognised to have been caused by a meteor impact (Shoemaker 1987). The crater is usually called 'Meteor Crater' and it is also said to be the best-preserved impact site on Earth (Anon 2025). It can be found 57 miles (92 km) southeast from Flagstaff, near the city of Winslow, in Navajo County, and is located off Interstate 40. The temperature there is warmer than Flagstaff, and can be very hot. A visit to the meteor crater is like taking a step back in time to a moment that altered the Earth's landscape forever.

The crater now measures roughly 3,900 ft (1.19 km) diameter and 560 ft (171 m) deep, with a rim rising 148 ft (45 m) above the surrounding plains and a centre filled with 690–790 ft (210–241 m) of rubble. The crater shows how stunning the power of a meteorite impact is, even after all the time since the event. The crater was created fifty thousand years ago during the Pleistocene epoch, when a nickel-iron meteorite (meteoric iron) of about 160 ft (49 m) across collided with our planet. The impactive force was comparable to more than 2.5 million tons of TNT, and left behind a massive depression in what is now the Arizona desert – the local climate of the Colorado Plateau was much cooler and damper then and it was grassland (Roddy & Shoemaker 1995; Kring 2014).

It was first thought that the meteorite hit the ground at up to 45,000 miles per hour (20 km/s), but recent research indicates it was much slower, at 29,000 mph (12.8 km/s). About fifty percent of the original bulk of the meteorite is thought to have been vaporised during the plunge through the atmosphere, and the rest mostly vaporised on impact, leaving hardly any remains in the crater (Schaber 2005). Since it was formed, the crater's rim is thought to have dropped 50–65 ft (15–20 m) at the crest due to natural erosion, and the crater basin increased by about 100 ft (30 m) because of sedimentation from lake sediments and alluvium (Poelchau *et al*. 2009). Pieces of the meteorite are called Canyon Diablo meteorites, after the nearby Canyon Diablo. In 1968, Meteor Crater was designated a Natural Landmark by the USA Department of the Interior.

The speed of the impact caused powerful shock waves in the meteorite, the ground, and the atmosphere, with the shock waves sweeping across the plain destroying everything for a radius of several miles (Anon 2025). In the ground, the rising pressure caused the iron and rock to melt, with some vaporisation. Outside the melted region, a vast amount of rock fragmented and was ejected; this excavated a giant bowl-shaped hollow, and what is seen today is the preserved remains of that. During the process, over 175 million tons of limestone and sandstone were thrown upwards that blanketed the area around the crater for more than a mile, leaving huge blocks of limestone on the rim and hurling fragments of rock and iron-nickel (the Canyon Diablo meteorites), some large, quite a few

miles away. The extreme pressures in some of these converted small pockets of graphite into microscopic diamonds. The dense hot cloud that rose out of the crater contained globules of molten iron-nickel and rock, and a lot of debris; these came down gradually as fallout, onto the crater and the surrounding area, as did meteorite fragments that had detached during the meteor's ride through the atmosphere.

The crater was probably known to local Native Americans, though the first written record was in an 1871 report by a man, Franklin, a scout with General Custer, and the crater was called Franklin's Hole after him until local settlers gave it other names such as Coon Mountain, Meteor Mountain, or Coon Butte, perhaps thinking it was an extinct volcano, maybe part of the local Hopi Buttes volcanic field (Kring 2017).

The first scientific paper that included a geological description of Meteor Crater was given by the mineralogist Albert E. Foote in 1891, at a meeting of the American Association for the Advancement of Science (AAAS) in Washington DC. He concluded that a huge iron meteorite had entered the atmosphere and burst. This interested the chief geologist of the US Geological Survey, Grove Karl Gilbert, (who was in the audience), and he soon after put forward two theories: (1) the crater was created by the impact of a meteorite; or (2) it was the result of a volcanically-driven steam explosion. Gilbert calculated that the volume of the crater and the rim debris were about the same, so the mass of the supposed impactor was missing, and no magnetic irregularities could be detected; and Gilbert claimed that meteorite fragments found on the rim were chance or had been put there. He thus concluded that Meteor Crater was caused by volcanic means, and this view held for twenty years (Kring 2017). (Oddly, Gilbert would later be one of the first scientists to suggest that the Moon's craters were caused by impacts, not volcanoes.)

At first unaware of Gilbert's work, in 1902 Daniel M. Barringer, a mining engineer from Philadelphia, having heard about the crater and its meteoritic irons, became interested in the site as a likely mining source (Anon 2025). A visit to it convinced *him* that it had been caused by the impact of a huge iron meteorite, and he assumed that much of the mass was buried below the crater floor. He started the 'Standard Iron Company' and filed four mining claims with the Federal Government to obtain the patents and ownership of the two square miles in which the crater sat (Arizona was not yet the 48th state of the Union).

Barringer came to Meteor Crater in 1903 and spent the next 26 years trying to find the giant iron meteorite and extract the ore. He meticulously described the strata and the various materials he found, as well as the absence of eruptive rocks or other evidence of volcanic activity, and produced eight arguments against a volcanic steam explosion theory and three others against any other volcanic action (Kring 2017). But with his funds drying up, Barringer abandoned the exploration in 1929, and though he died that year, he did live to see his impact theory accepted (Anon 2025; Kring 2017).

However, though many experts in the geology field were still unsure of Barringer's theory, Eugene (Gene) Merle Shoemaker continued to study the crater (as his PhD thesis), and found coesite and stishovite, rare forms of silica that are only found where quartz-bearing rocks have been severely shocked by instantaneous overpressure, at the site: shocked quartz is not created by volcanic action (Shoemaker & Kieffer 1974; Shoemaker 1987). This increased the scientific awareness of Barringer's theory, as did the Apollo missions to the lunar surface. During the 1960s and 1970s, NASA astronauts prepared for the Apollo Moon missions by training in the crater and this sort of field training still occurs (CLSE 2025).

The Barringer family still owns the land, with the facilities at Meteor Crater leased to and run by a separate corporation, 'Meteor Crater Enterprises'. All the facilities at Meteor Crater were built, maintained, and staffed by the company. Both the family and the Enterprises owners consider the property as a public trust and contribute to science and education by donating grants, scholarships, and awards.

Visiting the Barringer Meteor Crater

When visitors arrive, they are greeted by the educational and interactive Discovery Center and Museum, which tells about impact science and the Crater history and contains hands-on exhibits and displays. There you can see and touch the huge

1,406 lb (639 kg) Holsinger Meteorite, the largest found at Meteor Crater, or investigate the science and history of meteorite impacts around the world, including the Siberian blast of 1908 (Anon 2025). Interactive exhibits and displays show how Meteor Crater was formed and what current research is doing to understand similar cosmic events. Other attractions include a movie theatre, where a 15-minute show on the history of the site is shown. An indoor Blast Zone moonbase-themed area is available for younger children to learn and play. The 4D Experience Room features the COLLISION! movie, which is a 15- minute journey into space led by a commander and first officer that begins when the audience takes its seats for an immersive flight down into the crater and then into space to intercept an asteroid on a collision course with Earth. As Meteor Crater has a long association with NASA and space exploration, and the astronauts preparing for the first moon landing trained there for what they could expect in space, the Apollo 11 test capsule is located outside as a reminder.

References

Anon (2025) *Meteor Crater: A Must-See Natural Wonder*. https://meteorcrater.com/.
CLSE (2025) *Training: Field Training and Research Program*. Center for Lunar Science and Exploration. https://www.lpi.usra.edu/exploration/training/.
Fairchild, H.L. (1907) Origin of meteor crater (Coon butte), Arizona. *Geol. Soc. America Bulletin 18 (1) 493–504*. https://zenodo.org/records/2336684.
Kring, D. (2014) *Guidebook to the Geology of Barringer Meteorite Crater, Arizona (a.k.a. Meteor Crater), 2nd edition*. Lunar and Planetary Institute. LPI Contribution No. 2040. https://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/.
Poelchau, M., Kenkmann, T. & Kring, D. (2009) Rim uplift and crater shape in Meteor Crater: Effects of target heterogeneities and trajectory obliquity. *Journal of Geophysical Research Planets 114 (E1) 14pp.* https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2008JE003235.
Roddy, D.J. & Shoemaker, E.M. (1995) Meteor Crater (Barringer Meteorite Crater), Arizona: Summary of Impact Conditions. *Meteoritics, vol. 30, no. 5, page 567.* https://articles.adsabs.harvard.edu/pdf/1995Metic..30Q.567R.
Schaber, G.G. (2005) *The U.S. Geological Survey, Branch of Astrogeology – A Chronology of Activities from Conception through the End of Project Apollo (1960–1973).* U.S. Geological Survey Open-File Report 2005-1190. https://pubs.usgs.gov/of/2005/1190/of2005-1190.pdf.
Shoemaker, E.M. & Kieffer S.W. (1974) *Guidebook to the Geology of Meteor Crater, Arizona*. Publication no. 17, Reprinted 1988, Center for Meteorite Studies, Arizona State University. https://www.lpi.usra.edu/publications/books/barringer_crater_guidebook/shoemaker-kieffer/Shoemaker_Kieffer_Guidebook.pdf.
Shoemaker, E.M. (1987) *Meteor Crater, Arizona*. Geological Society of America Centennial Field Guide – Rocky Mountain Section, 1987, pp399-404. http://arrowsmith410-598.asu.edu/2009/Lectures/Lecture16/i0-8137-5402-X-2-0-399Shoemaker.pdf.

Image Credits

Meteor Crater: NASA, ISS-038-E-67508, Nikon D3X S/N with 1000 mm lens, Mar 3 2014, Spacecraft altitude 221 nmi, Sun elevation 17 deg. (See: Kring, D. (2014)).
Iron-nickel meteorite: © S.M. Cayless
Polished slice of iron meteorite: © S.M. Cayless
Apollo Test Capsule: © C.R. Farland

TERMINOLOGY

Meteoroids are rocks in space that range in size from grains of dust to small asteroids.

Meteors are meteoroids that enter planetary atmospheres at high speeds and burn up as shooting stars or fireballs.

Meteorites are meteoroids that survive the passage through the atmosphere and hit ground.

City Lights

By Arryll Idrennis

A sky illumines city's light
And outcompetes mere mortals' night…
The incandescent stars, fresh born
In nurseries of stellar storm,
Send clouds of dust and light and ray
To turn dark night to dazzling day.

Galactic dusty swirls advance,
Streaming astral tresses dance –
A dying star's last relic breath,
Or supernova's cosmic death
Spread thin across the cosmic space
To fill its void with endless grace.

Nature's power draws dust-filled rays,
That merge in clouds of deeper haze;
To distil down and blur the sight
That glows above in breadth of light;
And flanking all, with lancing spark
More distant suns to pierce the dark.

But yet aglow, the stream of light
That blazes 'cross the city's night…
Those stars conceived in stellar storm
To swell and birth in brilliant form…
They now in clouds of stardust grow
To fire the night's pellucid glow.

T Coronae Borealis remains quiet

By Alan Cayless FRS

Over the last year we have reported on T Coronae Borealis, a recurrent nova that brightens significantly approximately every 80 years (Cayless, 2024). With the last event having taken place in early 1946, the next brightening has been eagerly anticipated. A recent prediction by Jean Schneider of the Paris Observatory suggested that the next eruption of T Coronae Borealis may occur on or around the 10th November 2025 (Schneider, 2024). This prediction was based on the timings of previous outbursts being a multiple of the 228-day orbital period of the T Coronae Borealis system.

However, as of late November no outburst has been seen so far. Based on the orbital period, the next possible date would be 25 June 2026. With a Right Ascension of 16:00, T Coronae Borealis is currently poorly placed for observing but we will continue to watch with interest over the coming months.

References

Cayless, A. (2024) Nova watch: impending drama in Corona Borealis, The Jeety Starn, 4, Stirling Astronomical Society. https://www.stirlingastronomicalsociety.org.uk/resources/028-jeety-starn-sep-2024.pdf.

Schneider, J (2024) When will the Next T CrB Eruption Occur?, American Astronomical Society, https://iopscience.iop.org/article/10.3847/2515-5172/ad8bba/ampdf.

Interesting Asteroids (6)

By Sandi Cayless

The fourth of an occasional series on asteroids, here we deal with a binary system, the near-Earth asteroid **Didymos**, which has the formal designation 65803 Didymos (1996 GT), and its natural satellite or moon Didymos I, or **Dimorphos**, with a provisional designation S/2003 (65803) 1 (IAU 2025; JPL 2025).

Didymos is Greek for *twin* and it was discovered on 11th April 1996 by Spacewatch at Kitt Peak. The asteroid is a rapid-rotator 780m in diameter belonging to the Amor group of near-Earth asteroids (named for original object 1221 Amor); the orbital perihelion of an Amor group object is slightly greater than the orbital aphelion of Earth, which means that it does not cross Earth's orbit – most Amors cross Mars' orbit (IAU 2025; JPL 2025; NASA 2024). However, Didymos is also considered to belong to the Apollo asteroid group (Space Reference 2021). As well as being classified as a Near Earth Asteroid (NEA) it is classified as a Potentially Hazardous Asteroid (PHA).

Didymos is also interesting in that it has a satellite – binaries make up 15% of all known asteroids (ESA 2024). The suggestion that it *was* binary began when multiple echoes were detected in the data from NASA's Goldstone Solar System Radar, sited in the Mojave Desert in California (NASA 2024). The nature of the system was clarified by photometric observations between 20-24 November 2003 and confirmed independently by other analyses, including Arecibo radar imaging (Pravec *et al*. 2003; JPL 2025; NASA 2024). The system was found to have an orbital period of 11.9 hr, with Didymos rotating with a period of 2.26 hr. Light-curve amplitude measurements showed that Didymos was almost a sphere, and with eclipse/occultation observations, early estimates of the relative diameters of the pair were about 800 and 150 metres. These were verified by later radar analysis, with Didymos shown to be an oblate spheroid of estimated diameter 780±30 m and its moon of 150±30 m diameter (Naidu *et al*. 2020). The name of the system was suggested by Joseph Montani (JPL 2025).

Didymos orbits the Sun at 1.0–2.3 AU every 2.11 years; it has an orbital eccentricity of 0.38 and is inclined 3° to the ecliptic. The minimum present distance between Earth's orbit and that of the asteroid of 0.04 AU (6.0 million km) will change with perturbation; it passed at 7.18 million km from Earth in November 2003 and will again approach closely, to 5.86 million km, in November 2123 (JPL 2025). Didymos also now and again closes in on Mars: its next close fly-by of the Red Planet will be in July 2144, at 4.68 million km (JPL 2025). Didymos also crosses the closer parts of the main asteroid belt, where inter-asteroidal collisions are more likely; it has been estimated that an object collides with Didymos about every 73–84 thousand years with an energy equivalent to that of the DART mission satellite (see below), and during its average NEA lifetime (8-10 million yr), Didymos has probably been hit many times (Bagatin *et al*. 2024).

Asteroid 65803 Didymos	
Argument of Perihelion (°)	319.58986
Ascending Node (°)	72.98451
Orbital Inclination (°)	3.41407
Orbital Eccentricity	0.3832284
Perihelion Distance (AU)	1.0130870
ΔV w.r.t. Earth (km/sec)	5.2
Semi-Major Axis (AU)	1.6425644
Mean Anomaly (°)	167.22108
Mean Daily Motion (°/day)	0.46818820
Aphelion Distance (AU)	2.272
Period (years)	2.11
Absolute Magnitude	18.11
Diameter (km)	0.78
Phase Slope	0.15
Satellite	(65803) Didymos I (Dimorphos)
	Data: IAU/JPL

Didymos is spectroscopically classified as an S-type asteroid in the SMASS (Small Main-Belt Asteroid Spectroscopic Survey) II (JPL 2025), meaning that its spectrum suggests it is a siliceous (stony) body. Dimorphos is also an oblate spheroid covered in boulders (Barnouin *et al*. 2023), and may have been formed by rotational fission, a mass-shedding event, as a result of Didymos' rapid rotation: loose debris was cast off the asteroid to form an orbiting ring that over time accreted into the body that is now Dimorphos (Madeira *et al*. 2023; NASA 2024). Analyses have shown that Didymos and Dimorphos both have weak surface features, suggesting that Didymos' surface is 40–130 times older than Dimorphos', and estimated at 12.5 million years old, while the moon is less than 300,000 years old (Talbert 2024). Both bodies are believed to be, like many near-Earth binary asteroids, rubble piles of aggregated particles rather than a uniform mass (Richardson *et al*. 2022).

The binary system also has another claim to fame: the moon Dimorphos was the target of NASA's Double Asteroid Redirection Test (DART), a mission to deliberately collide a spacecraft with the moon to alter its orbit around Didymos (kinetic deflection). DART was the first trial designed to demonstrate kinetic impact as a means of deflecting an asteroid from its course at a scale applicable to planetary defence (Cheng *et al*. 2023). The DART mission launched on 24th November 2021, on a SpaceX Falcon 9 rocket from Vandenberg Air Force Base, California, and intercepted Dimorphos on 26th September 2022 (NASA 2024). DART hit Dimorphos at 6.6 km/s when the moonlet was about 11 million km from Earth. The aim of the mission was to establish how much the spacecraft's impact changed Dimorphos' velocity by measuring the change in its orbit around its primary.

Images of the impact were sent back to Earth as the spacecraft crashed into Dimorphos by DART's only onboard instrument, a high-resolution imager named DRACO (Didymos Reconnaissance and Asteroid Camera for Optical navigation), which had been used to guide DART to the Didymos system. However, DART also carried a hitch-hiker: the LICIACube (Light Italian CubeSat for Imaging of Asteroids), an Italian Space Agency (ASI) spacecraft the size of a shoebox. LICIACube split from DART days before collision and captured images of the impact and the ejecta arising from it (NASA 2024).

Before impact, Dimorphos was an oblate spheroid with a boulder-strewn surface but with almost no craters (Barnouin *et al*. 2023). After the DART impact, Dimorphos' orbital period around its primary decreased by 33 minutes and the over 1 million kg of debris ejected into space produced a dust plume that caused transient brightening of the Didymos system and resulted in a 10,000 km long dust tail that endured for several months (Li *et al*. 2023). Modelling predicted that the DART impact would cause global resurfacing and shape-deformation of the moonlet, perhaps leaving a large impact crater (Raducan & Jutzi 2022; Nakano *et al*. 2022; Raducan *et al*. 2023). Observations of brightness fluxes in the Didymos system after the impact indicate that the hit may have either substantially distorted Dimorphos into an ellipsoid or sent it into chaotically tumbling rotation (Scheirich & Pravec 2023; Pravec *et al*. 2023). If Dimorphos is in such a transitional perturbed state, it will be hit by irregular tidal forces by Didymos before its eventual return to a tidally locked state within several decades (Meyer *et al.* 2023).

LAST COMPLETE IMAGE OF DIMORPHOS. 12 km FROM SURFACE, 2 SECONDS BEFORE IMPACT

A further study of the effects of DART's impact on Dimorphos will be made by the European Space Agency (ESA) Hera mission (ESA 2024). Hera is ESA's first planetary defence spacecraft, and the car-sized craft lifted off on a SpaceX Falcon 9 from Cape Canaveral Space Force Station, Florida, USA, on 7th October 2024 to perform the first detailed survey of the binary unit, although it will focus on Dimorphos. About 100 European companies and institutes in 18 ESA Member States took part in developing the Hera mission. The plan includes the deployment of twin CubeSats, initially for close manoeuvring in Dimorphos' ultra-low gravity to obtain scientific data, and then to land. The main craft will use visual tracking to attempt self-navigation around both asteroids. Mission control and tracking into deep space is being directed from ESA's European Space Operations Centre in Darmstadt, Germany. Hera plans to answer uncertainties remaining from the DART mission, relating to the mineralogy, structure and precise mass of Dimorphos, and the nature of the results of the impact – was there a crater left by DART's impact at the crash-scene, and if so, what size is it, or was the whole asteroid reshaped? The Hera mission is planned to arrive at the Didymos system in Autumn 2026. We all look forward to its safe arrival and exciting results.

References

Bagatin, C.A., Dell'Oro, A., Parro, L. M. *et al*. (2024) Recent collisional history of (65803) Didymos. *Nature Communications 15 (1) 3714*. https://www.nature.com/articles/s41467-024-48094-7.

Barnouin, O.S., Ballouz, R.L., Marchi, S. *et al.* (2023) The Geology of the Didymos System. 54th Lunar and Planetary Science Conference, March 2023, LPI Contrib. No. 2806. Lunar and Planetary Institute. https://www.hou.usra.edu/meetings/lpsc2023/pdf/2605.pdf.
Cheng, A.F., Agrusa, H.F., Barbee, B.W. *et al.* (2023) Momentum transfer from the DART mission kinetic impact on asteroid Dimorphos. Nature. 616 (7957) 457–460. https://www.nature.com/articles/s41586-023-05878-z.
ESA (2024) *Planetary defence mission Hera heading for deflected asteroid*. European Space Agency. https://www.esa.int/Space_Safety/Hera/Planetary_defence_mission_Hera_heading_for_deflected_asteroid. Accessed 29 Sep 2025.
IAU (2025) The International Astronomical Union Minor Planet Center (65803) Didymos = 1996 GT [Ref: Minor Planet Circ. 52326, 13 July 2004]. https://minorplanetcenter.net/db_search/show_object?object_id=65803.
JPL (2025) Jet Propulsion Laboratory Small-Body Database Lookup, 65803 Didymos (1996 GT); https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=Didymos.
Li, J-Y., Hirabayashi, M., Farnham, T. *et al.* (2023) Ejecta from the DART-produced active asteroid Dimorphos. Nature 616 (7957), 452–456. https://www.nature.com/articles/s41586-023-05811-4.
Madeira, G., Charnoz, S., Hyodo, R. (April 2023) Dynamical origin of Dimorphos from fast spinning Didymos. Icarus 394 115428: 16. https://arxiv.org/abs/2301.02121.
Meyer, A.J., Noiset, G., Karatekin, Ö. *et al.* (2023). Tidal Dissipation in Didymos Following the DART Impact (PDF). 54th Lunar and Planetary Science Conference March 2023. Lunar and Planetary Institute. https://www.hou.usra.edu/meetings/lpsc2023/pdf/2105.pdf.
NASA (2024) Didymos and Dimorphos. https://science.nasa.gov/solar-system/asteroids/didymos/.
Naidu, S.P., Benner, L.A.M., Brozovic, M. *et al.* (2020) Radar observations and a physical model of binary near-Earth asteroid 65803 Didymos, target of the DART mission. Icarus 348, 113777. https://echo.jpl.nasa.gov/asteroids/naidu.etal.2020.didymos.pdf.
Nakano, R. Hirabayashi, M., Agrusa, H.F. *et al.* (2022) NASA's Double Asteroid Redirection Test (DART): Mutual Orbital Period Change Due to Reshaping in the Near-Earth Binary Asteroid System (65803) Didymos. *The Planetary Science Journal 3 (148), 16pp.* https://iopscience.iop.org/article/10.3847/PSJ/ac7566/pdf.
Pravec, P. *et al.* (2003) (65803) 1996 GT. *IAUC (International Astronomical Union Circular) 8244.* http://www.cbat.eps.harvard.edu/iauc/08200/08244.html.
Pravec, P., Scheirich, P., Meyer, A. J. *et al.* (2023) Dimorphos's Post-Impact Lightcurves and Constraints on Its Post-Impact Spin State and Shape. Asteroids, Comets, Meteors Conference June 2023. Lunar and Planetary Institute. https://www.hou.usra.edu/meetings/acm2023/pdf/2052.pdf.
Raducan, S.D. and Jutzi, M. (2022) Global-scale Reshaping and Resurfacing of Asteroids by Small-scale Impacts, with Applications to the DART and Hera Missions. *The Planetary Science Journal 3 (128) 15pp.* https://iopscience.iop.org/article/10.3847/PSJ/ac67a7/pdf.
Raducan, S.D., Jutzi, M., Zhang, Y. *et al.* (2023). Low Strength of Asteroid Dimorphos As Demonstrated by the Dart Impact. 54th Lunar and Planetary Science Conference February 2023. Lunar and Planetary Institute. https://www.hou.usra.edu/meetings/lpsc2023/pdf/2033.pdf.
Richardson, D.C, Agrusa, H.F., Barbee, B. *et al.* (2022) Predictions for the Dynamical States of the Didymos System before and after the Planned DART Impact. *The Planetary Science Journal 3 (157) 23pp.* https://iopscience.iop.org/article/10.3847/PSJ/ac76c9/pdf.
Scheirich, P. and Pravec, P. (2023). Post-Impact Mutual Orbit of the Didymos Binary System Derived from Photometry. Asteroids, Comets, Meteors Conference June 2023. Lunar and Planetary Institute. https://www.hou.usra.edu/meetings/acm2023/pdf/2050.pdf.
Space Reference (2021) Didymos 65803 Didymos (1996 GT) https://www.spacereference.org/asteroid/65803-didymos-1996-gt.
Talbert, P. (2024) *NASA's DART Mission Sheds New Light on Target Binary Asteroid System.* NASA Asteroid Watch Article, Jul 30, 2024. https://science.nasa.gov/missions/dart/nasas-dart-mission-sheds-new-light-on-target-binary-asteroid-system/.

Image Credits

Last complete image of Dimorphos: NASA/Johns Hopkins APL.

Comet Lemmon – an Autumn Comet

By Alan Cayless FRAS

October saw a welcome visitor to our autumn skies in the form of Comet C/2025 A6 Lemmon. This long-period comet was visible towards the end of the month, making a good target for observation with binoculars or small telescopes.

Throughout history, comets have appeared in our skies from time to time. Long before the development of the telescope, many comets were bright enough to be seen with the naked eye. Sometimes remaining in the sky for days or weeks, comets are characterised by a bright but diffuse head and a long tail. With their spectacular appearance, and because they did not fit into the ordered motions of the stars and planets, comets were often seen as portents or signs. There are recorded sightings of comets as far back as Chinese manuscripts from 240 BCE, and perhaps most famously the comet depicted in the Bayeux Tapestry preceding the Battle of Hastings in 1066. Edmond Halley (1656–1742) realised that there were many similarities between the 1066 comet and other comets seen in 1531, 1607 and 1682. Halley suggested that these could all have been apparitions of the same comet, orbiting the Sun in an extended elliptical orbit and returning at regular intervals of approximately 76 years, famously predicting that the comet would return in 1758 (Halley 1705). Although it was not seen again until after Halley's death, the comet now designated as 1P/Halley did indeed return in 1758 – and more recently in 1910 and 1986.

Comets are frozen collections of ice and dust, typically having an irregularly shaped core just a few kilometres in diameter. They originate in the outer regions of the Solar System: up to 100,000 astronomical units (AU) from the Sun, the Oort cloud is a vast cloud of minor objects primarily made up of chunks of rock, ice and dust left over from the early days of the Solar System. From time to time, interactions or collisions between these objects will send one of them towards the inner parts of the Solar System where they may provide us with a once-in-a-lifetime long period comet, or perhaps be deflected by the gravitational pull of Jupiter to become a periodic comet like Halley. Comets are mostly inert in the further reaches of the Solar System but when close to the Sun, heat from the Sun causes gas to be emitted, forming the bright coma surrounding the head of the comet. Gas and dust carried on the solar wind form the tail, which can stretch for vast distances.

Comet C/2025 A6 Lemmon was discovered in January 2025 by the Catalina Sky Survey telescope at the Mt Lemmon Observatory in Arizona (University of Arizona College of Science Lunar and Planetary

Comet C/2025 A6 Lemmon, imaged by Douglas Cooper on the 23rd of October

Observatory, 2025). The orbit was determined to be elliptical, with a period of between 900 and a thousand years. There is always a risk of comets breaking up as they round the Sun, and some previous comets have not lived up to their original expectations, falling apart before reaching Earth. In this respect Comet Lemmon was a little different, as its orbit was scheduled to take it past Earth *before* perihelion, passing within 0.6 AU of Earth on 21 October. This suggested that there would be a good chance of the comet remaining intact for its closest approach to Earth. Additionally, Comet Lemmon was well placed for visibility from the northern hemisphere, firstly below Ursa Major in mid-October and then with a track taking it between Arcturus and Corona Borealis on the evenings of the 21 to 23 of October.

Mid-October brought a disappointing period of cloudy skies. For about two weeks ahead of the closest approach there was little possibility of observing the comet. Fortunately the skies did clear on the 21st and subsequent evenings and Comet Lemmon lived up to expectations, giving us a great view and opportunity for photographs.

Having rounded the Sun on 08 November, Comet C/2025 A6 Lemmon is now on its way back out towards the outer Solar System, perhaps to return in a thousand years.

References

Halley, E. (1705) Astronomiae cometicae synopsis, *Philosophical transactions*, 24, pp. 1882-1899, Royal Society, London. https://www.jstor.org/stable/102980.

University of Arizona College of Science Lunar and Planetary Observatory (2025) *Catalina Sky Survey*, https://catalina.lpl.arizona.edu/.

The First Letter Home

By Sandi Cayless

Hello, back there…

You'll recall the year of Mercy
When our shuttle left the pad;
She was destined up to orbit, then deep space;
We docked our ride so tamely
You'd think it was a gameplay –
But little did we figure what we'd face…

It was ten whole weeks of waiting
And six more we'd then to fill,
Until our ship was set for Mars' red sky.
Our holds were full of plenty,
And our air still sweet and dainty;
But our hearts felt it so hard to say bye-bye.

There was half a year of dreary…
And one more of starlit dull,
Before we made our orbit round Mars Base.
We'd got there safe and thankful,
But we'd still to reach the ground –
And so little did we figure what we'd face…

There are rock mounds in the darkness
That litter all the ground;
There are icy blasts of sand across the plain;
The slopes are so darn slippy
And our boots so less than grippy –
That we lose one step for every two we gain…

The light's a sharp-set dazzle
And it bounces off the rocks;
Those icy blasts still sweep across the plain.
But we've hunkered down in caverns
That the early rovers found,
So at least we've got a place to dodge the rain…

Speak to you soon…

Happy Observing!

December 3 brings us Mercury at its highest altitude in the morning sky. On December 4, from around 16:50 BST, look for the Moon and M45 passing within 48.4 arcminutes of each other. At their highest point, they will be visible (clouds permitting!) at 23:07, when they will be at 57° above the southern horizon, in Taurus. The December

Moon is also the third and final Supermoon of the year, the Cold Moon, which will be visible for most of the night (see Issue 5 of *The Jeety Starn* for an article on the Naming of Full Moons). The phi (φ)-Cassiopeid meteor shower (active Dec 1-8) will peak around December 6. The shower's radiant is in Andromeda, although with the Moon 2 days past full, there will be a lot of interference! The φ (phi)-Cassiopeids originate from an unknown parent body. The Moon and Jupiter make a close approach (appulse) on December 7, and will be best seen from Stirling around 19:39, when they will be 7° above the horizon, to the north-east. Asteroid 16 Psyche is at opposition in Taurus on 8 December, and best seen around midnight. On the 9th, the December Monocerotid meteor shower (active 5-20 Dec) peaks, and will be at its best around 02:00. Comet C/1917 F1 (Mellish) is the parent body of this shower.

A lunar occultation of Regulus (α Leonis) will be visible from Stirling on 10 December, from 07:15 GMT; Regulus will reappear 08:18. The 12th brings the peak of the σ (sigma)-Hydrid meteor shower (active 3-15 Dec) at about 04:00 GMT, but the hourly rate is small at 1-2/h. These have no known parent body. The Geminids (active 4-17 Dec) peak on 14 December should produce a better show, with over 100 meteors per hour likely, and the Moon close to new. The parent body of the Geminids is asteroid 3200 Phaethon. Our astrophotographers will have a good view of the Running Man cluster (NGC 1977) in Orion's sword, as well as the Orion Nebula, on the 15th. Any stray meteors over the next few nights may belong to the Comae Berenicid shower (active 12-23 Dec) or the December Leonis Minorids (active 5 Dec-4 Feb), but on the 19th, look out for Comet 240P/NEAT as it passes perihelion. From Stirling it is at its highest at 21:43, at 46° to the south, and will be observable until about 02:22. December 21 brings midwinter and the shortest day in the northern hemisphere; in astronomical terms, this is the beginning of winter, when the Sun reaches its most southerly point, at a declination of 23.5°S in Capricornus. This heralds the Ursid meteor shower (active 17-26 Dec), which peaks on 22 December and is likely to produce 9-10 meteors per hour. The Ursids arise from the stream of debris left in the wake of their parent body, comet 8P/Tuttle, a periodic Jupiter-family comet with a 13.6-year orbital period. On December 27 there will be a conjunction of the Moon and Saturn. The two reach their highest point at 17:37 in the south, the Moon in Pisces and Saturn in Aquarius. The end of the month is a good time to view open star cluster NGC 2232 and the Rosette Nebula (Caldwell 49), both in Monoceros (binoculars or small telescope), and December ends with a close approach of the Moon and M45 (55.4 arcminutes of each other) in Taurus.

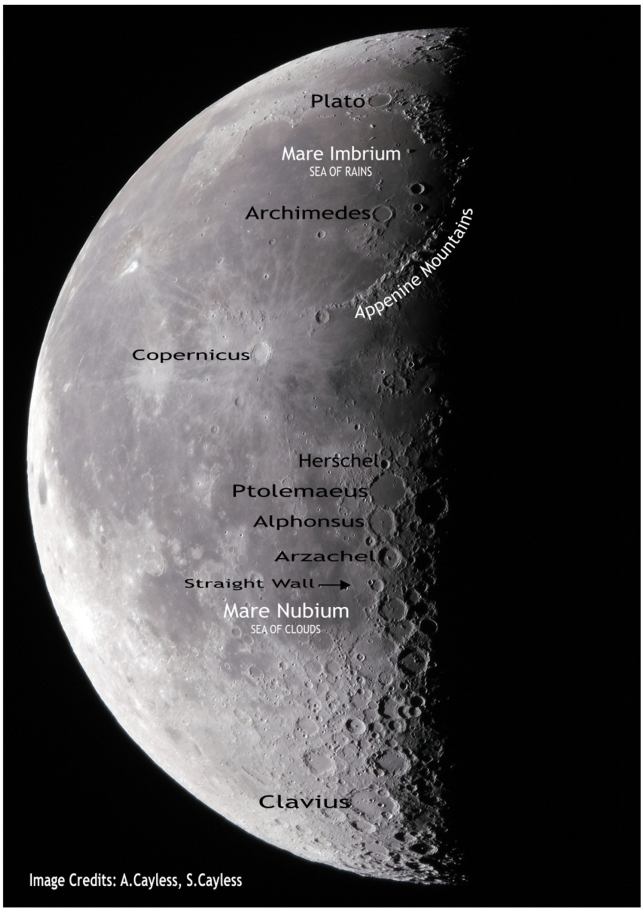
The 2nd day of January in the New Year sees main-belt Asteroid 40 Harmonia in opposition and well placed in Gemini for viewing from Stirling (RA = 06h51m50s; Dec = 23°54'N; Mag = 9.0). The Full Moon of 3 January (the Wolf Moon) is at aphelion, and in conjunction with Jupiter in Gemini, and will be visible all night. This date also sees the peak of the Quadrantid meteor shower (12 Dec-12 Jan), with its radiant in Boötes. This strong shower, its parent body Asteroid 196256 (2003 EH1), should produce a peak rate of about 118 meteors per hour. On 4 January periodic comet 24P/Schaumasse makes its closest approach to Earth (0.59 AU) and will be visible in Virgo from about 01:40, reaching its highest point at 06:24. At a predicted magnitude of 8.0, it is not likely to be visible without binoculars or a telescope, but will continue to be visible, reaching its brightest on 7 January and passing perihelion on 8 January.

The 5 January sees a close approach of the Moon and M44 (the Beehive Cluster) and from Stirling, they will be visible from about 20:00 in the constellation of Cancer, reaching their highest point at about 02:00. Jupiter reaches perigee on January 9 in Gemini, and will be visible from Stirling just after 17:00, to 07:46. The planet reaches opposition on 10 January, reaching its highest point about midnight.

Keen astrophotographers may want to note that on 15 January the open star cluster M47 (NGC 2422) in Puppis should be just visible between about 23:30 and 01:00, but will only reach 19° above the southern horizon. The waning crescent Moon may help observation, but a good skyline is a must. However, the spiral galaxy NGC 2403 in Camelopardalis (discovered by William Herschel) will reach its highest point about midnight on the 15th and will be well-placed for observation by telescope. The γ (gamma)-Ursae Minorid meteor shower (active 15-25 Jan) reaches its peak about 19 January, but as a weak stream, only 2 meteors per hour are likely. Just before dawn or after dusk are the best time to spot one. On 23 January, the 5-day old Moon, Saturn and Neptune will closely approach each other, and will be in conjunction (i.e. share the same right ascension). From Stirling they can be seen from about 17:26, in Pisces, and will set at 21:44.

Also on 23 January, the large and bright main-belt Asteroid 44 Nysa, a rare class E (enstatite achondrite) asteroid, will be visible in Cancer, reaching its highest point near midnight. It is also at perigee, and will be visible from Stirling about 19:15 until around 05:40. At a peak magnitude of 8.6, it is faint and will need binoculars or a telescope to view. January 27 brings a close approach of the 9-day old Moon and the Pleiades open star cluster (M45) in Taurus. They can be seen (weather permitting) from 17:40; they reach their highest point at 19:34 and will sink around 02:30. January ends with the Moon and Jupiter in conjunction on the 31st, in Gemini, from 17:10 BST, 21° above the eastern horizon, reaching their highest point at 22:45.

February begins with another close approach of the Moon and M44 (the Beehive Cluster) in Cancer, which is visible from around 18:15 BST. This coincides with the Full Moon, often called the Snow Moon as it may be a time of heavy snowfall. Uranus ends its retrograde motion on 4 February, and can be seen in the evening sky from about 18:30 BST, in Taurus. On February 9, the Moon passes last quarter and will appear almost half-lit, which makes this a good time to observe many interesting features. The almost circular crater Archimedes (52 mi diam) sits on the edge of Mare Imbrium, and to its southeast is the curve of the Apennine Mountains, among which are some of the highest lunar peaks. To the west is the crater Copernicus (53 mi diam), which is remarkable for its detail and the central peak of the crater floor. Follow this across towards the terminator to observe the crater chain of Ptolemaeus (with impact crater Herschel on its northern rim), Alphonsus and



Arzachel, the latter with detailed walls and a central peak. Southwest of Arzachel and in Mare Nubium is the Straight Wall, an escarpment about 68 miles long, 1.5 miles wide, rising to little more than 0.2 mile (1000 ft) above the Mare floor and with a slope of about 7°. The Wall's appearance changes markedly with the sun angle, and so appears different at other lunar phases. One of the most impressive features to the south is the huge crater Clavius (140 mi across), with high and well defined inner walls, and many smaller impact craters on its floor and along its rim. [The monolith in the film *2001: A Space Odyssey* was uncovered in this crater; if you spot it, check your equipment…]

The next major event is the annular eclipse of 17 February, alas only visible from Antarctica. A partial eclipse will be visible from SE Africa and in various southern territories. However, M81 Bode's Galaxy (NGC 3031) in Ursa Major will be worth viewing (telescope) after this time, reaching its highest point on 19 February at about midnight over Stirling. M81 is a *grand design spiral* galaxy, with conspicuous, well-defined continuous arms circling it that cover a substantial part of the galactic circumference. A great deal of star formation occurs in the spiral arms, where there are a wealth of bright, hot, short-lived massive stars (NASA 2025). The Moon and the Pleiades open star cluster (M45) make another close approach on 24 February, in Taurus. The optimum time of closest approach is at 03:04 GMT. The Moon and Jupiter are in conjunction on February 27 and are best seen at 20:50, in Gemini. Main-belt Asteroid 7 Iris is at opposition in the constellation Sextans on the same date, and best viewed from Stirling around midnight. This large, possibly remnant planetesimal, is the fourth-brightest object in the asteroid belt (mag +7.8), and at opposition is about as bright as Neptune. Iris is an S (stony)-type asteroid. February rounds off as it began, with another close approach of the Moon and M44 (Beehive Cluster) in the constellation of Cancer.

Happy observing all!

Reference

NASA (2025) *Grand Design Galaxy*. https://science.data.nasa.gov/science-discovery-engine/my-search-stories/grand-design-galaxy.

Many thanks to all our contributors to this quarter's issue of *The Jeety Starn*. Members, please hand submissions to the editor, or any contributions can be sent via the Society's contact email address. Illustrations and snippets also welcome!

S.C.

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