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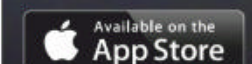


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IMAGING Capture striking photos of deep sky objects **P36**

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DEEP SKY Dive straight into the Coma galaxy cluster **P52**

AUSTRALIAN SKY & TELESCOPE

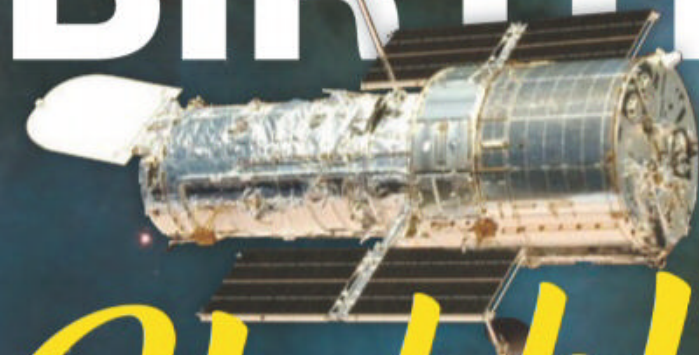
THE ESSENTIAL MAGAZINE OF ASTRONOMY

SEEING DOUBLE

Meet the Solar System's binary worlds

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Revealing the mysteries of the cosmos for 30 years **P10**

Hubble!

TEST REPORT



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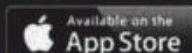
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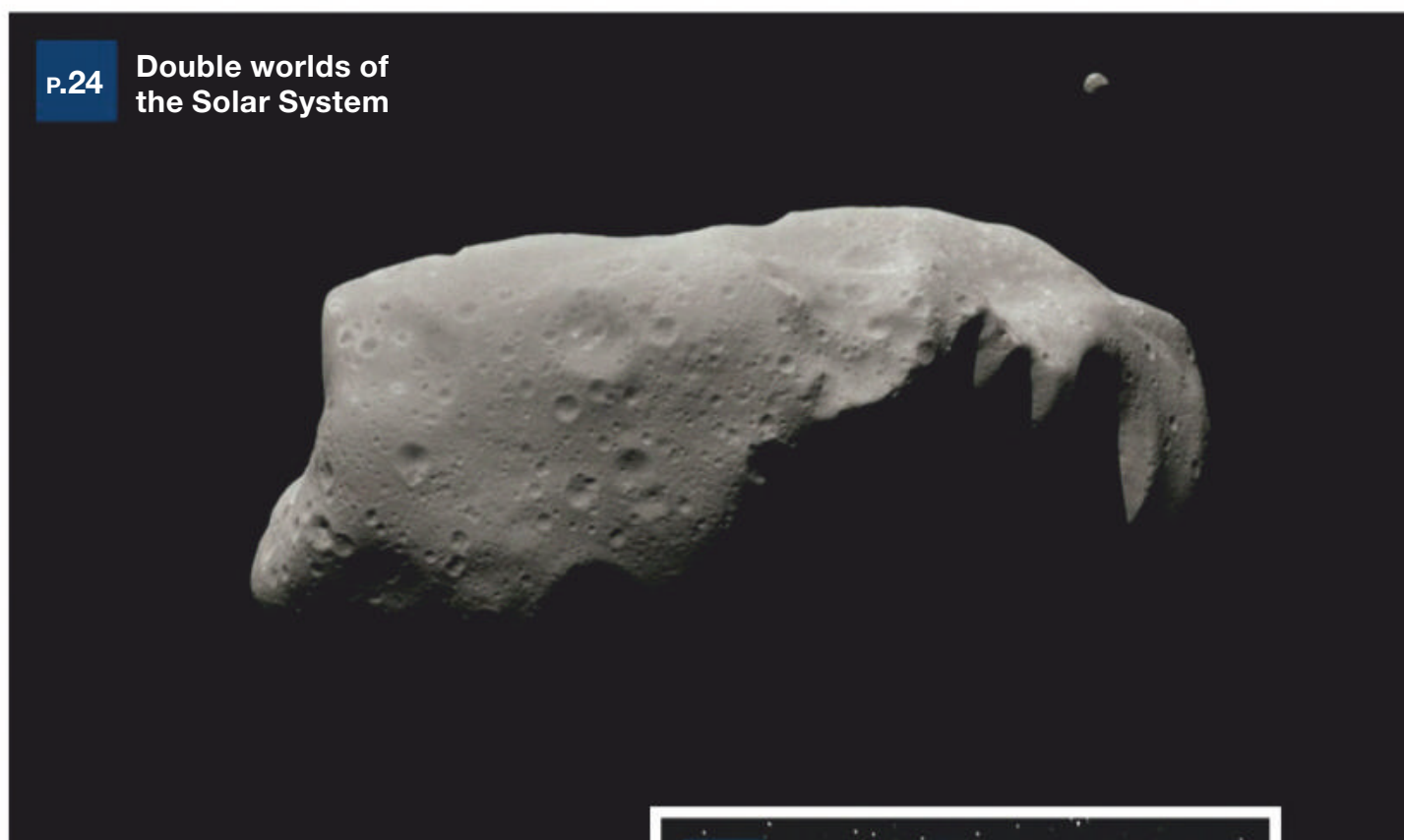
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The Hubble Space Telescope's image of 'Mystic Mountain,' a region of nebulosity in Carina. Turn to page 10 for more images.



The world's most famous telescope

PRIOR TO 1990, IF YOU'D ASKED anyone in the street if the surname 'Hubble' meant anything to them, almost certainly you would have received a 'no'. Not many people outside the science and science enthusiast world had heard of Edwin Hubble and the contributions he made to our understanding of the cosmos. But since the launch that year of the space observatory that bears his name, 'Hubble' has become synonymous with amazing discoveries, spellbinding cosmic imagery and — on several occasions — daring spacewalks to fix and upgrade the orbiting outpost.

If you're old enough, you'll recall that no sooner had astronomers begun to take calibration images than they realised something was seriously wrong with the optics — all the pictures were blurry. (Mind you, for some purposes, even those blurry images were still better than could be produced at the time by Earth-bound telescopes.) Fortunately, Hubble was designed to be periodically upgraded in orbit, so during the first servicing mission in 1993 some corrective optics were installed and the telescope got its 2020 vision back. And subsequent missions vastly extended Hubble's capabilities.

Hubble will soon make way for its replacement, the larger James Webb Space Telescope. But its long and distinguished career of pushing back the boundaries of astronomical knowledge will forever live on in the incredible data and images it has produced. Happy 30th birthday Hubble!

Jonathan Nally, Editor

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Founded in 1941 by Charles A.
Federer Jr. and Helen Spence Federer

Printed by Webstar

Australia distribution by Network Services. New Zealand distribution by Ovato Retail Distribution Australia. © 2020 AAS Sky Publishing, LLC and Paragon Media. No part of this publication may be reproduced, translated, or converted into a machine-readable form or language without the written consent of the publisher. Australian Sky & Telescope is published by Paragon Media under licence from AAS Sky Publishing, LLC as the Australian edition of Sky & Telescope. Australian Sky & Telescope is a registered trademark of AAS Sky Publishing, LLC USA. Articles express the opinions of the authors and are not necessarily those of the Editor or Paragon Media. ISSN 1832-0457

AUSTRALIAN SKY & TELESCOPE (ISSN 1832-0457) is published 8 times per year by Paragon Media Pty Limited, © 2020 Paragon Media Pty Limited. All rights reserved.

NASA's TESS announces first-year roundup

SCIENTISTS WORKING with NASA's Transiting Exoplanet Survey Satellite (TESS) announced the official catalogue that summarises the mission's first year of exoplanet-hunting results.

From July 2018 to July 2019, TESS searched for planets in the southern sky, revealing more than 1,100 planet candidates. Of these, 37 — so far — have been confirmed via follow-up observations and the results published

in peer-reviewed journals. The catalogue will be available in an upcoming issue of *Astrophysical Journal Supplements*, according to catalogue manager Natalia Guerrero (MIT).

Like its predecessor, NASA's Kepler mission, TESS finds planets by watching for dips in starlight caused when a planet transits across the face of its star. But unlike Kepler, TESS watches stars close to Earth. By design, all of the

◀ This artist's illustration shows one of the TESS mission's confirmed planets, TOI 1338b. The world is 6.9 times Earth's radius and orbits two stars in a system 1,300 light-years away.

planets it finds are within about 3,000 light-years, and some are much closer. With these discoveries, astronomers can do more than tally an exoplanet census — they can get to know our planetary neighbours one by one.

Perhaps the most famous discovery within the first-year catalogue is TOI 700d. This Earth-size world is the outermost known planet in its system. It circles the cool, red star every 37 days, putting it in the star's *habitable zone*, the region where (under the right conditions) liquid water could exist on its surface. TOI 700d is one of only a few Earth-size planets found in their stars' habitable zones so far and the first one that TESS has discovered.

■ MONICA YOUNG

Read about more TESS-discovered planets at <https://is.gd/TESSfirstyear>.

Betelgeuse 'faints'

BETELGEUSE, THE RED SUPERGIANT star that marks Orion's western shoulder, has faded markedly in a behaviour termed 'fainting'. The star typically varies in brightness between magnitudes 0.3 and 1.2, but observations in December and January indicate a steep drop in brightness to magnitude 1.5, a historic low.

Betelgeuse is a semiregular variable, its brightness varying as the star expands and contracts on a roughly 425-day period. Betelgeuse also shows changes on a longer, roughly 6-year cycle due to other internal forces. At its largest and coolest, the star would balloon out to Jupiter's orbit if put in place of the Sun.

Ultimately, Betelgeuse will run out of fuel and explode as a core-collapse supernova. Cosmically speaking, this event is just around the corner: Astronomers have predicted that the star will explode within 100,000 years or so. For this reason, the current drop in brightness provoked much discussion.

However, while the supergiant's current behaviour is certainly out of the ordinary, it doesn't necessarily mean an eruption is imminent.

Edward Guinan (Villanova University), who has been monitoring the star for more than 25 years with Richard Wasatonic (also at Villanova) and amateur Thomas Calderwood, suggests that the star happens to be near the minimum of its 5.9-year cycle at the same time as it's reaching a deeper than usual minimum of its 425-day cycle. Guinan encourages observers to monitor the star while it's in this unusually faint and cool state.

■ BOB KING

Find out how to keep tabs on Betelgeuse yourself at <https://is.gd/Betelgeuse>.

▶ Amateur Tim Wetherell used the same telescope, camera and exposure time to capture the striking difference in Betelgeuse's brightness between February 2019, when it was in mid-cycle, and January 2020, when the star 'fainted' to a historic low.

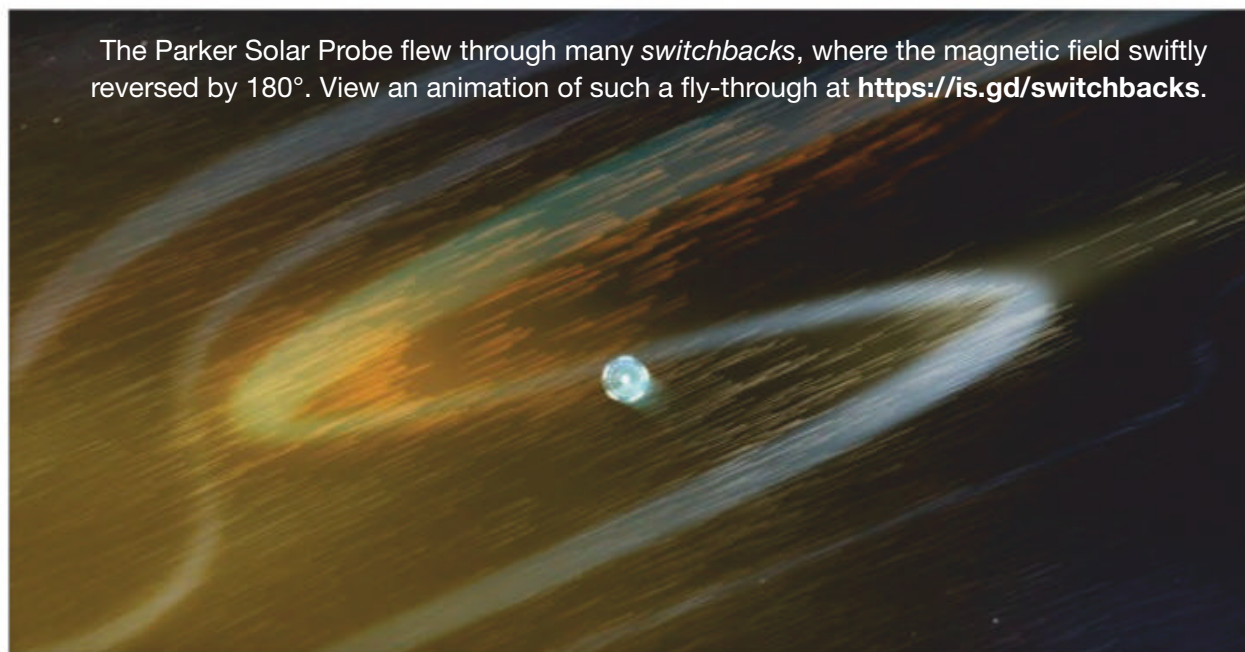


Feb 2019



Jan 2020

The Parker Solar Probe flew through many *switchbacks*, where the magnetic field swiftly reversed by 180°. View an animation of such a fly-through at <https://is.gd/switchbacks>.



Parker has seen thousands of these events already, each one lasting anywhere from a few seconds to a few minutes. The team is confident that the rogue waves originate closer to the Sun's surface but awaits data from future close passes to determine their source.

Parker is also helping scientists understand how charged particles emanating from the Sun escape its gravity and flow into the Solar System. As the Sun spins, its magnetic field grips the corona, forcing it to rotate like a rider on a merry-go-round. Yet near Earth, the solar wind flows directly away from the Sun, as if riders had jumped off the carousel. Parker's path near the Sun enables it to see the transition.

To the scientists' surprise, at Parker's closest point, SWEAP was already recording the solar wind whipping around the Sun at 35 to 50 km/s... 15 to 25 times faster than some theoretical models predicted. Why it's moving so fast remains a mystery.

"Our standard models of the Sun are missing some very fundamental physics, and this mission has a great chance of revealing what is really happening," Kasper says.

The Parker Solar Probe also made the second of seven Venus flybys on December 26, 2019, passing about 3,000 km from the planet's surface. While Parker's instruments were turned off during much of the first Venus pass, they were on during the second pass, and the team is eager to analyse data on the Venusian atmosphere.

■ DAVID DICKINSON

First science from the Parker solar probe

THE PARKER SOLAR PROBE TEAM has announced key findings from the spacecraft's first two perihelion passes in November 2018 and April 2019. These results mark the first public release of data from NASA's flagship heliophysics mission, which aims to understand the Sun's outer atmosphere, or *corona*, and the solar wind that emanates from it.

During its first two passes Parker already swooped within 24 million kilometres of the Sun's visible surface, equivalent to just over half of Mercury's distance from the Sun at perihelion, or 35 times the Sun's radius. Parker carries a host of instruments into this hostile territory: The SWEAP instrument suite measures properties of the plasma, the FIELDS package measures magnetic and electric fields, and ISOIS characterises high-energy particles. The Wide-Field

Imager for Solar Probe (WISPR) also obtains white-light images of the corona.

Researchers had hoped to use Parker to take a closer look at *Alfvén waves*, which are thought to transfer energy from the Sun's visible surface to its hot corona. These waves travel along magnetic field lines loaded with plasma, like vibrations traveling along strings of beads. Researchers were expecting to see stronger waves as the probe neared the Sun, but the number of so-called 'rogue' waves that swept over the spacecraft took them aback.

"The speed of the [solar] wind could jump by more than 500,000 kilometres per hour within seconds," says SWEAP principal investigator Justin Kasper (University of Michigan). *Switchbacks*, 180° reversals in the magnetic field, often accompanied these velocity spikes.

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Upgrades will boost Australian radio telescopes

TWO OF THE CSIRO'S radio telescope facilities — Parkes and the Australia Telescope Compact Array (ATCA) — are to receive major upgrades that will dramatically boost their productivity. Both are part of the Australia Telescope National Facility, owned and operated by the CSIRO and funded by the federal government. The upgrades are being financed by Australian Research Council Linkage Infrastructure, Equipment and Facilities (LIEF) grants.

Parkes will be given a sensitive new receiver system, called 'cryoPAF,' which will triple the telescope's field of view. The \$3 million project is being supported by a \$1.15 million LIEF grant. The 'PAF' part of the cryoPAF name denotes that it will be a phased-array feed, which is essentially a cluster of radio antennas located side-by-side, and situated at the focus point of the telescope... at the apex of the legs, high above the surface of the dish.

A telescope normally can look in only one direction at once, but with a phased-array its 'eye' can be electronically steered (without needing to move the telescope) to scan more of the sky. In the case of cryoPAF, the

telescope will have a field of view three times greater than normal.

The 'cryo' part of the name indicates that the receiver electronics will be cooled (to -253°C) to reduce electrical 'noise,' which might otherwise overwhelm the weak radio signals the receiver is designed to detect.

The grant application was headed up by The University of Western Australia, which will direct the construction and commissioning of cryoPAF, which will be designed, built and installed by the CSIRO.

Phased-arrays are not new — they've been used for a long time in advanced military radars and even medical imaging. A CSIRO-built phased-array has been used on the Australia Square Kilometre Array Pathfinder (ASKAP) telescope in Western Australia, while a prototype of cryoPAF was deployed on the Parkes telescope in 2016.

"Their further development at radio wavelengths has technology applications beyond radio astronomy with the potential to fuel the growth of space-related industries here in Australia," said Dr Douglas Bock, Director of CSIRO Astronomy and Space Science.

◀ CSIRO's Parkes radio telescope is to be equipped with a new receiver system, called 'cryoPAF,' which will triple the telescope's field of view.

cryoPAF's wider field of view will enable it to make more complete surveys of the sky in less time than previous receiver systems.

"The new receiver will help astronomers to study fast radio bursts and pulsar stars, and observe hydrogen gas throughout the Universe," said Professor Lister Staveley-Smith from The University of Western Australia node of the International Centre for Radio Astronomy Research, who led the grant application.

The second LIEF grant, worth \$530,000, will fund work that is part of a \$2.6 million upgrade of the ATCA.

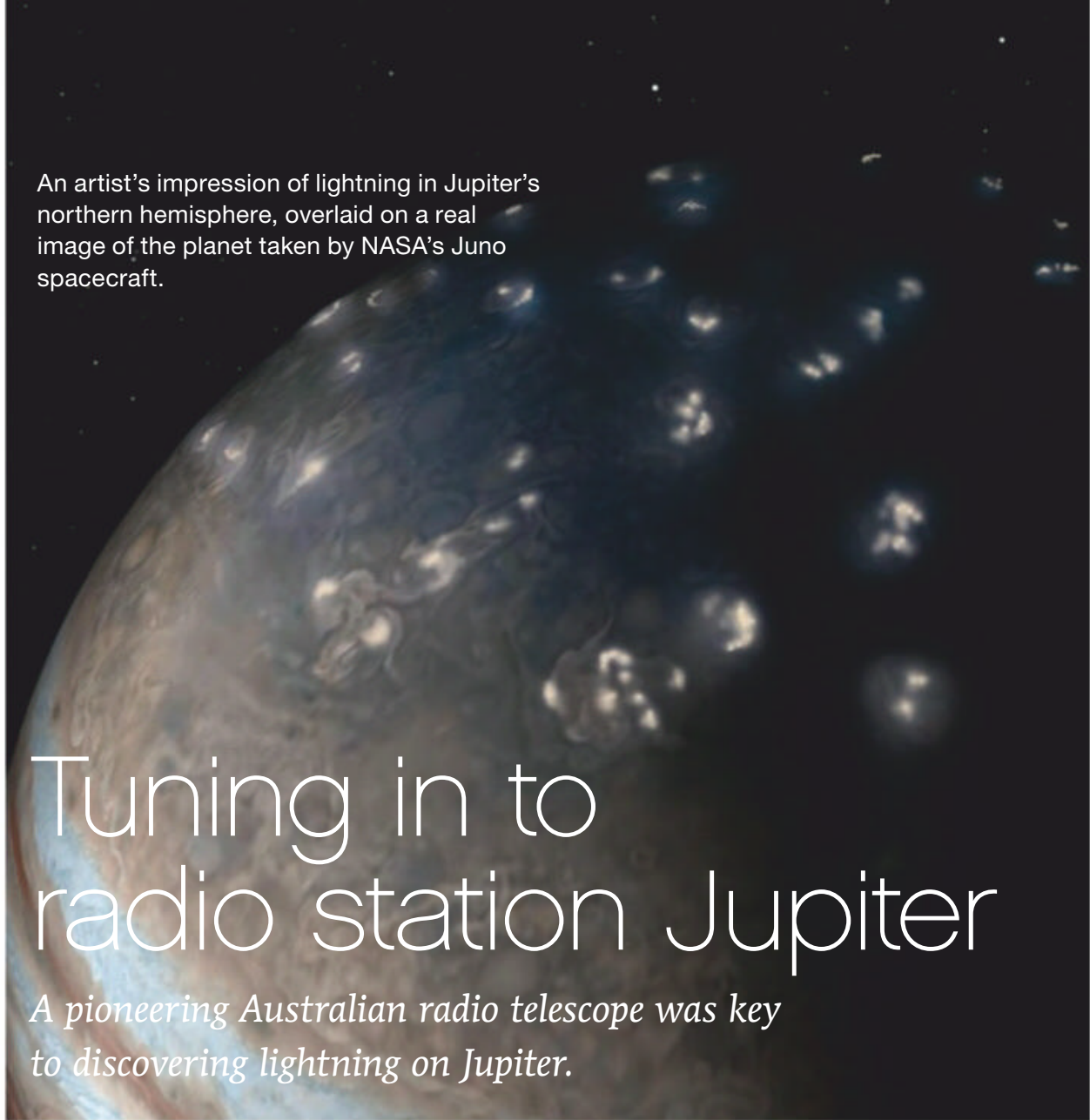
Under this project, the ATCA digital signal processor will be replaced with a GPU-powered system that will double the telescope's bandwidth capacity. GPUs are graphics processor units, specialised computer chips optimised for fast processing of data. Originally intended for use in PCs and games consoles, GPUs have long now been pressed into service for computers that need to crunch huge amounts of scientific data.

The GPU project is being led by Professor Ray Norris from Western Sydney University, alongside CSIRO and seven other university partners.

"The upgrade will enable the telescope to study radio counterparts to gravitational wave sources, and it will enable it to make detailed observations of initial discoveries made with the Australian Square Kilometre Array Pathfinder and other Australian telescopes," Professor Norris said.

"We've been developing specialised instrumentation for radio telescopes since the 1940s, when the field of radio astronomy first emerged, for our own and international telescopes," said Dr Bock. "Through our close collaborations with research partners and our expertise in technology development, we'll keep the telescopes at the cutting edge of science."

■ JONATHAN NALLY



An artist's impression of lightning in Jupiter's northern hemisphere, overlaid on a real image of the planet taken by NASA's Juno spacecraft.

Tuning in to radio station Jupiter

A pioneering Australian radio telescope was key to discovering lightning on Jupiter.

We are used to hearing static produced by thunderstorms interfering with radio and TV broadcasts, though the problem is much less troublesome since we shifted to FM broadcasting. The huge and violent sparks that we know as lightning move immense electrical charges between clouds or from clouds to the ground, generating electromagnetic waves across the radio band.

But it didn't occur to anyone that such storms might be found on other planets of our Solar System, or that the static they produce might be detectable. That is, until it was found, quite by accident. The discovery was announced in April 1955 but the work had been going on for months.

1955 was still early days for radio astronomy. Serious studies had been going for only a decade and new instruments were still under development. One such was the Mills Cross, invented and named after the Australian, Bernard Mills. Looking like a huge 'X' with arms hundreds of metres long and made up of dozens of separate antennas, the radio telescope

could focus on a small patch of the sky, with the location of that spot able to be varied by changing the way the antennae were connected together.

Two researchers from the Carnegie Institution in Washington, Bernard Burke and Kenneth Franklin, had set up the Cross so that it looked directly overhead and let the turning of the Earth bring different parts of the sky into the field of view. After trying the telescope out on known sources of radio noise such as the Crab Nebula, they detected another burst of static close by that seem to show up at the same time each day. At that stage they could not exclude the possibility that the static came from some source on Earth, like interference from car ignitions or powerlines.

More careful measurements over some months found that the source crossed through the beam not at exactly the same time but rather four minutes earlier each day. That suggested the radio noise was not from a terrestrial source but from some object far from Earth and appearing to move with the stars and other celestial objects as the Earth turned. The yearly movement of the

Earth around the Sun makes all such objects rise four minutes earlier every day. Similar reasoning led Karl Jansky two decades earlier to identify the Milky Way as a source of radio noise.

But what was the far away source? A star? Something like the Crab Nebula? Some abnormal galaxy? Again, more precise timings over a longer period of time provided a clue. The unknown source was found to be moving not exactly with the rest of the heavens but at a slightly different rate.

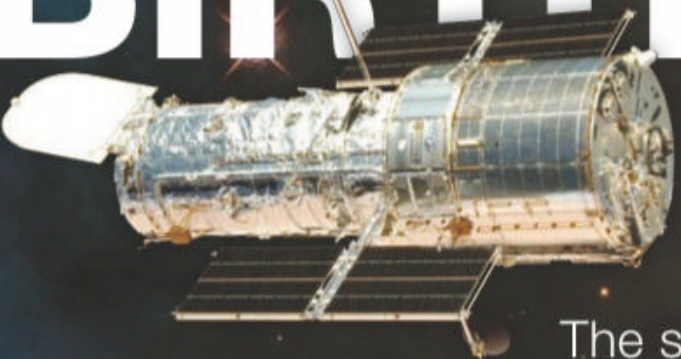
The researchers soon realised that Jupiter was close in the sky to the Crab Nebula at the time the latter was being observed and the anomalous static recorded. Since Jupiter has its own motion around the Sun it is not quite in synch with the rest of the heavens, but in fact was exactly aligned with the movement of the unknown source of static. So, by April 6, 1955, Burke and Franklin felt confident enough in their results to tell a scientific meeting that Jupiter was broadcasting radio noise. Radio Jupiter has been found.

Later research showed that the process generating radio waves on Jupiter differs from the way terrestrial thunderstorms make static. Jupiter is a very different environment, with a very strong magnetic field and a close satellite (Io) that is wracked by volcanic activity. Io's many volcanoes spew out particles which become charged, spiralling around Jupiter's magnetic field lines and emitting radio waves; the mechanism is called synchrotron radiation.

Much more precise instruments have since become available, enabling the distribution of the radio noise to be mapped in detail. We can see the links between the planet's magnetic field, the movements of the satellite Io and Jupiter's aurorae (yes, it has those too). Radio studies of Jupiter now form a busy field of research. But it all began with a chance discovery and the persistence of two scientists looking for an answer.

■ **DAVID ELLYARD** presented SkyWatch on ABC TV. He is the author of *Who Discovered What When* and *Who Invented What When*.

HAPPY BIRTHDAY *Hubble!*

A detailed illustration of the Hubble Space Telescope, showing its cylindrical body, solar panels, and various instruments, set against a backdrop of a vibrant, colorful nebula with swirling clouds of gas in shades of blue, purple, and orange, punctuated by numerous bright stars.

The super-achieving orbiting telescope turns 30 this month.

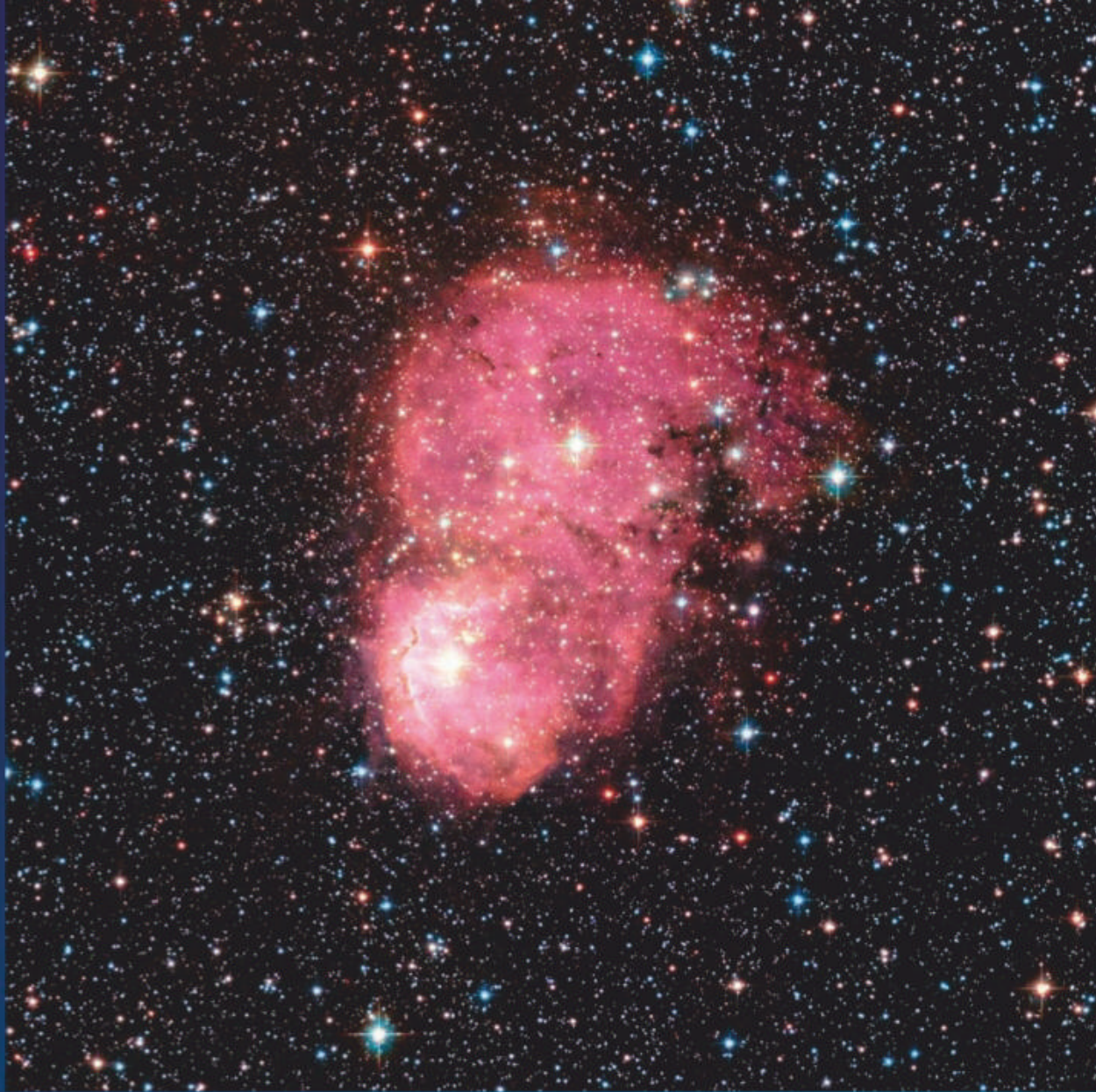
THIS MONTH THE HUBBLE Space Telescope (HST) celebrates three decades of continuous operations in Earth orbit. Conceived at the beginning of the 1970s, launched in April 1990, still going strong in 2020 and with a long list of discoveries and incredible images behind it, the HST has rightly earned its status as the world's most famous telescope.

And what more appropriate way could there be in which to celebrate the HST's 30th birthday than with a spread of its best images? Out of the thousands that have been produced over the past three decades, the ones on these pages are just a handful that caught our eye. You can browse through hundreds more at spacetelescope.org.

MYSTIC MOUNTAIN

Around 7,500 light-years away in the southern constellation Carina, these immense pillars of dust and gas are being slowly torn apart by the heat and stellar winds of young, hot stars hidden deep within.

NASA/ESA/M. LIVIO/HUBBLE 20TH ANNIVERSARY TEAM (STSC); NASA/ESA/STSCI/K. SANDSTROM (U. CALIF., SD)/SMIDGE; NASA/ESA/A. SIMON (GSFC)



▲ **NGC 248** This nebula is located 200,000 light-years away in the Small Magellanic Cloud galaxy. It's pink colour reveals it to be an emission nebula; blue nebulae shine only with reflected light.



JUPITER Although Hubble has mainly concentrated on deep sky objects, it has also kept an eye on some of our Solar System's planets. This image of Jupiter was taken in 2017 when the planet was 670 million kilometres away.



▲ **VEIL NEBULA** This small section of the Veil Nebula is part of area catalogued as NGC 6960, but also known as the Witch’s Broom Nebula.

▼ **MESSIER 106** A relatively close galaxy — only 20 million light-years away. This image combines Hubble imagery with extra data captured by amateur astrophotographers, Robert Gendler and Jay GaBany.



NASA/ESA/HHT; NASA/ESA/HHT (STSCI/AURA)/R. GENDLER (FOR HHT)/J. GABANY



MESSIER 102

Seen almost edge-on, this galaxy (also known as NGC 5866 or the Spindle Galaxy) is revealed to have a dust lane that appears to divide it in two, as well as a glowing outer halo.



EAGLE NEBULA

This updated image was made in 2015, but the original shot by Hubble in 1995 made the covers of magazines all over the world. The gas and dust formations were dubbed the 'Pillars of Creation'.



▲ **IC 4406** This planetary nebula, located about 2,000 light-years away in the southern constellation Lupus, is sometimes called the Retina Nebula for obvious reasons.

▼ **RING GALAXY** A ring of bright blue stars circle the yellowish core of what once was spiral galaxy. The ring is wider than our entire Milky Way galaxy. Known only as AM 0644-741, this ring galaxy is 300 million light-years away.



Constellation

Close-up

Argo Navis

This ancient formation survives only in fragmentary form.

OF THE 48 CONSTELLATIONS DESCRIBED in Claudius Ptolemy's *Almagest*, 47 survive to the current day. The sole exception is Argo Navis, the ship that carried the mythical Greek hero Jason and his fellow Argonauts to the end of the known world in quest of the Golden Fleece. Its stars ended up distributed among four nautically themed constellations: Carina, the keel or hull; Vela, the Sails; Puppis, the poop deck; and Pyxis, the compass. Pyxis is small and dim, but Carina, Vela and Puppis are all big, bright, and spangled with naked-eye star clusters. If you put them back together, they'd be the biggest constellation in the sky — much bigger than Ptolemy's original Argo, in fact. For shorthand, I will call the original constellation Old Argo Navis, and use Greater Argo Navis to denote modern Carina, Vela and Puppis.

The standard explanation for Argo Navis's dismemberment is that the French astronomer Nicolas-Louis de Lacaille (1713–62) chopped it up — and there is some truth to that. It's a fair bet that the constellation would still be alive and well today if Lacaille hadn't sailed to South Africa to observe the southern skies. Lacaille did indeed slice Pyxis off Argo, but he used the terms Carina, Vela and Puppis only to describe aspects of Greater Argo Navis. He would have been horrified to know that they would end up replacing it. Lacaille doomed Argo to extinction not because he despised it but because he loved it too much.

Another way to view Argo's demise is that it resulted from impersonal forces: the globalisation of European culture, the invention of the telescope, and the rising power of science and innovation with respect to tradition and authority.





SAILING THE SOUTHERN SKIES
Argo Navis once sailed intact, but it has since been splintered into several separate and distinct constellations. Here the Carina Nebula glows high in the Chilean sky above a dish of the ALMA submillimetre array.

Argo Navis is a southerly constellation, making it particularly vulnerable to the change in perspective — both physical and cultural — that marked the advent of the modern Western world. The southernmost stars of Old Argo were barely visible from the southernmost edge of the ancient Greco-Roman world. Toward the end of the 1500s, Dutch astronomers ventured south of the equator, where Argo Navis floats high in the sky rather than low upon the waters of the Mediterranean. They found it natural to connect Old Argo Navis to another bright star pattern just out of sight of the ancient world, plus the single most dazzling stretch of the Milky Way. And that, in turn, set the stage for the constellation's dissolution.

Observing northern Puppis

Let's tour Greater Argo Navis and see what can we see with our unaided eyes.

A most prominent formation is a tight, elegant triangle of medium-faint stars, numbered 1, 2 and 3 in Ptolemy's catalogue, and today called 11, Rho (ρ), and Xi (ξ) Puppis, respectively. They form a medium-faint but eye-catching triangle that Ptolemy described as the **Stern Ornament**. For users of binoculars and telescopes, Xi is also the jumping-off star for the rich, compact open star cluster **M93** just 1.5° to its northwest, one of the little gems of the Messier list. Keen-eyed stargazers with favourable skies, forearmed with

certainty of its existence, can now detect M93 even without optical aid. But it's much fainter than any deep sky object noted by pre-telescopic observers.

Not so with magnificent **M47**, one of the brightest open star clusters in the sky. It lies in a sea of 5th-magnitude stars that Ptolemy neglected and that was appended to northern Puppis in modern times. To my eye, 4th-magnitude M47 is the most prominent feature of that sector, much as M44 (the Praesepe or Beehive Cluster) dominates the constellation Cancer. I can see M47 easily without optical aid. It's similar in brightness to M41 in Canis Major, which was known to the ancients, so Ptolemy could have catalogued M47 but didn't. The same could be said for many other 'cloudy' spots in the night sky, most notably the Andromeda Galaxy. Ancient astronomers had no way of knowing that these fluffballs were significant.

That all changed in 1609 when Galileo Galilei turned his telescope to M44 and resolved the cluster into dozens of individual stars. You can experience the same thing by viewing M47 through binoculars or a small telescope, which resolve it into a dozen or so bright, young, blue stars, with a sprinkling of red giants.

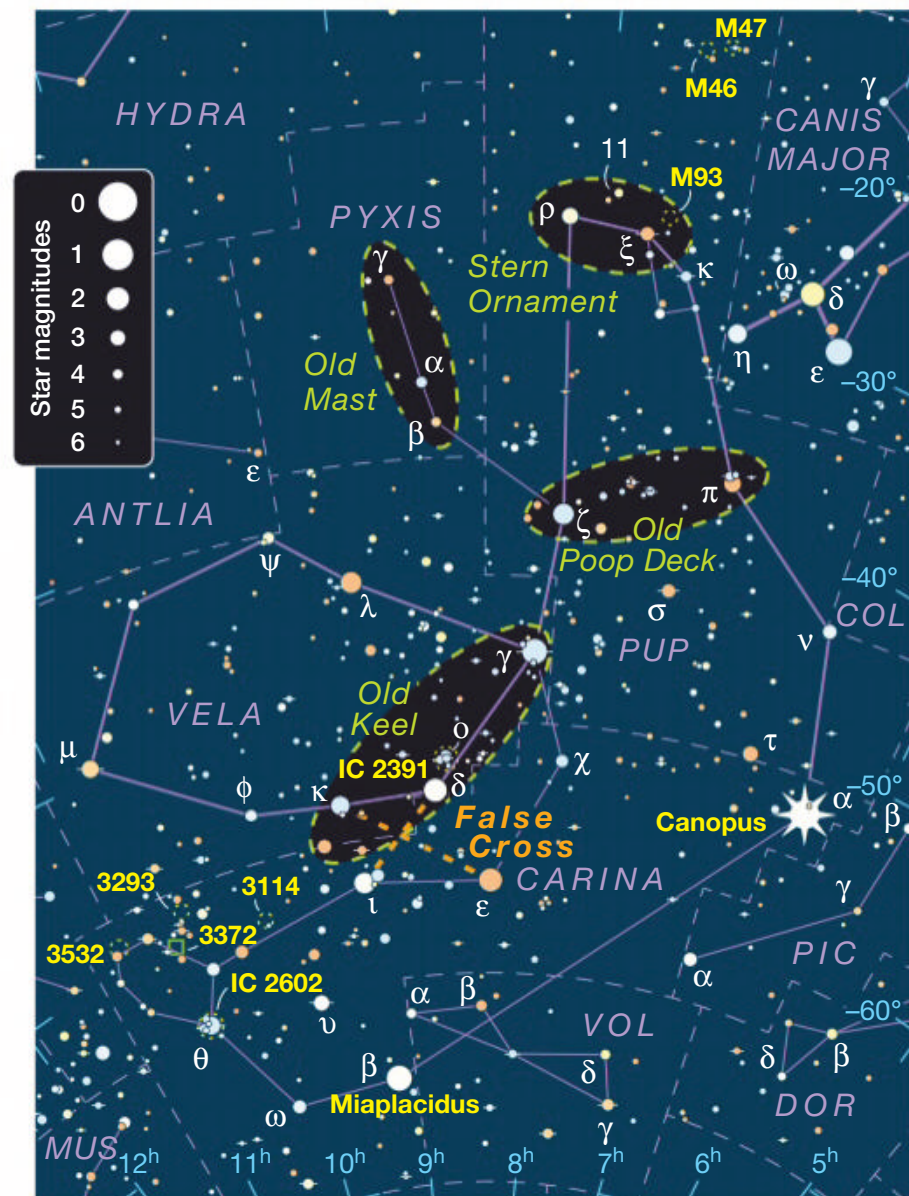
Under dark skies, you may also spot **M46** naked-eye as a similar-sized but much fainter cloud of light 1° to M47's left. The contrast between the few bright stars of M47 and the innumerable faint stars of M46 makes this one of the sky's finest fields for binoculars and telescopes of all sizes.

Lower left of the Stern Ornament you can find a faint but striking straight line composed (north to south) of the stars now known as Gamma (γ), Alpha (α), and Beta (β) Pyxidis. Those, together with Delta (δ) Pyxidis just to Gamma's upper left, form Ptolemy's **Old Mast**, which Lacaille sliced off intact to form the modern constellation Pyxis, the Compass. The straight line works well either as a mast or a nautical compass needle.

The Milky Way runs through northern Puppis, so it's full of medium-bright star clusters, a fine area to explore with binoculars and telescopes. But the next feature south of the Stern Ornament that a naked-eye observer is likely to notice is the wide star pair formed by 2.2-magnitude Zeta (ζ) Puppis and 2.7-magnitude Pi (π) Puppis, plus a scraggly line of stars connecting them. According to Ptolemy, these marked the poop deck, the ship's highest horizontal surface. I will call it the **Old Poop Deck** to distinguish it from the modern Puppis, which is much bigger.

Old Argo's brightest star is the dazzling **Canopus**, magnitude -0.7 , second only to the Sun and Sirius in brightness. In Ptolemy's time, before bright artificial lights, Canopus must have been an unmistakable beacon for an Egyptian sailor heading home to pick up yet another shipload of wheat to feed Rome's hungry masses. But for modern, southern stargazers, it is an unforgettable sight.

Old Argo's second-brightest star is 1.8-magnitude Gamma Velorum. Gamma forms a prominent zigzag line together with 2nd-magnitude Delta and Kappa (κ) Velorum to its





▲ **SPARKLES IN THE STERN** The open star cluster M93 lies in the constellation that Ptolemy called the Stern Ornament and that today we know as Puppis. If you know where to look, you might even be able to spot this compact cluster with the naked eye.



▲ **DOUBLE DELIGHT** The rich open star cluster M46 holds a surprise: the planetary nebula NGC 2348 floats in front of the cluster, but the two objects are not associated. You should be able to spot the cluster without optical aid, but you'll need a telescope for the planetary.

lower left. If you extend that line to Gamma's upper right to include Sigma Puppis, plus a bunch of fainter stars in between, you end up with the stars Ptolemy described as forming Argo's keel. I will call it the **Old Keel** to distinguish it from the modern constellation Carina, which is a very different grouping, barely overlapping with the Old Keel.

Also in view now is **IC 2391**, the Omicron (o) Velorum Cluster, a prominent hazy patch surrounding 3.6-magnitude Omicron, just 2° upper right of Delta Velorum. Of all Greater Argo's many bright naked-eye star clusters, this is the only one that falls within the region that Ptolemy assigned to Argo Navis. Binoculars show that it's a very coarse cluster dominated by five or six stars ranging from magnitude 4 through 6. One of the stars is a wide double; can you split it with binoculars?

Historical interlude

We have now visited about half the 45 stars that Ptolemy assigned to Argo Navis. He described the remainder as scattered around the deck and various other parts of the ship. It's a little hard to visualise Old Argo Navis; the depiction in Johannes Bayer's 1603 atlas *Uranometria* (shown on page 20) is as good as any and better than most. Note that the ship is sailing to the left, and the front half is missing, facts that all ancient authors agreed on.

Conspicuously absent is 2.7-magnitude Mu (μ) Velorum. Although it's farther north than many other of Ptolemy's stars, and also fairly bright, he neglected to include it in his catalogue.

Granted, measuring the positions of one-thousand-plus stars using ancient technology was a daunting job. Even so, Ptolemy's star catalogue is pretty sloppy, especially in its southernmost reaches. He could have done a better job if he

had been highly motivated. Just as Ptolemy didn't care much about faint fuzzies, he also didn't care all that much about individual stars except for the ones near the ecliptic, which are essential for measuring the positions of planets. And he cared greatly about planets, both because of the intellectual challenge of analysing their motions and because he was a passionate astrologer.

My own theory as to why Ptolemy included Delta and Kappa Velorum in Old Argo, but missed Mu, is that Delta and Kappa lie athwart the eye-catching Milky Way. For ancient sailors, Old Argo was where the Milky Way intersected the Mediterranean Sea on spring evenings. It's also where the Milky Way starts to get bright again after a long dull stretch in what's now Monoceros. Sadly for the ancients, the very brightest part lies just a little farther south, out of sight of the Mediterranean and all the major cultural centres of the ancient Western world. To get a good view of Greater Argo Navis as a whole, you need to be south of the equator, where the entire super-constellation floats high in the evening sky from February through May.

The first modern European ships to reach that far south were those of the Portuguese, probing down Africa's west coast in search of a new route to the Indies, which Vasco da Gama finally achieved in 1498. But eager to maintain their monopoly on the fantastically lucrative spice trade, they published little that might have been of use to others venturing into the Southern Hemisphere.

In 1595 some Dutch merchants, eager to break the Portuguese monopoly, launched an expedition of their own, and its navigators *did* publish a catalogue of the far-southern stars. The cartographer Petrus Plancius used that to fill in the blanks left by Ptolemy, publishing the world's first complete celestial globe. In addition to showing many new

constellations in the far-southern sky, the globe extended Argo Navis to the east, reaching all the way to Centaurus.

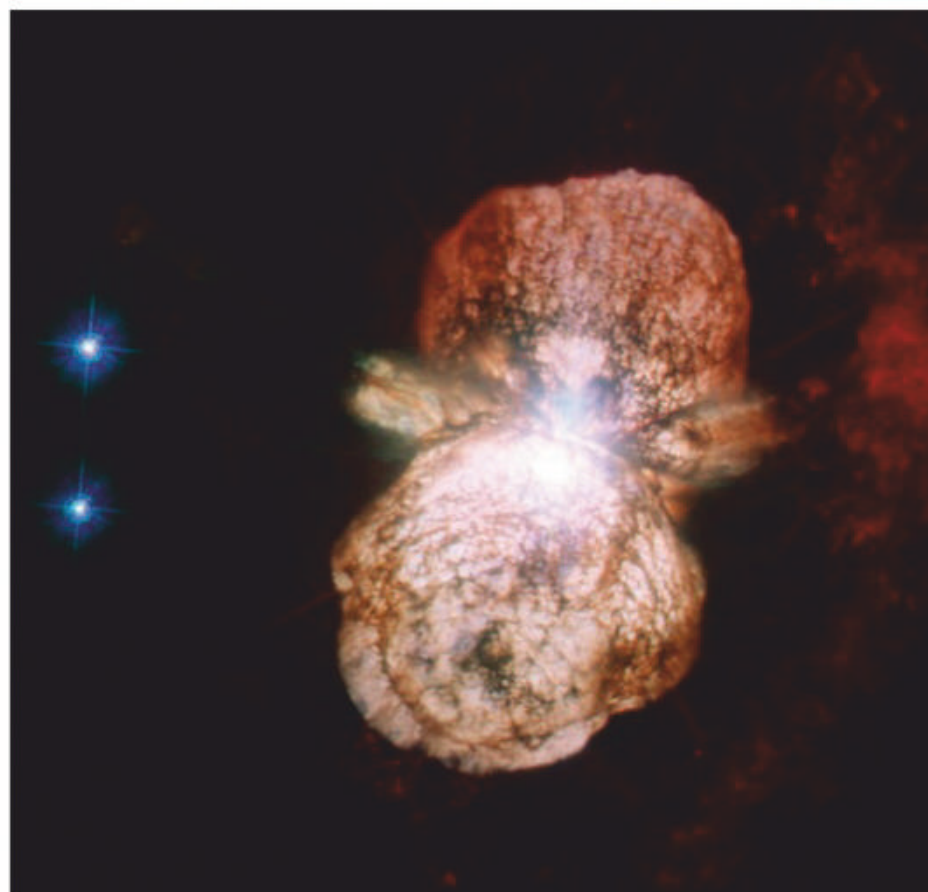
The final chapter prior to Lacaille took place in 1677, when the British prodigy Edmond Halley interrupted his college studies to take a telescope to the South Atlantic island of Saint Helena and remeasure the far-southern stars with much greater accuracy. He reclaimed the stars that Plancius had added to Argo and turned them into the constellation Robur Carolinum (Charles's Oak) to flatter Charles II, then king of England. The two different visions — Greater Argo versus Old Argo plus Robur Carolinum — coexisted and competed for the better part of a century.

With that as background, let's continue our tour and take a look at the stars contested between Plancius and Halley.

Greater Argo Navis

The pot of gold at the end of the Carina Milky Way is the incomparable Eta Carinae Nebula, **NGC 3372**, which is a large, prominent bright patch to the unaided eye under any but the brightest skies. It appears much bigger and brighter than the Orion Nebula, despite being six times more distant, in the next Milky Way spiral arm in from our own. The nebula becomes overwhelmingly complex and beautiful with even the slightest optical aid, crisscrossed with dark dust lanes and spangled with bright concentrations. Every increase in aperture and magnification reveals something new; you could spend a lifetime observing this object and see something new each time you look.

By amazing good luck, the Eta Carinae Nebula lies directly behind one of the densest concentrations of naked-eye star clusters in our own arm of the Milky Way, and those clusters are embedded in an extremely rich star field. The overall



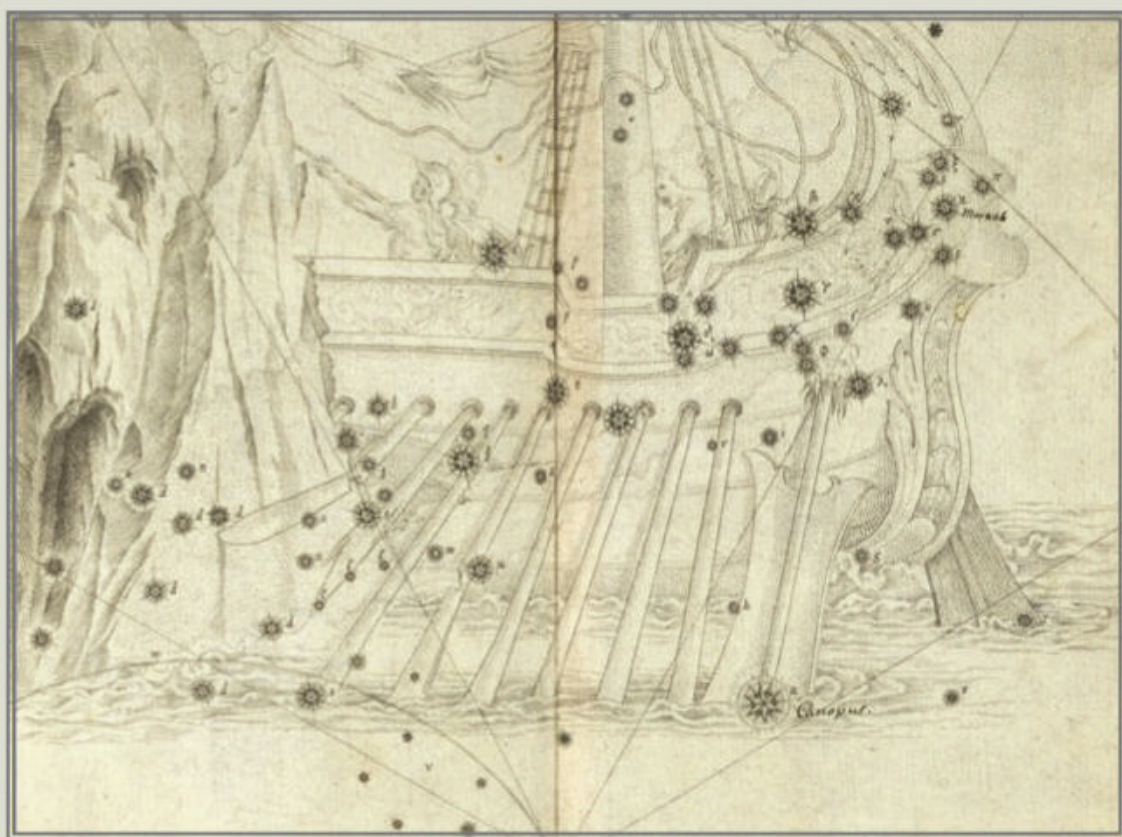
▲ **SUPERNOVA CANDIDATE** Eta (η) Carinae, which powers the eponymous nebula, is one of the most luminous and mysterious stars known. It is shrouded from direct view by a dust cloud called the Homunculus Nebula. It consists of at least two supermassive components, the brighter of which is probably ripe to explode as a supernova — perhaps even tonight.

effect of bright-on-bright-on-bright is unlike anything else in the sky. To my eye, this area outshines the star clouds in Cygnus, Scutum and Sagittarius by a large margin. It's full of fascinating features, but for now we'll concentrate on the four brightest clusters.

BAYER'S URANOMETRIA

In 1603, Johannes Bayer published *Uranometria*, the first atlas to cover the entire celestial sphere. For most of the sky, Bayer used the recent star catalogue of the Danish astronomer Tycho Brahe, which was extremely accurate. For the Ptolemaic stars too southerly to see from Denmark, Bayer used Ptolemy's low-quality data. And for far-southerly stars he used the Dutch star catalogues, which were better than Ptolemy's but nowhere near as good as Tycho's. Bayer labeled the brightest stars in each constellation with lowercase Greek letters, most of which have survived to the current day.

Bayer always tries to be faithful to Ptolemy's descriptions; for instance, he shows Canopus on the end of one of the two steering oars, the ancient equivalent of rudders. He cleverly explains the fact that Argo is only half a ship by showing the Clashing Rocks, though in the traditional Greek myths those smashed only Argo's stern ornament, not its front half.





LITTLE GEM NGC 3293 is a young open star cluster seemingly superposed on wispy clouds of gas and dust lanes in this European Southern Observatory image. The stars likely formed about 10 million years ago, and the cluster lies at a distance of some 7,600 light-years.

NGC 3532 rivals the Eta Carinae Nebula in brightness, though not in size. It's a stunning, huge, rich collection of bright stars through binoculars and small telescopes. **NGC 3293** is a tiny, almost stellar bright patch to the unaided eye, and optical aid reveals it as an extremely rich and compact group of bright and medium-bright stars, which are responsible for its nickname, the Little Gem. **NGC 3114** is intermediate in size and brightness between NGC 3532 and NGC 3293. Through binoculars it's a sparse group of bright stars that reminds me of a claw.

Well away from the Milky Way, the Southern Pleiades, also called **IC 2602**, consists of 2.8-magnitude Theta (θ) Carinae surrounded by a group of 5th-magnitude stars that I can only partially resolve without optical aid.

Tracing up the Milky Way far to the northwest, the **False Cross** draws the eye irresistibly. It consists of Kappa and Delta Velorum from the Old Keel plus Iota (ι) and Epsilon (ϵ) Carinae. I have drawn dashed lines onto the stick figure on page 18 to emphasise the asterism. It's strikingly similar in shape and orientation to the Southern Cross, though a tad bigger and fainter. I see both groupings as kites rather than crosses, since both lack a centre star. Continuing

two of the kite's sides to the northwest, the parallelism between Gamma Velorum and much fainter Chi (χ) Carinae reinforces the bond between Old Argo and its southerly extension.

Greater Argo does indeed look like a ship, much more so than Old Argo, since it's now a whole ship rather than just a half. Not only has Old Argo been stretched far to the left, it's also pivoted counterclockwise so that the stars of the Old Keel now mark the bottom of Vela, the sails.

Enter Lacaille

That's how things stood when Lacaille sailed for South Africa in 1750. His main purpose was to determine the scale of the Solar System by measuring Mars' parallax in conjunction with Jérôme Lalande back home in France. That's exactly the same reason why British Lieutenant James Cook sailed to Tahiti 19 years later, using Venus rather than Mars as the target object.

In retrospect, however, Lacaille's modest contribution to the scale-of-the-



◀ **PLACIUS GLOBE** Petrus Plancius was a Dutch-Flemish astronomer and cartographer. He is renowned for having produced the first complete celestial globe, such as the one shown here.

Solar-System problem is dwarfed by his gargantuan feat of measuring the position and brightness of some 10,000 far-southern stars — all this accomplished in two years using a telescope with a half-inch aperture. He also tallied dozens of deep sky objects. Lacaille stamped his mark indelibly on the southern sky, and he surely earned the right to do so through his hard work and dedication.

After returning to France, Lacaille published his results in 1756 in a French science journal. He didn't have time to reduce all of his observations to equatorial coordinates (right ascension and declination), but he catalogued almost 2,000 of the brightest stars, together with a map and a lengthy introduction discussing this work.

Lacaille then started to polish his results and translate them from French to Latin, a task that was interrupted by his premature death. The results were published posthumously

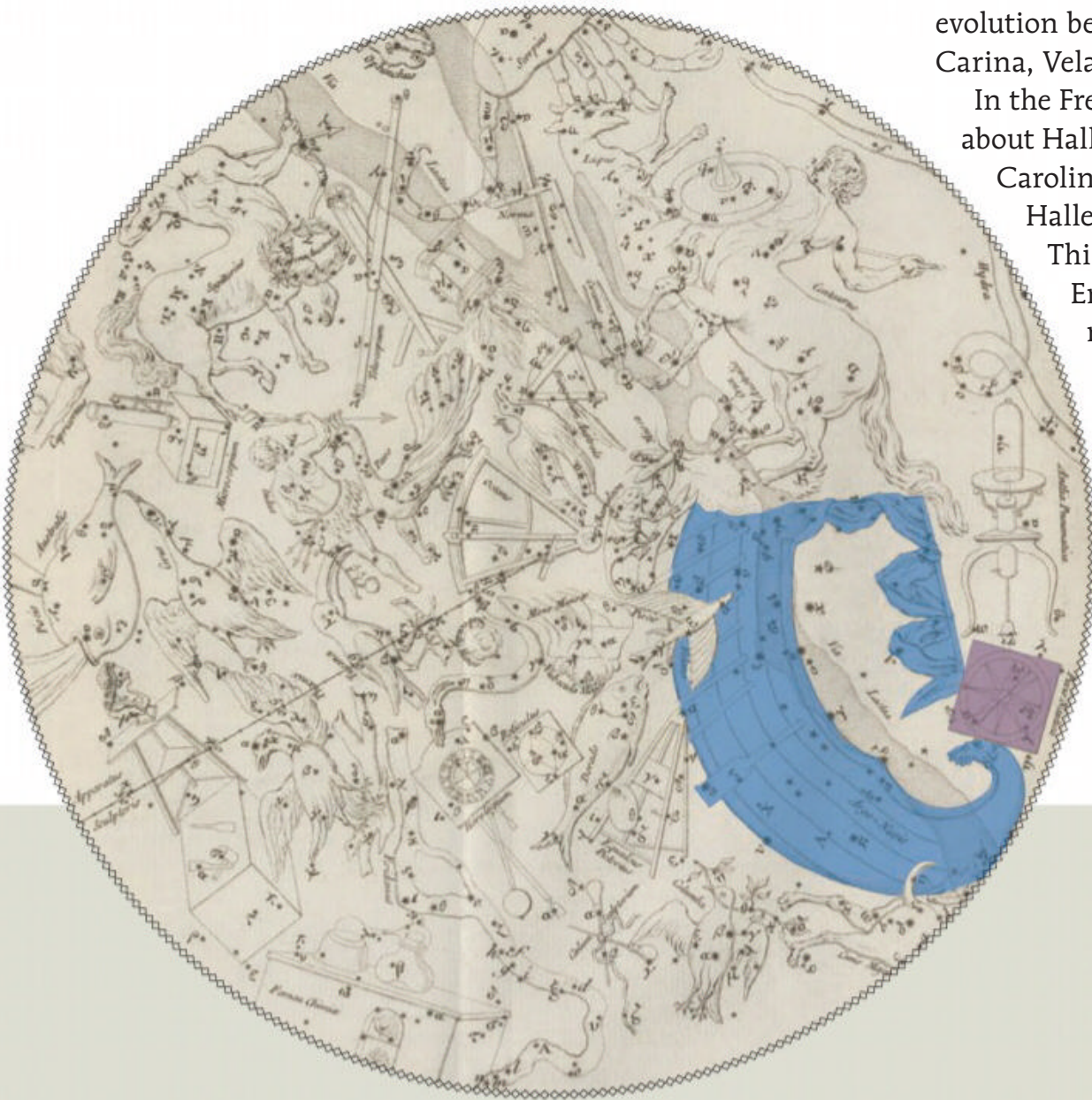
A HUMAN COMPUTER

Nicolas Louis de Lacaille (1713–1762) was an outstanding surveyor and astronomical observer with a flair for rapid and accurate computation, an extremely important skill before the advent of mechanical and electronic calculators.



in 1763. Much later, British astronomers completed the task of reducing all his star measurements to equatorial coordinates, publishing a catalogue of 9,766 stars in 1847. Comparing the three catalogues illustrates the evolution between the original Greater Argo and the modern Carina, Vela and Puppis.

In the French introduction, Lacaille complains bitterly about Halley's theft from Greater Argo to form Robur Carolinum, stooping even to sneering at the fact that Halley was just 21 when he invented his constellation. This might be partly national rivalry; France and England were competing for global dominance, resulting in the Seven Years' War and ultimately Napoleon's defeat at the Battle of Waterloo in 1815. But Lacaille does have a compelling aesthetic argument: He says that Halley desecrated the beauty and symmetry of Greater Argo by stealing its most beautiful stars. This may explain why Lacaille could be so scathing about Robur Carolinum while he himself stole the stars of the Old Mast to form Pyxis. None of the 14 new constellations that Lacaille invented contains a star brighter than



► **LACAILLE'S CHARTS** Lacaille's charts and tables covered the entire sky south of the Tropic of Capricorn. They're dominated by two giant traditional constellations: Argo Navis (highlighted here in blue) and Centaurus. Pyxis, composed of stars that Lacaille filched from Argo, appears in purple.

► **LACAILLE'S CATALOGUES** The table at left shows excerpts from Lacaille's French and Latin star catalogues, published in 1756 and 1763, respectively, plus the 1847 version published in England. Only the constellation, star letter and magnitude are included; celestial coordinates and other information have been omitted for clarity. Surprisingly, the 1847 catalogue used the nominative form of constellations' names instead of the usual possessive form.

French, 1756			Latin, 1763			English, 1847		
Du Navire <i>Canopus</i>	α	1	Argūs <i>Canopus</i>	α	1	ARGO	α	1
		6			6			6
		6			6			4½
		6			6			6
Pouppe du Navire	<i>G</i>	6	Argūs in puppi	<i>G</i>	6	Puppis	<i>G</i>	5½
		6			6			6

3rd magnitude, and precious few even reach 4th magnitude. He reserved all the bright stars to glorify the constellations invented by the Dutch. He even appended 1.7-magnitude **Miaplacidus** (Beta Carinae) to Greater Argo, when he could easily have used it for purposes of his own had he desired to do so.

Bayer had done a rather haphazard job with the far-southern sky, based on unreliable sources, so Lacaille also re-lettered the far-southern constellations. If you see a Greek letter for a star south of declination -30° , it almost certainly comes from Lacaille rather than Bayer. When he came to Greater Argo Navis, Lacaille understandably ran out of letters. Even in this article, which mentions only a few selected bright stars, we have used about half the Greek alphabet. Bayer's practice after running out of Greek letters was to continue with lowercase Roman letters. But Lacaille was greedy; he noted that Greater Argo contains more than 160 stars readily visible to the unaided eye, and contrary to Bayer's practice, he insisted on giving letters to each. So he subdivided his Navire (French for ship) into "la Pouppe, le Corps & la Voilure," meaning the Poop, the Body, and the Sails. Then he ran through the Roman alphabet, both lower case and upper, for each subdivision.

Incidentally, Carina can mean both a ship's keel and its entire structure; Lacaille's use of "Corps" makes it clear that he meant the latter. So it's more accurate to translate Carina as the Hull than the more usual Keel.

I think that Lacaille was showing off. Sure, he saw a lot more stars in Argo than Ptolemy had, but he had the benefit of a telescope. And it's dramatically much easier to see a faint object without optical aid if you have a telescope handy to reassure you that it's not an optical illusion.

You can see the results in the table at the bottom of page 22. Canopus, being one of the 24 truly splendid stars, rates a Greek letter as the Alpha star "du Navire" (of the Ship). Four entries later we have the G star of "Pouppe du Navire," the Poop of the Ship.

Things change a little in the Latin version of 1763. Now each one of the stars has a constellation listed, not just the ones that have letters. That means that unlike both Ptolemy and Bayer, Lacaille had completely tiled the sky with constellations, leaving no gaps between them. But in both the French and Latin versions, Lacaille never uses the terms Poop, Hull and Sail without also saying "of the Ship." And letterless stars are assigned to Argo, not to its subdivisions.

Nomenclature changes yet again in the 1847 catalogue. Now "of the Ship" has been dropped, and Puppis, Carina and Vela are treated as full-fledged constellations. To drive the point home, letterless stars are assigned to the components, not to Argo itself. But the Greek-letter stars are still "of Argo".

Affairs remained much like that for the next 80 years; both Argo Navis and its constituent parts coexisted uneasily, with different authors using different terminology. And finally, in 1928, the International Astronomical Union decided to extirpate Argo and rename Canopus from Alpha Argus to Alpha Carinae.

THE VOYAGE OF THE ARGO

The constellation that Ptolemy called Argo Navis was associated with several different ships in ancient history, but most Greco-Roman authors agreed that it was Jason's Argo. The Argonauts who sailed aboard it included Hercules, Castor, Pollux, Orpheus and all the other great heroes alive at that time. They sailed to Colchis, in what is now the country Georgia, to retrieve the fleece of the golden ram that ended up in the sky as the constellation Aries. The painting above by Willy Pogány is from Padraic Colum's children's book *The Golden Fleece and the Heroes Who Lived Before Achilles*, still in print almost a century after first publication.



The most memorable character in the Argo legend is the sorceress Medea, daughter of King Aeëtes, owner of the Golden Fleece. She betrays her father for love of Jason, who in turn betrays Medea after they return home to Greece. In one version of the story Jason loses everything that he owns and dies when the prow of the rotting Argo falls on him as he sits under it contemplating his past glory.

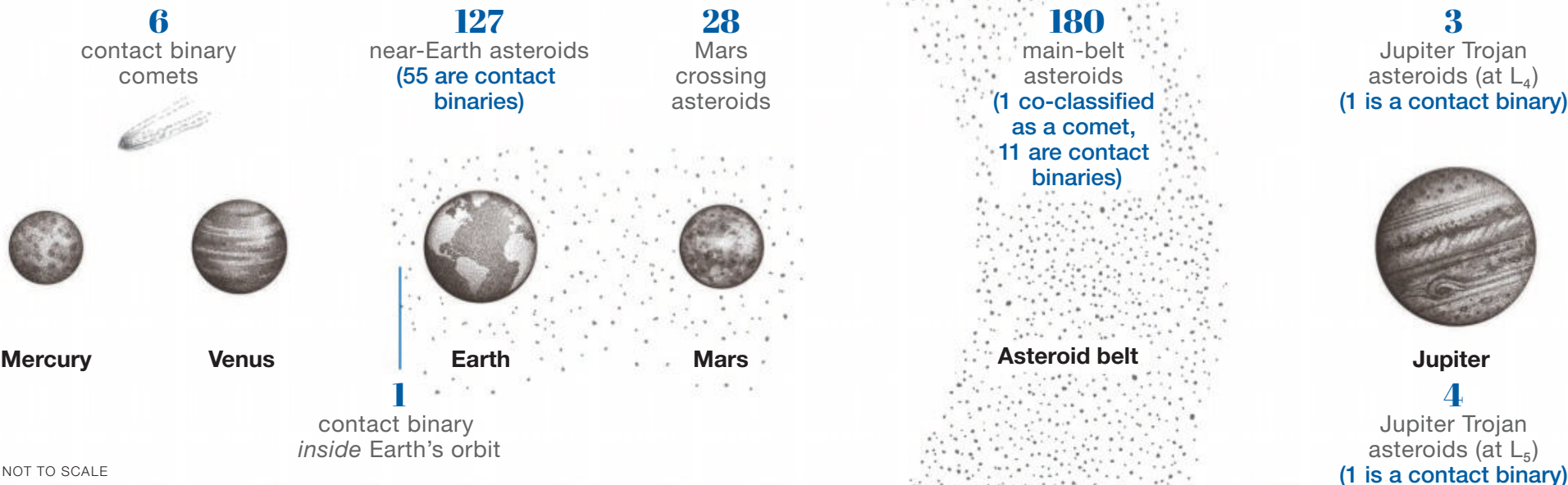
Ironically, Lacaille's Roman letters have been forgotten, while the subdivisions that he introduced to make Roman lettering feasible ended up cannibalising their parent constellations. Things would probably have turned out very differently if he had used numbers rather than letters to denote Argo's naked-eye stars.

■ **TONY FLANDERS** had one of his best views of Greater Argo a few hours after watching a total solar eclipse from Argentina on July 2, 2019.

FURTHER READING: My favourite resource for constellation history is Ian Ridpath's superb book and website *Star Tales* (ianridpath.com/startales/contents.htm).

PRIMITIVE WORLD The Kuiper Belt object 2014 MU₆₉ (now officially named Arrokoth) is a contact binary, each lobe a hodgepodge of smaller regions. Scientists think this is the most unchanged object from the Solar System's formation that a spacecraft has so far encountered.

Binary Worlds



The wide variety of binary objects in the Solar System not only surprised astronomers but is now also helping us understand the birth of planetary systems.

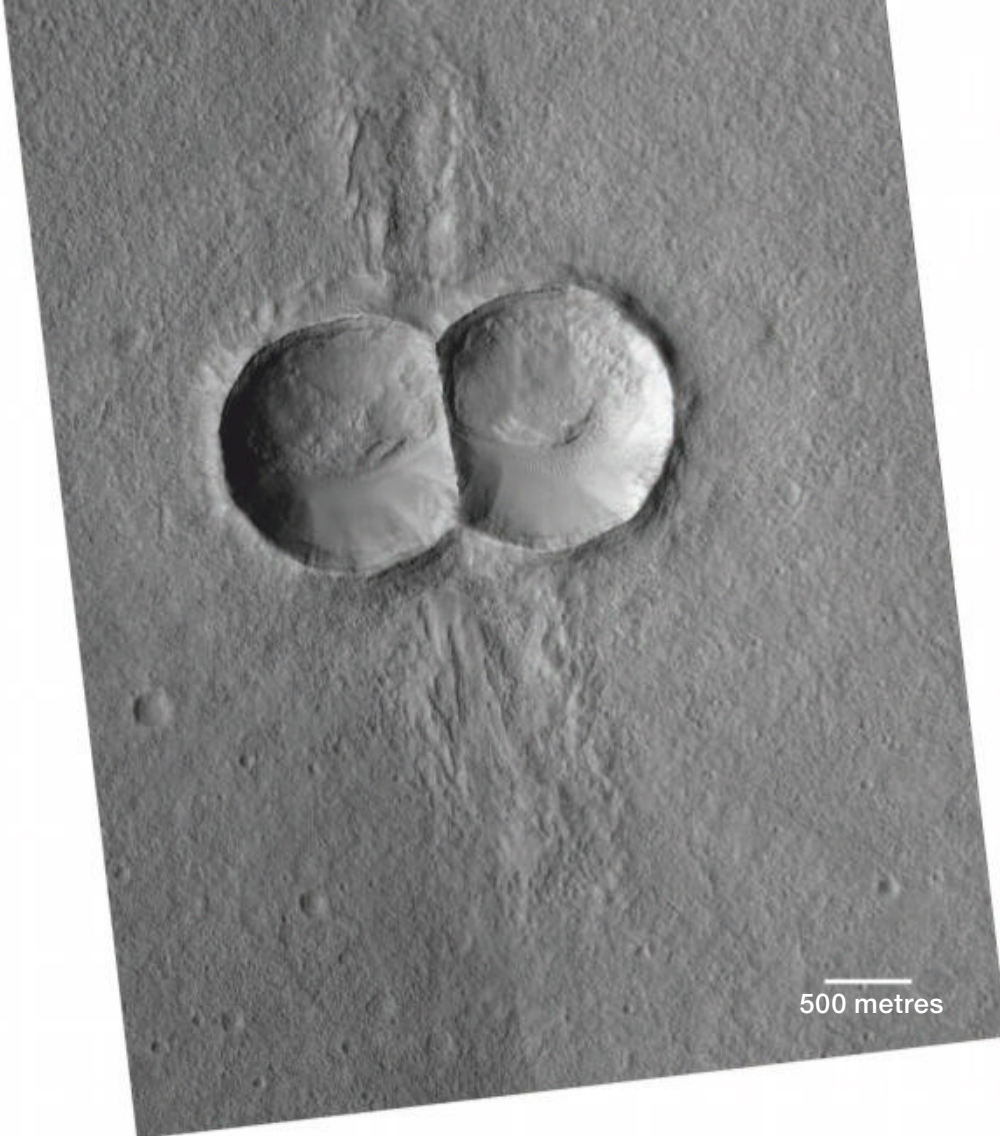
ASTRONOMERS HAD HOPED TO SEE something interesting when they steered the New Horizons spacecraft on course to visit a Kuiper Belt object soon after it flew past Pluto. They chose the object 2014 MU₆₉ because its nearly circular orbit beyond Neptune marked it as among the most primordial objects known in the Solar System, and its path put it within reach for New Horizons. They nicknamed it Ultima Thule, meaning ‘beyond the known world.’ On November 8, 2019, its official name became Arrokoth, meaning ‘sky’ in the Powhatan Algonquian language.

All Hubble recorded was a tiny spot in the sky, but when astronomers watched Arrokoth occult a distant star, the little world’s silhouette hinted at a pair of objects orbiting close to, or even touching, each other. So controllers were both hopeful and anxious as the spacecraft bore down on Arrokoth for its close encounter early on New Year’s Day 2019.

Our first close-up view of Arrokoth bore out those hints: It showed a contact binary shaped like a giant snowman. The two lobes seem to have bumped very slowly into each other sometime early in their history and stuck together. Subsequent images revealed that the two reddish lobes are fairly oblong, joined on their long ends, with brighter stuff spread around the junction almost like glue.

Arrokoth is not alone in its strange shape. Observers have found many binaries in the Solar System, both contact binaries like Arrokoth and ones in which the members don’t touch but orbit each other. They appear in the Kuiper Belt, the main asteroid belt and even among comets and the objects that come near Earth. Some scientists wonder if binaries might have been a standard stage of planet formation.

Yet just 30 years ago, most astronomers doubted these binary worlds existed.



▲ **DOUBLE CRATER** The shared rim and plume-like ejecta of this Martian double crater formed when two objects hit simultaneously. The impactor may have consisted of two loosely connected objects of the same mass.

Discovering binaries

The first hints came in the 1970s, when observers recording the light curves of stars occulted by asteroids saw unexpected variations before or after the asteroid passed in front of the star. Geologists found a few terrestrial craters that appeared to have formed in pairs. And in August 1989, Steven Ostro (Jet Propulsion Laboratory) and colleagues used the 305-metre Arecibo radio telescope to reveal the peanut shape of the potentially hazardous near-Earth asteroid 4769 Castalia (1989 PB). His team suspected the 1.4-kilometre asteroid might be a contact binary rotating every four hours.

Binaries are everywhere and come in varied forms. Some pairs are touching; others have widely separated orbits. Some pairs are equal size; others differ widely in size.



Saturn



Uranus



Neptune

Kuiper Belt

115
trans-Neptunian
objects
(14 are contact
binaries)

The first convincing evidence of a pair of asteroids orbiting each other, however, was a byproduct of NASA's Galileo mission to Jupiter. The spacecraft had to pass through the main asteroid belt, so planners arranged flybys of two asteroids. The second, on August 28, 1993, revealed that the 60-km oblong asteroid 243 Ida was orbited by a 1.5-km moon, later dubbed Dactyl. The images of little Dactyl moving along with the much larger Ida were finally enough to convince Brian Marsden, the long-time director of the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics, that binary asteroids existed.

More discoveries followed. Some have involved radar, others were made using ground-based telescopes with adaptive optics or the Hubble Space Telescope, which can resolve separate bodies if their orbits take them far enough from each other. Often the best data come from spacecraft exploring objects up close, like Galileo's visit to Ida and New Horizons' flybys of Pluto and Arrokoth. The Rosetta mission to famous 'rubber duck' Comet 67P/Churyumov-Gerasimenko, for example, showed us spectacular close-ups of a contact binary nucleus. But extremely precise measurements from far away of how an object's brightness changes over time have identified more than half of known binaries.

As of November 2019, astronomers had identified 375 asteroids and trans-Neptunian objects with at least one companion: 359 have one, 15 have two, and the record holder, Pluto, has five. These objects are spread throughout the Solar System: 72 near-Earth asteroids, 28 Mars crossers, 169 objects in the main asteroid belt (one of them a comet), five Jupiter Trojans and 101 beyond Neptune. An additional 67 inner Solar System and main-belt asteroids, two Jupiter Trojans, 14 trans-Neptunian objects, and six comets are contact binaries, including Arrokoth.

That adds up to quite a diverse bestiary. Binaries are everywhere and come in varied forms. Some pairs are touching; others have widely separated orbits. Some pairs are



▲ **IDA AND DACTYL** Asteroid 243 Ida and its moon, Dactyl, as seen by the Galileo spacecraft en route to Jupiter. The moon's discovery shocked much of the science community when announced in 1994.

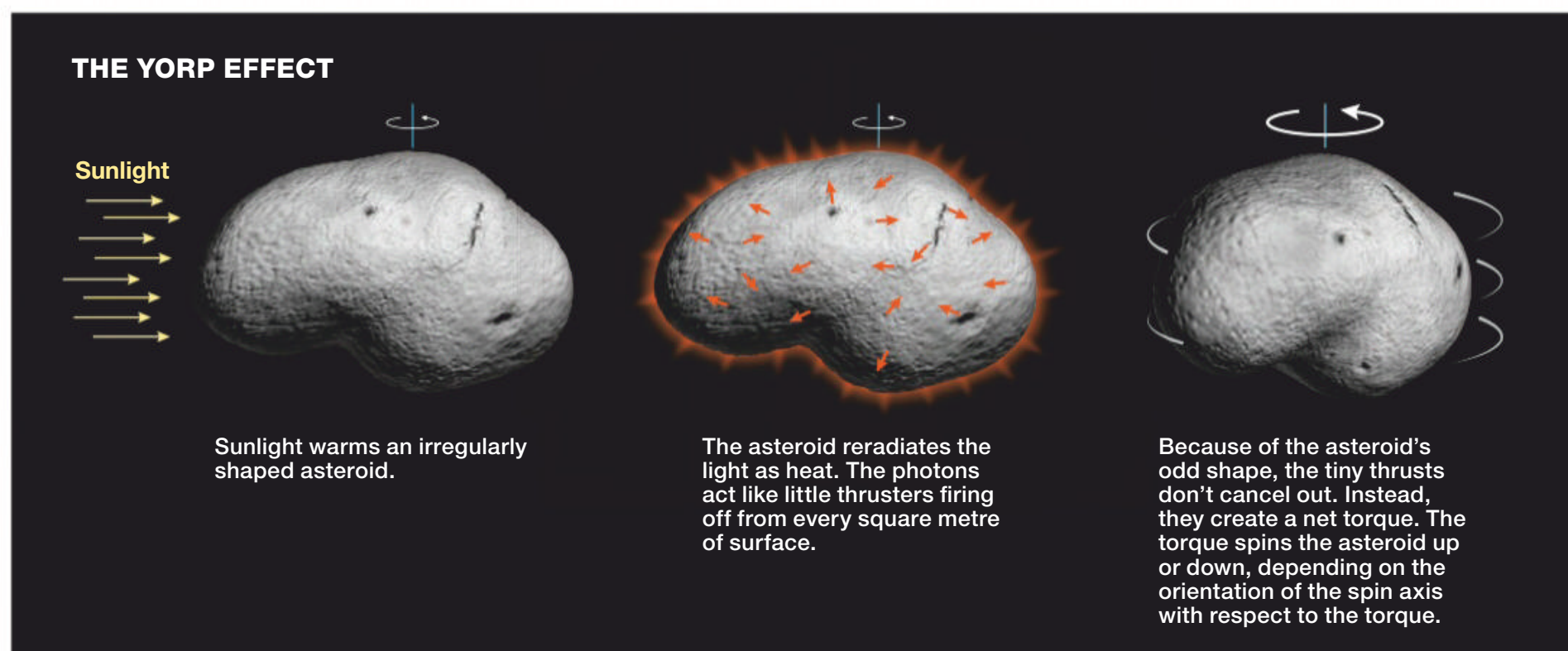
equal size; others differ widely in size. Some rubble piles spin off chunks that orbit the main body for a while, then slowly return to merge with it. Astronomers think their differences reflect where they formed and where they have wandered since.

To sort through the bestiary, we will start with near-Earth binaries and move outward through the Solar System to Arrokoth and other objects in icy orbits beyond Neptune.

Near-Earth binaries and the YORP effect

Radar has discovered about three-quarters of the multi-member near-Earth asteroids, says Patrick Taylor (Lunar and Planetary Institute). Maximum size is a few kilometres. He says that one-sixth of near-Earth asteroids wider than 200 metres are binaries; another one-sixth are contact binaries like Castalia and Arrokoth, with two similar-size lobes touching each other and rotating jointly.

The separate members of near-Earth binaries generally orbit only a few kilometres from each other, or a few times the



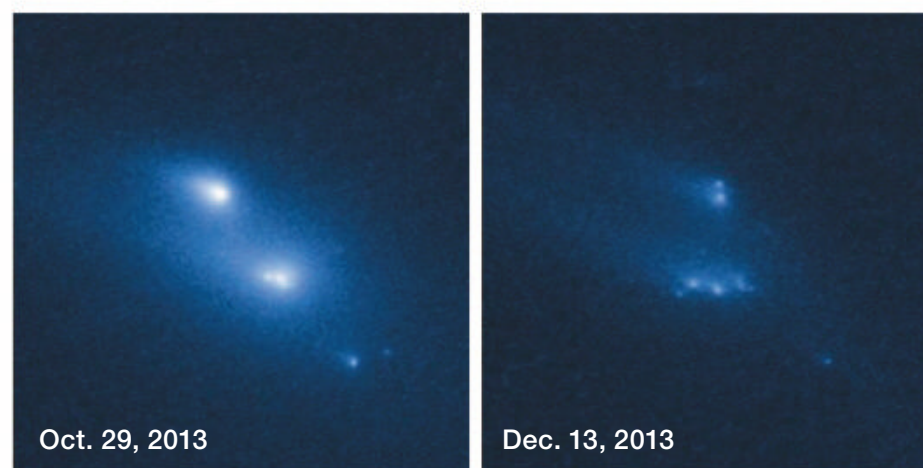
size of the primary. The bigger objects tend to spin fast, with 'days' lasting only 2.2 to 4.5 hours. The smaller components typically are 4% to 58% the sizes of the primaries.

Near-Earth orbits are chaotic, and objects normally stay in them for only around 10 million years before colliding with a planet or the Sun or being ejected out of the region. Most near-Earth objects are 'rubble piles,' accumulations of material held together loosely by gravity, which makes them vulnerable to three processes that can break them apart before they are lost. Collisions can knock pieces out of the rubble pile, which then drift back to form binaries with their parent bodies. Close gravitational encounters with planets can tear apart both asteroids and comets, as happened when Comet D/Shoemaker-Levy 9 passed near Jupiter on July 7, 1992.

The third process relies on far weaker forces, but over time it is far more effective because it is powered by sunlight. Light carries momentum that it can transfer to objects when reflected or absorbed and re-radiated, and the induced torque can change the spin of an irregularly shaped object. The process is called the *YORP effect*, and depending on the object's rotational orientation it can either speed up or slow down its rotation. "It's very weak, a measurable force but not a huge force," says Daniel Scheeres (University of Colorado, Boulder). Over long periods, the YORP effect can spin up a rubble-pile asteroid enough for the centrifugal force at its equator to exceed the body's gravitational attraction, and pieces can drift away.

The strength of the effect depends on the intensity of the incident light. It's stronger for near-Earth objects and much weaker in the main belt, which lies farther from the Sun. Also, the smaller the object, the more a given amount of sunlight can increase its spin. "This means that these effects are only active on small bodies," Scheeres says. His students have measured the YORP effect as it spun up small defunct artificial satellites in geostationary orbit within months to years. Asteroids are more massive, so it takes hundreds of thousands to hundreds of millions of years to spin them up. But the Sun shines relentlessly. Many single near-Earth asteroids are spinning nearly fast enough to start shedding material, and all the near-Earth binaries have close orbits, both outcomes expected from the YORP effect.

Asteroid rubble that has spun off may drift away, but it generally does not escape permanently. Instead, it goes into orbit around the asteroid, where in theory escaped pieces might accrete to form a smaller, stable companion for the original asteroid. Details are unclear, including how much material would escape, how much would stay to form the resulting binary companion, and how large it would be. However, Scheeres says, formation of a new object in orbit could in theory trigger the related 'binary YORP effect,' which can cause the pair to either spiral in or out depending on details. If the two spiraled out, they could become separate objects. But if they spiraled in, they could merge with each other to re-form a single object, even though some mass would be lost.



▲ **ASTEROID BREAKUP** Main belt object P/2013 R3 disintegrated unexpectedly in 2013. Each piece had its own comet-like dust tail. Researchers suspect the YORP effect might have spun the asteroid up until it flew apart.

Main belt and comets

The YORP effect is much weaker farther out in the main asteroid belt, so other effects are likely responsible for most of its 169 orbital binary asteroids. Estimates of the fraction of binaries in the main belt vary widely because few have been observed closely enough to detect whether these are multiple objects. Main-belt binaries include a wide variety of relative sizes and orbital spacings, and many are much larger and more widely spaced than objects with orbits near Earth's.

Collisions are known to happen in the main belt, a region of space that is much more stable and densely populated than the region of near-Earth orbits. Collisions could form widely separated pairs with a large primary and a very small secondary, like Ida and Dactyl.

Only about 10 contact binaries have been spotted in the main belt, most detected by radar. That number includes a peculiar object among the Trojan asteroids that share Jupiter's orbit, 624 Hektor. It's a large contact binary orbited by a smaller moon. Ground-based adaptive optics show the larger body is a peanut-like contact binary measuring about 400 by 200 km, orbited by a 12-km moon. That makes Hektor both a contact binary and an orbital binary. In 2014 Franck Marchis (SETI Institute) and colleagues calculated that the moon's orbit is stable. They proposed that two 200-km components had collided, forming a contact binary and ejecting a fragment that became the moon.

Although we think of asteroids as rocky objects, some two dozen objects originally designated main-belt asteroids have been reclassified as comets after they began spouting comas or tails. One, P/2013 R3, broke up into several pieces that went their separate ways in 2013. Another, initially designated asteroid 2006 VW₁₃₉ and later numbered 300163, has now been recognised as the first orbital binary comet. In 2017, a team led by Jessica Agarwal (Max Planck Institute for Solar System Research, Germany) published Hubble images showing two roughly kilometre-size objects in an elongated orbit around each other that spanned 100 kilometres. No binary asteroid has the same combination of wide separation, similar-size members, high orbital eccentricity, and cometary

emissions. Agarwal says the binary may have formed either when the two pieces split from a single collision fragment, or when two fragments from a collision hooked up gravitationally in the aftermath. Intriguingly, it is one of 11 objects in main-belt orbits traced to the breakup of a 10-km object 7.5 million years ago. Yet none of the others has shown similar cometary emissions.

Contact binaries are common in comets. Four of the six comets imaged by spacecraft have two distinct lobes. The most impressive images are from Comet Churyumov-Gerasimenko, which show that ices began eroding from both lobes of the rubber duck after the incoming comet passed Jupiter's orbit. Close-ups near the 'neck' show networks of cracks where the two lobes meet, a sign of weakening that might be linked to stress or ice sublimation.

How such an object forms remains a big question. Comets are thought to have formed 20 to 30 astronomical units from the Sun, then to have been pushed far beyond Neptune's orbit during the time of planetary migration. They stay there until perturbations send them inward to the planetary region, where encounters with the giant planets make them the periodic comets we see in the inner Solar System. Comet Churyumov-Gerasimenko, for example, now has a 6.44-year orbit that takes it just beyond Jupiter.

David Nesvorný (Southwest Research Institute) says mergers like those that produced Arrokoth in the Kuiper Belt might produce an object shaped like Comet Churyumov-Gerasimenko. But he doubts that the process could occur often enough to explain why two-thirds of the nuclei imaged so far are contact binaries.

Primordial planetesimals on ice

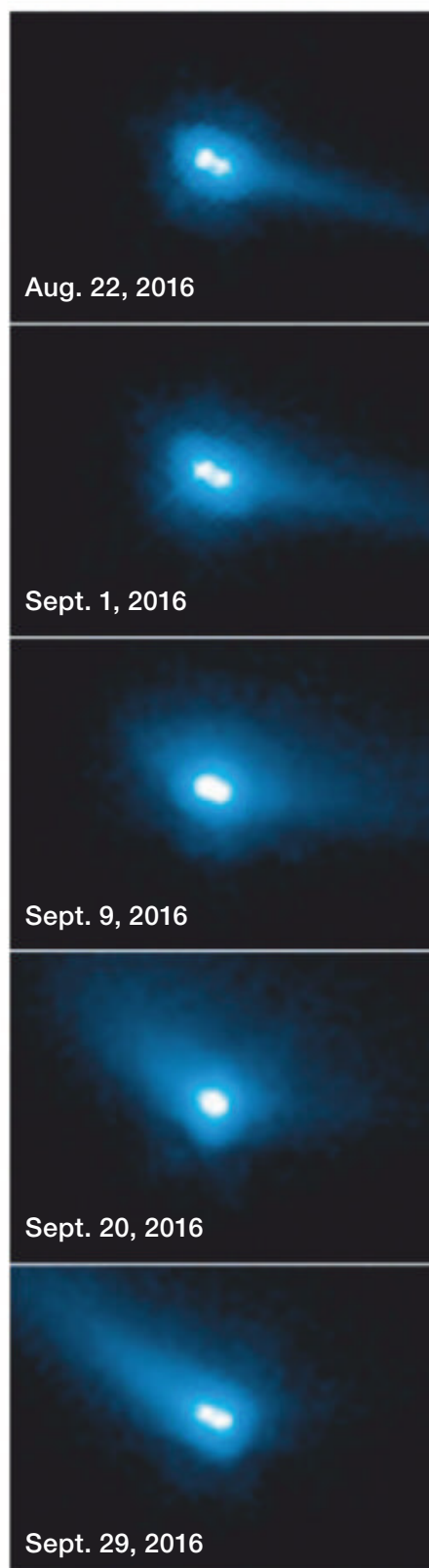
The New Horizons spacecraft launched in January 2006 to explore Pluto and the other objects in the Kuiper Belt that stretches beyond the orbit of Neptune. So far it has delivered spectacular close-up images of two Kuiper Belt binaries: Pluto with its five moons and the contact binary Arrokoth. The

► **BINARY COMET** This series of Hubble images reveals that the nucleus of 2006 VW₁₃₉ is made of two objects revolving around each other. Astronomers think that the main-belt object has only been a binary for about 5,000 years. (The tail's changing orientation is due to the change in the Sun-Earth-object alignment between observations.)

two share many features that come from having spent billions of years in the icy fringes of the Solar System. However, even before New Horizons reached Arrokoth, we had learned that the Kuiper Belt is a refuge for a diverse range of objects that differ in their orbits, origins and early histories.

Discovered 90 years ago, Pluto is the exemplar of a class of objects called *plutinos* that formed closer to the Sun, were scattered when Neptune migrated outward and became locked into an orbital resonance with Neptune. Pluto's largest moon, Charon, was discovered in 1978 and is so large that the duo's centre of mass lies outside Pluto entirely — the two bodies orbit a common centre. The system likely formed when a giant impact on proto-Pluto blasted debris into orbit that accreted to form Charon.

Hubble spotted two small new moons in the spring of 2005, soon before the New Horizons launch. Two more followed in 2011 and 2012. The four small moons are neatly spaced with orbital periods about three, four, five and six times Charon's. Nesvorný says how they formed remains "a big puzzle".



Contact binaries are common in comets. Four of the comets imaged by spacecraft have two distinct lobes.

UP CLOSE Spacecraft have imaged six comet nuclei up close. Four of these have a bilobe shape.



1P/Halley
Vega 2,
1986

David Jewitt (then University of Hawai‘i) and Jane Luu (then University of California, Berkeley) discovered the second of more than 2,000 known Kuiper Belt objects in 1992. Initially called 1992 QB₁ — and recently renamed 15760 Albion — it is smaller and fainter than Pluto. Albion’s orbit is also more circular and lies almost flat in the plane of the Solar System. Many more such bodies have been found in similar orbits and are called *cold classical objects* because their orbits are more planet-like than Pluto’s.

Cold classical objects are thought to have formed directly from the outer part of the protoplanetary disk and remained unaltered for the past 4.6 billion years. That makes them the most pristine planetesimals we’ve found. Astronomers wanted New Horizons to visit one, but Albion was out of its path so they searched for another and found Arrokoth in 2014. The images showed their choice was right. Arrokoth “is as primordial as it gets,” says William McKinnon (Washington University in St. Louis). “It has not been disturbed and was not part of any large-scale rearrangement or orbital scattering.”

When images revealed Arrokoth was a contact binary, observers first assumed the lobes were round. As more photos gave better perspective, Audrey Thirouin (Lowell Observatory) recalls, the squashed shapes “kind of surprised all of us”. Two flattened oblong disks, 22 km and 14 km long, respectively, had collided end to end with no obvious deformation. They’re spinning around an axis that passes through the larger one, close to the contact point. They also show several distinct regions, which may be remnants of smaller pieces that accreted to form each lobe. Astronomers saw similar units on comets Churyumov-Gerasimenko and 9P/Tempel 1.

Scientists had predicted that about a third of all trans-Neptunian objects should be contact binaries. Thirouin and Scott Sheppard (Carnegie Institution for Science) have found that 10% to 25% of cold classical objects may be contact binaries made of equal-size members, lower than the 40% to 50% they found for *plutinos*. But we are still in the early days; observations are difficult and uncertainties are large.

The fraction of objects with companions in this region is high. Most of the largest objects found have at least one moon. “Binaries are much more common in the Kuiper Belt than anyone had appreciated,” says McKinnon.

Curiously, more binaries have been found among 100-kilometre cold classical objects than had been expected. “We are talking about the majority of 100-kilometre objects being binaries,” says Nesvorný. “That’s really interesting.”

The result shows intriguing similarities to computer models of the Solar System’s formation, which predict building blocks of the same size range. The models show that, as gas and dust collapse under their own gravitation into 100-kilometre-class bodies, an effect called the *streaming instability* mixes the stuff in a way that helps it stick together. Conditions in the collapsing cloud cause the clumps to form binaries with similar-size components.

In both the model and for real trans-Neptunian binaries, 80% of the time the two bodies circle each other in the same direction as the pair revolves around the Sun. Nesvorný says the theory applies over a wide range of conditions, so the streaming instability could seed planetesimal formation around other stars, too.

More painstaking measurements and analysis are needed to identify binaries and to extract information on their orbits. Theoretical models need further analysis and more computer power. And more is on the way from New Horizons, which will not finish sending its Arrokoth data until September 2020 and may yet fly by a third Kuiper Belt object. Yet the dramatic close-ups of Arrokoth in the Kuiper Belt and Comet Churyumov-Gerasimenko closer to us have already shown us the richness of the minor planets that not too long ago were just faint dots through even our best telescopes.

■ **JEFF HECHT** writes about science and technology and is a fellow of the Optical Society. His most recent books are *Understanding Lasers* and *Lasers, Death Rays, and the Long, Strange Quest for the Ultimate Weapon*.



19P/Borrelly
Deep Space 1,
2001



81P/Wild 2
Stardust,
2004



9P/Tempel 1
Deep Impact,
2005



103P/Hartley 2
Deep Impact/EPOXI,
2010

The celebrated explorer was also a remarkably proficient and prolific astronomer.

TWO HUNDRED AND FIFTY YEARS AGO, in March 1770, Lieutenant James Cook of the British Royal Navy was busy mapping the coastline of New Zealand during the first of his three great voyages. Thanks to these voyages, which crisscrossed the Pacific Ocean east to west and north to south, Captain Cook (as he later became) is widely recognised as one of the greatest explorers of all time. Fewer people know that astronomy also played a major role in his life and expeditions.

Cook observed transits of Venus and Mercury across the face of the Sun, a number of solar and lunar eclipses, lunar occultations (including one of Saturn) and comets. Most important, he became extraordinarily skilled at the astronomical observations necessary for determining his local time, latitude and longitude.

The roots of Cook's astronomical career can be traced back to 1758, when he served in the British Royal Navy in Canada.

TAHITI One of the main purposes of James Cook's first voyage was to observe the 1769 transit of Venus from Tahiti. This painting by expedition artist William Hodges shows the same location when Cook revisited it on his second voyage.

Captain Cook's astronomy



A chance meeting with a surveyor piqued his interest, and on his own initiative, Cook started learning the skills necessary for surveying. Due to the high quality of his charts and the influence of some friends in high places, Cook was assigned to survey the island of Newfoundland in 1763.

Cook's primary surveying instruments were a *theodolite* and a *telescopic quadrant*. Theodolites measure the horizontal and vertical angles between two points; they're still essential tools for any surveyor. The telescopic quadrant measures the angle between a target object and the zenith (its *zenith distance*), an essential step in determining the observer's latitude. Both theodolite and quadrant must be leveled with great accuracy, which prevents their use aboard a ship.

Although he had good latitudes for Newfoundland, Cook also needed a reference point with known longitude, which in turn required at least one accurate measurement of Greenwich Time. He found an opportunity in the form of an annular solar eclipse, whose centreline passed just south of Newfoundland on August 5, 1766. Cook's observations, made with the telescopic quadrant, were of the zenith distances of the Sun at first and last contact.

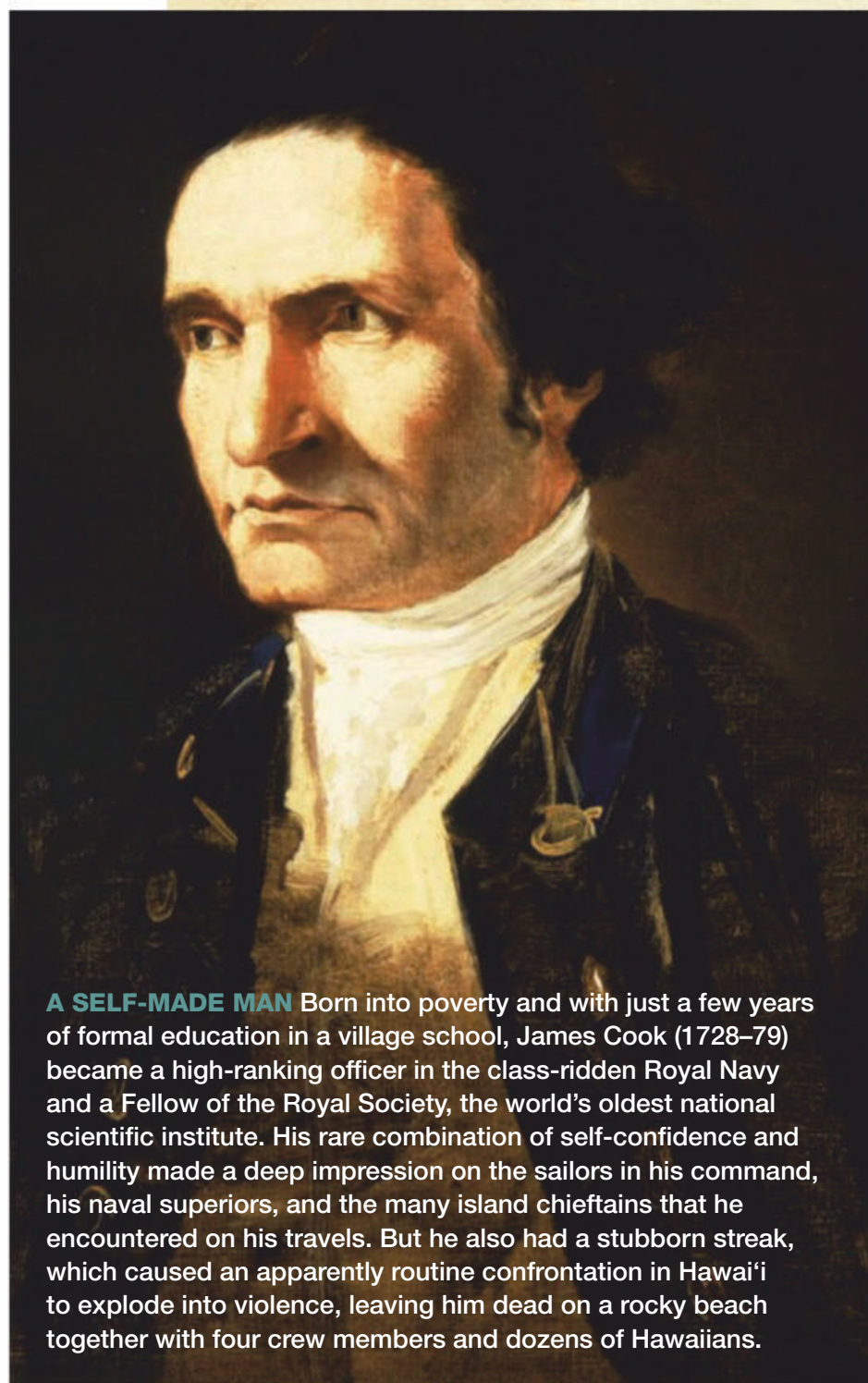
Cook didn't have the data or mathematical skills necessary to determine the longitude from his observations, so he took his results back to England, where a professional astronomer did the calculations. These involved determining the local time of Cook's zenith-distance measurements and correcting for refraction, the Moon's parallax and the Sun's semidiameter. The astronomer also applied the same corrections to observations of the same eclipse made from Oxford, England. Knowing the difference between the local times of the first and last contacts for the two locations as well as the known longitude for the Oxford observations, the astronomer calculated the longitude of Cook's location with an error of only 7.5 kilometres.

Cook's superiors were impressed by the care, accuracy and dedication he applied to his work, and Cook learned the value of astronomical observations. Cook's Newfoundland charts set a new standard for thoroughness and accuracy; they remained in use for more than a century.

The longitude problem

The oldest method for determining longitude at sea is *dead reckoning*: estimating the distance traveled from a known longitude based on the ship's direction and speed. Wind and ocean currents make it very hard to do this accurately. During the circumnavigation of the globe by Ferdinand Magellan's fleet between 1519 and 1522, his estimate of the longitude of the Philippines was off by 53 degrees, or approximately 5,600 kilometres.

In 1612, two years after he discovered Jupiter's four bright satellites, Galileo realised that their regular motions could serve as a 'universal clock' for determining longitude. In 1668 the great Italian-French astronomer Giovanni Domenico Cassini published accurate tables of the positions of Jupiter's



A SELF-MADE MAN Born into poverty and with just a few years of formal education in a village school, James Cook (1728–79) became a high-ranking officer in the class-ridden Royal Navy and a Fellow of the Royal Society, the world's oldest national scientific institute. His rare combination of self-confidence and humility made a deep impression on the sailors in his command, his naval superiors, and the many island chieftains that he encountered on his travels. But he also had a stubborn streak, which caused an apparently routine confrontation in Hawai'i to explode into violence, leaving him dead on a rocky beach together with four crew members and dozens of Hawaiians.

satellites, which were used to improve maps of Europe. The timing of other predictable astronomical events such as solar eclipses, lunar eclipses and occultations of bright stars by the Moon could also be used, but they aren't frequent enough to be practical.

Observing Jupiter's satellites is problematic because it requires a stably mounted telescope. That's fine when observing from land but problematic aboard a ship. What was needed was a predictable astronomical event that happened frequently and could be observed accurately at sea. In 1514 the German mathematician Johannes Werner suggested using the distance between the Moon and the Sun or other reference star for determining longitude. The Moon's orbital motion causes it to move through the background stars at 13.2° per day, or 33' per hour. So if the distance between the Moon and a known star can be measured accurate to, say, 3.3', that determines the time — and hence the longitude — within six minutes, which is six nautical miles at the equator.

Unfortunately, unlike Jupiter's satellites, which are far

from the Sun and strongly bound to their massive planet, the Moon is attracted roughly equally by Earth and the Sun, making its motion very complex. Only in 1755 did the German astronomer Tobias Mayer come up with a way to compute the Moon’s orbit sufficiently accurately to be useful for the lunar distance method.

The other alternative was to use a mechanical clock set to Greenwich Time. By the mid-1700s the best pendulum clocks had achieved an accuracy of a few minutes per year, but only if mounted on a stable platform. At the time of Cook’s first voyage (1768 to 1771), the only clock that could keep accurate time at sea was John Harrison’s H4 chronometer, which was unavailable because it was being evaluated for the Longitude Prize set up by the British Parliament in 1714.

But Harrison’s H4 clock was only expected to provide accurate time during the two-month trip from Britain to the West Indies; its cumulative error would have made it almost useless for Cook’s multiyear voyages.

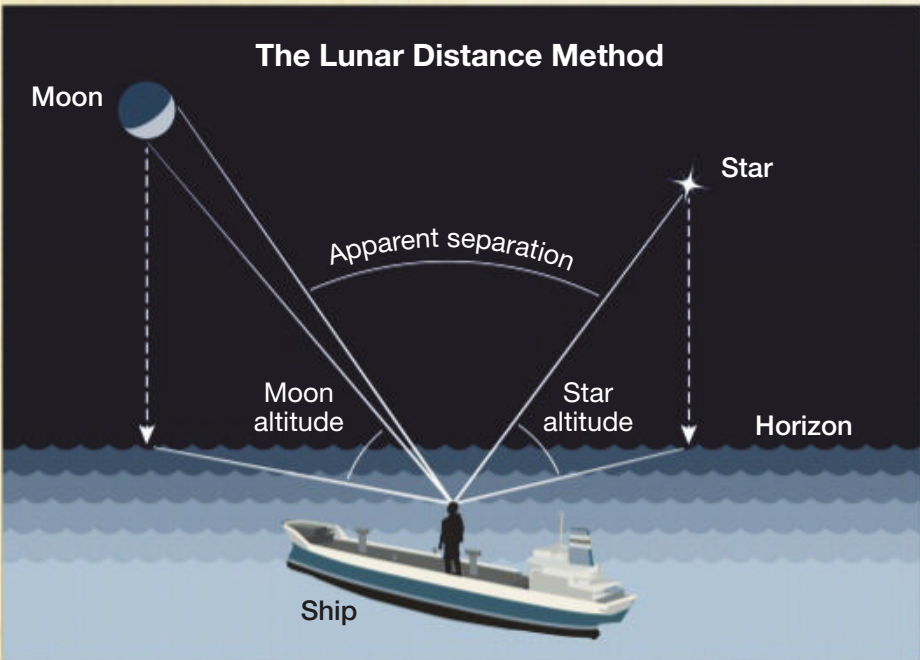
For his first voyage Cook used lunar distances as his primary method for determining Greenwich Time. He measured the angular distance between the Moon and the Sun or reference star with a sextant, and recorded the local time. He consulted the *British Nautical Almanac* to determine at what time the angular distance would be the same if observed from Greenwich.

Although the lunar distance method is simple in concept, other factors make it more complex in practice. Atmospheric refraction causes the Moon and the star to appear higher than they actually are. The Moon is also close enough to

Earth that its apparent position must be adjusted for parallax. So in addition to obtaining the angular distance between the Moon and the star, it’s necessary to measure the altitudes of the two objects above the horizon. Applying the corrections for refraction and parallax (called *clearing*) requires the use of spherical trigonometry. To simplify the computations, mathematicians developed a clever method using logarithms. This operation didn’t require the users to understand the underlying mathematics but only to follow a number of well-defined steps, looking up the necessary astronomical data from the *Nautical Almanac* and logarithm values from another book.

By the time of Cook’s second voyage (1772 to 1775), he brought along a few chronometers that were copies of Harrison’s H4 clock. Only one proved reliable, the one made by Larcum Kendall and referred to as K1, though Cook always called it “the watch”. The chronometers were set to Greenwich Time and were meant to eliminate the need for universal clocks based on astronomical phenomena. But astronomical observations were still necessary for determining local time. At first, Cook was reluctant to trust the timekeeping capabilities of chronometers and continued to use lunar distances to determine longitude.

To overcome the uncertainties that crept into the K1 watch’s accuracy over long timespans, Cook revisited two locations whose longitudes he’d determined during his first voyage. These were Venus Point in Tahiti (where he observed the June 3, 1769, transit of Venus) and Ship Cove, on the northern tip of the South Island of New Zealand, where he



▲ **LUNAR DISTANCE METHOD** Because the Moon moves through the stars so rapidly, it’s possible to calculate Greenwich Time by measuring the Moon’s angular separation from the Sun or other reference star. To compensate for atmospheric refraction, you also need to measure the angular altitudes of the Moon and star above the horizon.

► **LUNAR DISTANCE TABLE** This page from the *Nautical Almanac* shows lunar distances for January 1769 as they would appear to an observer in Greenwich, England.

[8] JANUARY 1769.				
Distances of ☾'s Center from ☉, and from Stars east of her.				
Days	Stars Names.	Noon.	3 Hours.	6 Hours.
		° ' "	° ' "	° ' "
1	☉ The Sun.	73. 12. 19	71. 51. 15	70. 30. 13
2		62. 24. 25	61. 3. 27	59. 42. 26
3		51. 35. 27	50. 14. 2	48. 52. 31
4		40. 41. 11	39. 18. 52	47. 30. 55
9	♈ Arietis.	87. 52. 15	86. 14. 59	84. 37. 30
10		74. 48. 33	73. 9. 46	71. 30. 48
11		61. 33. 20	59. 53. 12	58. 12. 56
12		48. 8. 19		56. 32. 31
12	♈ Aldebaran.	81. 2. 19	79. 21. 14	77. 39. 59
13		67. 29. 25	65. 47. 11	64. 4. 49
14		53. 48. 19	52. 5. 13	50. 22. 4
15		40. 2. 15	38. 18. 57	36. 35. 42
16	♊ Pollux.	26. 20. 5		34. 52. 34
16		67. 44. 32	65. 59. 3	64. 13. 29
17		53. 38. 58	51. 53. 9	50. 7. 22
18		39. 33. 57		48. 21. 36
18	♈ Regulus.	75. 59. 52	74. 12. 23	72. 24. 50
19		61. 39. 51	59. 52. 33	58. 5. 20
20		47. 24. 28	45. 38. 9	43. 52. 2
21		33. 20. 21	31. 36. 5	29. 52. 9
22	♈ Spica ♀	19. 38. 9	17. 58. 11	16. 19. 10
23		59. 38. 9	57. 57. 23	56. 16. 57
24		46. 21. 33	44. 43. 32	43. 5. 51
25		33. 27. 18	31. 52. 7	30. 17. 17
26	♈ Antares.	20. 56. 5	19. 23. 56	17. 52. 14
27		54. 5. 45	52. 34. 40	51. 3. 48
28		42. 2. 43	40. 33. 9	39. 3. 44
29		30. 9. 53	28. 41. 17	27. 12. 46
29	☉ The Sun.	115. 36. 24	114. 12. 56	112. 49. 41
30		104. 34. 8	103. 12. 8	101. 50. 16
31		93. 41. 28	92. 20. 18	90. 59. 12
		82. 53. 17	81. 32. 19	80. 11. 19



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spent an extended period repairing his ship.

Over the course of his three voyages, Cook visited Venus Point five times and Ship Cove six times. Knowing the longitudes of both locations, he could reset the time of the Kendall watch. He discovered that it worked very well indeed. Cook departed Ship Cove in November 1773 and returned 11 months later after sailing a counterclockwise route around the southern Pacific from latitude 71°S near Antarctica to 9°S in the tropics. The time kept by the Kendall watch (after applying its known correction rate) was found to be off by just 19 minutes and 31 seconds. Although not as accurate as the lunar distance method, it was much faster and easier to use, and it eliminated the possibility of observational and computational error. Cook was so impressed that he took the K1 on his third voyage as well.

The astronomical equipment that Cook carried included sextants, a telescopic quadrant, telescopes (both refractor and reflector) and an astronomical pendulum clock. Although he and his assistants could use the sextants both at sea and on land, the other instruments were useful only on land. Each time Cook dropped anchor for fresh water and food, firewood, ship repairs or to rest his crew, he took the opportunity to set up a tent observatory. Weather permitting, he'd make observations in order to determine a more accurate latitude and longitude than he could obtain at sea. Professional astronomers accompanied Cook on all his voyages to oversee the observations and computations, though his own observations often proved at least as accurate as theirs.

Charles Green (1734–71) was Cook's astronomer for his first voyage on the ship *Endeavour*. The British Navy supplied two ships for Cook's second voyage: the *Resolution* (with Cook as captain) and the *Adventure* (with Tobias Furneaux as captain). William Wales (1734–98) was the astronomer on the *Resolution* and William Bayly (1737–1810) on the *Adventure*. Two ships also went on the third voyage: the *Resolution* (with Cook as captain) and the *Discovery* (with Charles Clerke as captain). Bayly served as the astronomer on the *Discovery*, while Cook himself took on the duties of astronomer aboard the *Resolution*.

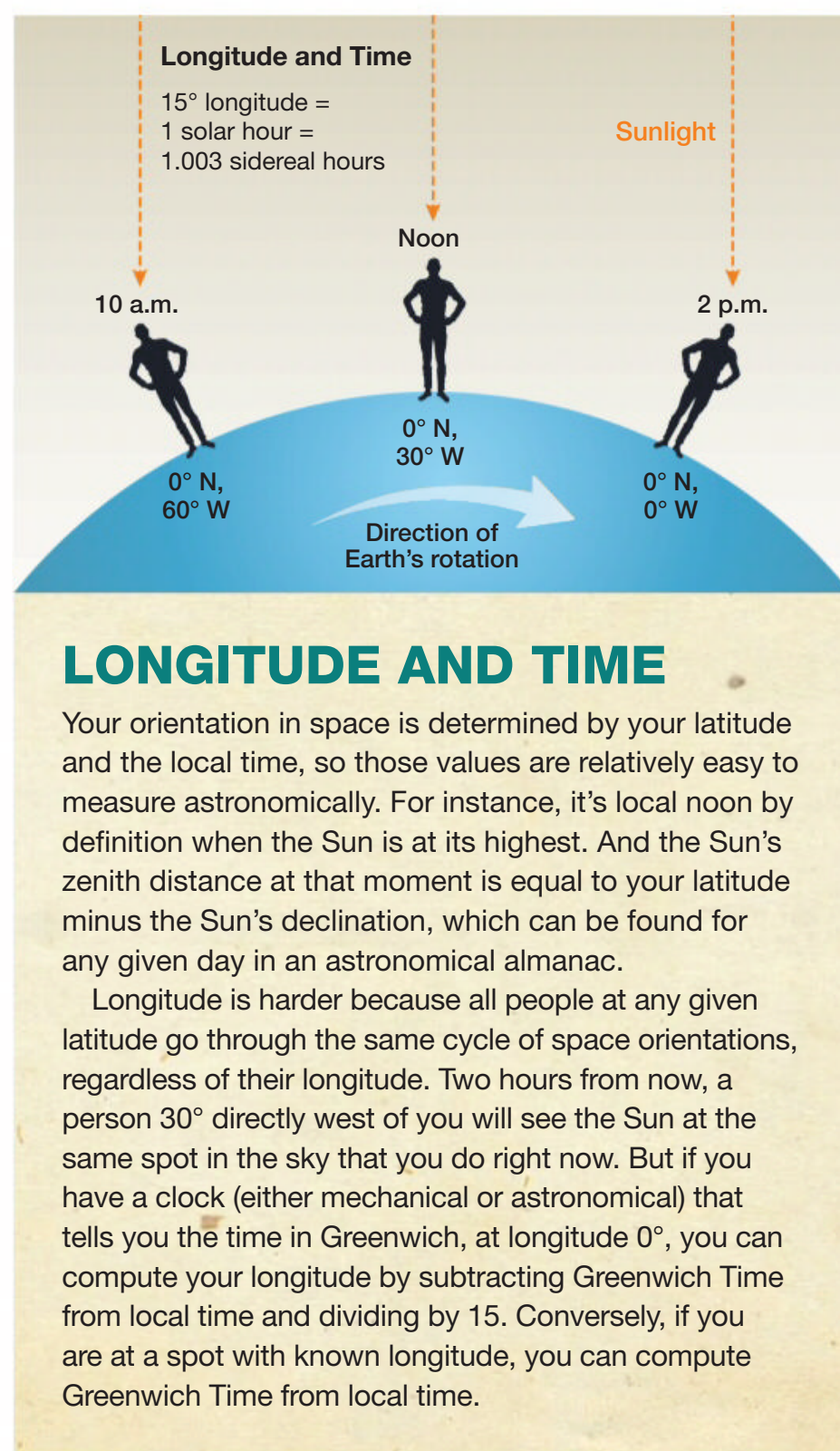
Nevil Maskelyne, Astronomer Royal from 1765 to 1811, didn't sail with Cook on any of his voyages, but he did play a key role in Cook's astronomical career. Maskelyne oversaw the British efforts for the 1769 transit of Venus, when several countries sent observers to widely scattered locations in hopes of measuring the distance to Venus by parallax. He sent Green to Tahiti, Wales to Canada and Bayly to Norway. Maskelyne also evaluated the contenders for the Longitude Prize, and his bias for using lunar distances delayed the acceptance of John Harrison's H4 chronometer as the best method for determining longitude at sea.

Here are a few examples of longitudes determined during Cook's voyages. In June 1770, during his first voyage, Cook landed in Queensland, near the location of modern-day Cooktown (named for him) after his ship nearly sank when

it ran into the Great Barrier Reef. While there, Green timed two eclipses of Io, yielding longitudes that deviated from the modern value by only 4.3 and 15.8 km. During the second voyage, Wales's longitudes for New Zealand's North and South Islands differed from the ones that Green measured during the first voyage, with Green's being 58 km too far east for the South Island and 43 km too far east for the North Island. Cook was upset by the error and blamed himself, but the discrepancy between these two highly skilled observers shows how difficult determining longitude could be.

Though Cook's best-known legacy is his exploration of the Pacific Ocean, his contributions to navigation through astronomical observations and the use of "the watch" were equally important.

■ **TED RAFFERTY** is a retired astronomer who worked for the US Naval Observatory for 32 years.





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Photographing deep sky targets over terrestrial landscapes in a single exposure can be a worthy challenge. In this article, the author shares tips to capture deep images such as this shot of the Orion hourglass as it rises over mountains. The single, 35-second image was taken with a modified Canon EOS 6D DSLR and 85-mm lens at f/2.2, ISO 12800.

Shooting one-shot Deepscapes

Here's how to capture striking photographs of deep sky objects above landscapes in a single exposure.

PICTURE AN IMAGE OF THE CONSTELLATION ORION rising above a distant hill, with M42 and the Horsehead Nebula displaying vivid colours and wisps of faint gas and dust. The reddish crescent of Barnard's Loop cradles the central stars of the Hunter's belt, spanning from Bellatrix to Saiph and back to Rigel. The large glow of Sharpless 2-164, the Angelfish Nebula, surprises you with its visibility in the photograph. Surely this must be a composite — such deep images are only possible using complex processing techniques to blend the moving sky with a stationary foreground, right?

Not so! While in the past such an image would have required hours of *Photoshop* wizardry, today's digital sensors

and fast, high-quality camera lenses make deep sky nightscapes such as this possible in a single short exposure. With planning, processing the images takes almost no time at all.

While it's common practice for nightscape photographers to blend several exposures to create a smooth, picturesque composition or add a foreground to a deep sky image, I prefer the challenge of capturing deep nightscapes in a single exposure by coupling old-school photography techniques with the latest digital cameras. The results give me the satisfaction and sense of accomplishment that just don't come from composites. Here are some tips on shooting your own single-exposure 'deepscapes'.

A good plan

The first thing needed to capture deep images of nebulae, galaxies and star clusters over an attractive foreground is a firm knowledge of the night sky. Sure, the Orion Nebula or Magellanic Clouds are obvious deepscape targets, but there are

many other objects that can expand your subject matter and add variety to your work. Virtually every major constellation offers something to focus on.

Knowing where an object will rise above the horizon can help you plan a composition before it's ready to photograph. A planetarium app can help give you a general idea of where an object is going to rise, but placing the sky in context to the landscape you intend to shoot requires more specialised tools.

Several apps are available to aid in planning your composition. *The Photographer's Ephemeris* (photoephemeris.com), *PhotoPills* (photopills.com), and *PlanIt!* (yingwentech.com) are some of the powerful tools available online or downloadable as Apple and Android apps that can help you to plan exactly where to position yourself so that your subject rises *precisely* above the foreground as you envisioned it. Most of these apps use built-in planetariums that combine a night sky map and a Google Earth view of your chosen location.

Transient objects such as comets require you to monitor astronomy websites to get up-to-date information about where these moving targets will be in your sky as they brighten enough to photograph in a single exposure.

Choosing a lens

Deepscape photography is more challenging than typical nightscapes in that you often use telephoto lenses with narrower fields of view. This means that you can only shoot for a short time before your subject becomes noticeably trailed. But a good choice for starters is a high-quality, fast prime-focus 35-mm or 50-mm f/1.4 lens that produces sharp star images when used at its widest aperture. I recommend that you stop the lens down to f/2 to reduce aberrations in the corners of the frame. Stopping down the lens also reduces vignetting to nearly imperceptible levels. Most recent full-frame DSLR and mirrorless cameras have decent noise characteristics. But the newest models tend to incorporate the latest sensors, which produce excellent images at the extremely high ISO speeds needed to 'freeze' the motion of your target over a landscape in short exposures.

A handy rule of thumb for nightscape photography is known as 'the rule of 500'. This states that for a fixed (non-tracking) camera, 500 divided by the focal length of your lens in millimetres gives the length of an exposure in seconds before stars appear trailed in your image. (And that also applies to the appearance of your foreground when the camera is tracking the sky.) For example, when shooting with a 35-mm lens,

► High-quality, fast lenses such as Sigma's Art lens series combined with the latest sensors will produce the best results.

you can expose for about 14 ($500/35 = 14.29$) seconds before stars are visibly trailed in a photo. This is not an exact rule, as the trailing will depend somewhat on the pixel size in your camera, which part of the sky you are shooting, and whether you use a full-frame or crop-sensor camera. But it should be close enough that stars and deep sky objects will appear relatively sharp and stationary.

A lens with a large maximum aperture (small f/ratio) delivers more light to your sensor and reduces the needed exposure time, especially when using a telephoto lens to image deep sky objects. Most zoom lenses aren't well-suited for extreme low-light photography, because they are often not as fast as a prime (fixed-focus) lens and often not as sharp at the ends of their zoom range.

With lens speed and the rule of 500 in mind, portrait lenses are excellent optics for capturing single-shot deepscapes. These lenses range from focal lengths of 85 to 135 mm. Canon, Nikon and several other manufacturers produce excellent portrait lenses, and don't be afraid to shop for older, manual-focus lenses on the used market. I recommend Sigma's Art lens series as my most frequently used lenses for short deepscape images. They work quite well at full aperture.

Portrait lenses can reveal a surprising amount of detail in deep sky targets. Nearby spiral galaxies start to display their spiral arms in exposures of as short as 20 seconds at high ISO. Many of the nebulae in Orion, including everything within Barnard's Loop, can be comfortably framed with a foreground object with a 135-mm lens on a full-frame camera.

For more resolution, you can step up to a 200-mm f2.8 lens or even longer. At this focal length, the Andromeda Galaxy (M31) shows its dust lanes, and larger globular clusters like Omega Centauri begin to resolve into individual stars.

Bending the rule

As mentioned above, the 500 rule gives you the maximum exposure to avoid trailing stars. But this rule isn't set in stone. A silhouetted mountain peak against the sky won't look





▲ Longer exposures are possible by adding a tracking head to your camera and tripod. Models that include a $\frac{1}{2}$ sidereal rate will double the exposure time you can achieve before stars appear trailed in a photo.

noticeably blurry in a short, tracked exposure, so you can track at full speed and go four to five times longer than the 500 rule recommends without losing foreground detail.

When shooting fields far from the celestial equator, you can increase the exposure because stars don't appear to move as much. For instance, midway between the celestial equator and poles, you can increase the exposure length by about 40% and still have acceptable stars. And you can expose areas near the celestial poles, such as the Southern Cross, up to 70% longer.

Without tracking, you'll quickly realise the 500-rule exposure limit is too short with a telephoto lens to adequately

record most deep sky objects. Take the 85-mm lens, for example. The rule of 500 limit with this lens is only about 6 seconds. The obvious solution is to attach the camera to a tracking mount to follow the target as the landscape moves below. In normal deep sky astrophotography, this enables you to expose as long as you can to improve an image's signal-to-noise ratio. However, our goal is to capture both the sky and objects here on Earth, so tracking for long periods blurs the foreground. The challenge is to reveal the celestial object in only a few seconds at extremely high ISO settings such as 6400 or more. One solution is to use a tracking mount that includes a $\frac{1}{2}$ sidereal speed tracking rate. This trick splits image trailing between stars and the landscape. Using this tracking rate, you can effectively double the exposure limit. Our new rule of thumb for exposure then becomes 1,000 divided by the lens focal length.

Even so, this may be still too short to record dim objects, particularly when the foreground has interesting details to capture. One trick to overcome landscape blurring on nearby foreground objects is to illuminate them with a torch briefly at the start or end of the exposure. They only need to be lit for a moment or so and then remain dark for the rest of the exposure, freezing their motion in a tracked exposure.

One issue with shooting at full aperture on a fast lens is a shallow depth of field — objects closer than the point at which a lens is set to focus will be noticeably blurred.

There's a great old-school technique you can use to overcome this issue. It works best with lenses that include a marked focal distance scale as well as a manual aperture ring. First, focus the lens on the foreground object of interest and illuminate it with a flashlight briefly at the beginning of the exposure. Then quickly but gently turn the focus ring of the lens manually to the marked infinity point on the lens, and let the exposure finish up. In the resulting image, both the stars and the illuminated foreground will appear sharp. If your camera is mounted on a sturdy tripod, you can experiment with stopping down the aperture of the lens at the start of the exposure to ensure the nearby subject is as sharp as possible, briefly light it up, then open the aperture and move the focus to infinity.

This focus-ramping technique is tricky to perform, particularly in the dark, so you'll need to practice it a few times to ensure you get it right.

Camera and ISO speed

This type of complex nightscape photography requires a detector suitable for low-light imaging regardless of the ISO setting used. Changing the ISO setting in your camera amplifies the signal recorded, increasing noise as well as

◀ Balancing colourful deep sky objects with lots of detail (such as the Carina Nebula, NGC 3372, seen here) with interesting foreground objects requires advanced planning. This shot was taken from the Atacama Desert in Chile using a 200-mm lens at f/3.5 paired with a Nikon D810a DSLR camera and tracked with the Vixen Polarie mount seen above. Total exposure was 25 seconds at ISO 12800.



the signal recorded, and is not a replacement for a high-sensitivity detector. The true sensitivity of a CMOS sensor is directly related to the size of its individual pixels. These tiny wells collect photons like buckets collect raindrops — larger pixels collect more photons before filling up (saturating) than small pixels do. Cameras using APS-sized detectors with more than 30 megapixels sound astounding but use tiny pixels that saturate quickly, which translates into white, colourless stars after post-processing. Full-frame cameras are better suited for deepscape imaging because they incorporate larger pixels in a bigger detector, and thus saturate at a much higher threshold.

Recent camera models designed for astrophotography such as the Nikon D810A and the Canon EOS Ra both utilise 30+ megapixel full-frame sensors with about 5-micron pixels. Although 5-micron pixels are a bit small, they are paired with powerful internal processors that finely control noise in images taken at high ISO speeds.

The benefit of these Canon and Nikon cameras is their spectrally enhanced internal filters which, compared to standard cameras, pass a larger percentage of the hydrogen-

▼ This group of ALMA radio telescopes below the Coal Sack and Southern Cross was taken by first focusing on the telescopes, quickly illuminating them with a torch, then changing the focus to infinity to record the stars and constellations all in the same exposure.

alpha ($H\alpha$) light that most nebulae emit. Since most deepscape targets include a lot of $H\alpha$, a spectrally enhanced camera will produce your best results. You can shop for one of these newer cameras, though several companies offer services to modify older DSLR and mirrorless cameras to pass more of this astronomically important wavelength.

Challenging skyglow

Deepscape photography by its very nature often requires shooting your subject close to the horizon where distant skyglow is more evident. Even in a totally dark sky, an atmospheric phenomenon known as *airglow* may visibly brighten the background sky, imparting an orange or greenish glow that obscures your intended subject. Skyglow or light-pollution filters can suppress the sky brightness and increase nebulae contrast, but keep in mind the image will need more exposure to overcome the reduced signal. Skyglow filters are more impactful with modified cameras.

Using additional filters can also impart a colour cast to your photos that is best corrected by setting a custom white balance in your camera. This is accomplished by setting your camera colour setting to auto (AWB) and photographing a grey card or a piece of white paper in daylight with your intended filter in place. Make sure the card or paper



completely fills the frame. Then simply change the colour setting to Custom White Balance and select this photo as the calibration image. Be sure to keep this photo on your memory card when shooting deepscapes, and to use the custom white balance setting.

Processing the results

Once you've shot your images, a little post-processing is necessary to achieve the best results. It's important that you shoot in RAW mode to get the most out of your night's work. I prefer to use *Adobe Lightroom* and *Adobe Camera Raw* (ACR), though Nikon and Canon offer their own processing programs that can accomplish much of the same enhancements.

My first step is to reduce noise in the image by opening it in ACR and first lowering the Texture slider by around 20. I select the Detail tab in the right column. Rather than adjusting the Luminance slider in the Noise Reduction area, I prefer to lower the Sharpening setting. Masks can also be applied to target certain areas for additional noise reduction after applying ACR, adding a layer mask over the areas you'd like to target and repeating the ACR process. Next I change the colour profile in the Basic tab to Adobe Standard, which slightly increases contrast and saturation. If necessary, I'll increase the Contrast and Vibrance sliders.

If I shot my deepscape at maximum aperture, I'll select the Lens tab and find the lens I used from the extensive pulldown menu, which corrects for vignetting and chromatic aberration in many lens designs. Other settings that can improve an image are the Shadow and Highlight sliders, which help to bring out faint nebulosity or suppress bright areas in a picture if necessary. The Dehaze slider is very



▲ Depending on the subject you are shooting, the stars don't always need to be in focus. In this case, these nightscape photographers are the focus of the composition.

powerful in increasing contrast in an image but requires restraint so as to not 'overcook' the result.

If you shot under light-polluted conditions, you can correct the white balance in the Basic tab. Keep in mind that shifting the colour slider to low temperatures in order to remove the orangish cast of light pollution from the sky background will also shift the colours of the stars, Milky Way and other celestial objects.

Using these tips, you too can shoot captivating deepscapes that bring your favourite deep sky objects down to Earth.

■ **BABAK A. TAFRESHI** captures the beauty of the Earth and sky from exotic locations worldwide. See more of his work at babaktafreshi.com.

▼ *Left:* Unilluminated foregrounds like the mountains seen here below nebulosity in Scorpius won't display much blurring in longer exposures, so you can expose a deepscape for roughly four times as long. This image was captured with a Nikon D810a camera and a 105-mm lens, and tracked for 25 seconds at ISO 12800. *Right:* Slight illumination on the arc limited this exposure to 15 seconds at ISO 6400 with a 50-mm lens at f/2.8.



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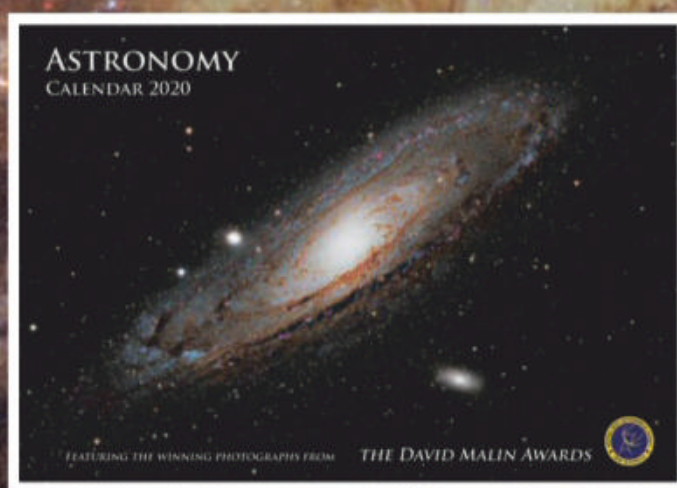


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One cluster or two?

One of my favourite objects in the autumn night sky is **Collinder 121** in the constellation Canis Major, the Big Dog. It's a complex view, because what we see isn't all one object.

Let's start with the visual anchor of the field, the bright star **Omicron¹ (o1) Canis Majoris**. It's a monster, a **K2** red supergiant, between 8 and 13 times the mass of our own Sun, and at least 220 times as large in diameter. It's a young star in absolute terms, only 18 million years old — stars that big simply don't last long before blowing themselves apart as supernovae.

Omicron¹ is only one of a gaggle of bright young stars in the field. Most of the rest are of type O and B, and they make up the Canis Major OB 2 association. CMa OB2 is centred a little more than 1,900 light-years away, not vastly different in distance from the nearby cluster Messier 41, which lies at 2,300 light-years. Like most of the nearby OB associations, CMa OB2 is pretty, especially through binoculars — but it's not Cr 121.

The real Cr 121 is a young, compact cluster that lies beyond CMa OB2 at a distance of about 3,200 light-years, but sorting it out from the foreground association took a lot of careful parsing of parallax data by many different teams of professional astronomers. Interestingly, our emerging conception of Cr 121 as a separate object from CMa OB2 is a pretty good match for the original description of the cluster by Per Collinder in 1931. He was apparently farsighted in more ways than one.

All these objects are our neighbours in the Orion Spur of the Milky Way. Be friendly and look in on them, will you?

■ **MATT WEDEL** will probably never separate CMa OB 2 and Cr 121 visually, but he sees no harm in repeated attempts.

USING THE STAR CHART

WHEN

Early March	10pm
Late March	9pm
Early April	8pm
Late April	7pm

These are standard times — add Daylight Savings if it applies to your location.

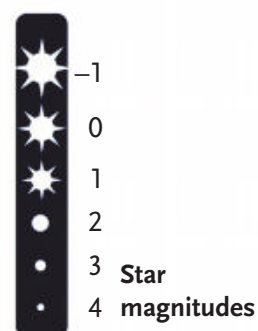
HOW: Go outside within an hour or so of a time listed above. Hold the map above your head with the bottom of the page facing south. The chart now matches the stars in your sky, with the circular perimeter representing the horizon and the centre of the chart being the point directly over your head (known as the zenith).

FOR EXAMPLE: Look at the chart, and you'll see that the bright star Achernar at the end of the constellation Eridanus (The River) is about one-third of the way from the southwestern horizon and the middle of the chart. So if you look to the southwest, you'll find Achernar about one-third of the way up from the horizon.

NOTE: The map is plotted for 35° south latitude (for example, Sydney, Buenos Aires, Cape Town). If you're much further north of there, stars in the northern part of the sky will be higher and stars in the south lower. If you're further south, the reverse is true.

ONLINE

You can get a sky chart customised for your location at any time at SkyandTelescope.com/skychart





The Great Comet of 1970

Fifty years ago this month a feathery visitor adorned the spring sky.

In Under the Sky this issue, I want to feature a celestial wonder that I witnessed 50 years ago — at its all-around best in April 1970, it was what may have been the most beautiful comet of the 20th century.

Enter Comet Bennett. At the time I had recently observed my first comet, Tago-Sato-Kosaka. I found this modestly bright object by myself with both naked eye and telescope in January 1970, the month after my 15th birthday. That was an incredibly thrilling and rewarding experience. But the March 1970 issue of *Sky & Telescope* soon arrived with a brief item announcing the approach of 'Bright Comet Bennett'.

Discovered at the end of December 1969 by accomplished amateur astronomer John Caister Bennett of South Africa, Comet Bennett (C/1969 Y1, or 1969i as it was then designated) was solely visible in the Southern Hemisphere until it sped north in its highly inclined orbit, passing the

Sun and emerging in bright morning twilight in March 1970.

My first sight of Comet Bennett came after watching in stronger and stronger morning twilight in the hope the comet would somehow be bright enough to be visible with the unaided eye when it finally rose above my treeline to the east. I was losing hope that morning and then it appeared — a starlike object brighter than Altair, with an awesome similarly bright short spike of intense tail.

I didn't record which date in late March I made that observation, but Bennett passed perihelion, 0.54 a.u. from the Sun, on March 20 and was closest to Earth, at a distance of 0.69 a.u., on March 26. On March 23, one observer followed Bennett naked eye until less than 5 minutes before sunrise, and on the 28th estimated the comet was magnitude -0.3 with 10° of tail visible even under bright moonlight.

◀ **BEAUTIFUL STRANGER** Comet Bennett graced the sky 50 years ago and proved to be one of the finest comets of the 20th century. J.U. Gunter captured this photo on the morning of March 28, 1970.

April's angel. The rapidly northbound Comet Bennett lofted magically higher and higher out of morning twilight like an angel. So, April 1970 was the month it was most splendid. Bennett sported both dust and gas tails. The gas tail was prominently curved and underwent dramatic changes as a strong (solar maximum) solar wind buffeted it. Through telescopes, Bennett also displayed an orange pinwheel of jets from its nucleus and, for master comet observer John Bortle, as many as five jets at once. What was most beautiful about Bennett through my 108-mm Edmund reflector that month was the silky strands of streamers in the first star-sprinkled several degrees of the tail — a phenomenon the like of which I've still never seen in any other comet with any telescope.

John Bortle and a few other observers traced Comet Bennett's tail out to well over 20° long. But what was amazing to me was that Bennett's tail wasn't at its brightest for just a few degrees of its length, like Hale-Bopp's and Hyakutake's. As I recall, Bennett's tail maintained similar great intensity out to roughly 10° or 12° . In my book *Comet of the Century*, I had the following to say: "It hung breathlessly like some vast shining swan's feather by the graceful constellation of Cygnus the Swan; it was a snowy sword laid in peace (but power!) near one of the brightest parts of the Milky Way's stream; it floated into the north circumpolar regions of Cassiopeia the Queen to spend ever more of the night aloft."

You can stay up late these nights and watch the constellations and stars wheel into view. But fifty Aprils ago, they were accompanied by the once-in-a-lifetime beauty of Comet Bennett.

■ **FRED SCHAAF** welcomes your letters and comments at fschaaf@aol.com.

High in the south after sunset during April, can be found the sparkling open star cluster NGC 2547. Located in Vela and catalogued by Nicolas Louis de Lacaille in 1751 when observing from South Africa, the cluster is a little over 1,000 light-years away and is thought to have formed around 30 million years ago.

Three planets before dawn

Venus is alone after sunset, but three planets shine in the east before the sunrise.

Venus will be our only naked-eye planetary companion in the early- to mid-evening hours for most of this month, with the others confined to the eastern sky in the post-midnight and pre-dawn hours until the final week of April.

But let's begin with **Mercury** (mag. -0.1, dia. 6.3", Apr 5). The innermost planet will be visible above the eastern horizon before sunrise. This is a great time to see it, before it starts to drop toward the horizon on its way towards superior conjunction (ie. on the other side of the Sun) in May. There will be a couple of pairings to look out for, too. The first will be with magnitude-7.9 Neptune, which will be just 1.4° to the north of Mercury on April 4, spreading to 1.6° by the following day. This pairing will be a good target for a low-power telescope or binoculars.

The other teaming will be with the extremely thin, young Moon on April

22 — but be warned that both Mercury and the Moon will be very, very low down, so you'll need a clear horizon (and possibly binoculars) to spot them in the dawn glow. (Make sure you don't go looking with binoculars if the Sun is above the horizon.)

Venus (-4.7, 30.6", Apr 15) remains prominent in the west after sunset. Take a look on the 3rd and 4th, and you'll see Venus shining very close to the members of the Pleiades star cluster — see page 55 for more details. This month the planet will reach a point called greatest illuminated extent, on the 28th at magnitude -4.7. This occurs when the planet covers the most amount of sky... which is not, as you might think, when it has a fully illuminated disk, but rather when it shows as a large crescent. A speaking of crescents, later in the month, on the 26th, the Moon will be close by.

Mars (0.6, 6.9", Apr 15) begins April

in company with Saturn (and Jupiter not far away, too), with the two planets only 1° apart. They'll both be about the same brightness, but the colour contrast will be interesting — the ruddy red of Mars and the off-white of Saturn. As the days pass, Mars will gradually move away from the Ringed Planet.

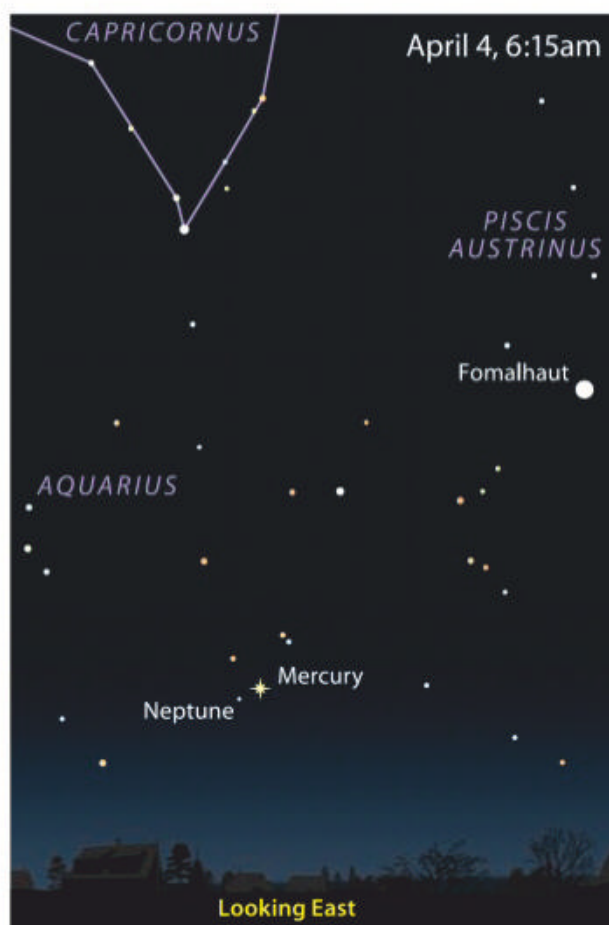
The Red Planet's apparent size is increasing as each month passes, as it heads toward opposition in October. Already its size has increased by 50% since January (from 4.5" to 6.9") — by October it will have more than trebled again to 22.3".

Jupiter (-2.2, 38.7", Apr 15) will be the brightest of the four planets visible in the morning sky this month, an unmistakable beacon sitting above Mars and Saturn. The giant planet and the last quarter Moon will be close together on the 15th. Don't forget to have a look for the planet's four large moons.

As mentioned above, **Saturn** (0.6,



▲ Three planets in the east before dawn.



▲ Neptune and Mercury come close.



▲ The Moon joins the line-up.

16.5", Apr 15) and Mars begin the month close together. On the 16th you'll see Jupiter, Saturn, the Moon and Mars almost in a straight line and with almost equal spacing between them. This should make for a great photo opportunity – please email your shots to us at contributions@skyandtelescope.com.au.

The Ringed Planet will reach western quadrature on the 21st; this is when the angle between the Sun, Earth and Saturn is 90°, the practical upshot of which is that at sunset the planet will be highest in the sky and therefore well placed for early evening viewing.

Uranus (5.9, 3.4", Apr 5) is out of the viewing equation this month, as it is very low down in the sunset glow and heading toward conjunction with the Sun on the 26th. It will be back in our morning skies at the end of May.

Finally, **Neptune** (7.9, 2.2", Apr 15) will be found low on the eastern horizon as the dawn glow rises, having reappeared in our skies following conjunction with the Sun in March. As mentioned above, Neptune and Mercury will be close on April 4th and 5th, but you'll likely need some optical aid to see them together.



▲ Venus shines in the west after sunset.

Moonlight and meteors

The Eta Aquariids start to ramp up in April.

April is a bit of a blank month for southern meteor showers, with only two of interest for 2020.

First up is the Lyrids, whose radiant is in the northern constellation Lyra. It's active from April 14 to 30, and rates can vary. The zenithal hourly rate (ZHR) is predicted to be 18, but of course Lyra is not at the zenith for us in the south. Nevertheless, it's worth keeping an eye on it – you might just spot a few Lyrid meteors. The best time to look is after midnight. Maximum is predicted for April 22, so the new Moon on April 23 will help.

A shower that can be considered sort of 'on and off' is the Pi Puppids. Much better placed deep in the south for Australasian observers, it has had unpredictable meteor rates over the years. Maximum is predicted for April 23 (so again, the new Moon will assist). This shower is best monitored prior to midnight, before Puppis sinks too low.

The good thing about April is that the Eta Aquariids begin to make their presence known. From the Southern Hemisphere, this shower is second only to the Geminids in terms of display. Etas

are often swift and bright, with many leaving trains lasting for minutes. Although fireball and bolide activity is minimal, the average Eta Aquariid meteor is magnitude 2.7, which is bright in comparison to some of the other major meteor showers. They are usually yellow or orange, but can be many other colours – I recall seeing blue and even green Etas in May 2009, and I have seen red in other years.

The Etas are active from April 19 to May 28, with maximum predicted for the morning of May 6 for Australasia. The International Meteor Organisation is predicting the shower's 12-year, Jupiter-influenced cycle will peak from 2020 until 2022. This year, however, a near full Moon will greatly affect observations and rates will be much lower than usual. The peak on the morning of May 6 could yield a ZHR of around 15 to 18 meteors from a dark sky. From town you may see 5 to 7.

■ **CON STOITSIS** is director of the Astronomical Society of Victoria's comet and meteor sections. Follow him on Twitter @vivstoitsis

SKY PHENOMENA

APRIL

- 2** Moon 4° south of Pollux
- 3** Venus 0.5° south of the Pleiades
- 4** Venus 0.8° east of the Pleiades
- 5** Moon 4° north of Regulus
- 8** Moon 7° north of Spica
- 11** Moon 7° north of Antares
- 15** Jupiter 2° north of the Moon
- 15** Saturn 2° north of the Moon
- 16** Mars 2° north of the Moon
- 18** Venus 10° north of Aldebaran
- 26** Moon 4° north of Aldebaran
- 27** Venus 6° north of the Moon
- 28** Venus greatest illuminated extent

LUNAR PHENOMENA

APRIL

- First Quarter 1st, 10:21 UT
- Full Moon 8th, 02:35 UT
- Last Quarter 14th, 22:56 UT
- New Moon 23rd, 02:26 UT
- First Quarter 30th, 20:38 UT
- Perigee 7th, 18h UT, 356,907 km
- Apogee 20th, 19h UT, 406,462 km

Comets come in groups and pairs

Plus the fascinating story of a Queensland town named 'Comet'.

Last December, two interesting (but intrinsically faint) comets were found by the Asteroid Terrestrial-impact Last Alert System (ATLAS) in Hawaii. They are fascinating objects.

The first, officially designated **C/2019 Y1 (ATLAS)** was discovered on December 16 as a fuzzy speck of magnitude 18. As further observations were obtained, an orbit was calculated which revealed a remarkable similarity with those of comets C/1988 A1 (Liller), C/1996 Q1 (Tabur) and C/2015 F3 (SWAN). The new comet therefore becomes the fourth member of what has become known as the Liller Group. Like the famous Kreutz Group, these comets are fragments of a single object that broke apart many years ago, possibly (although not necessarily) during an earlier perihelion passage.

Having passed through perihelion on March 15, the comet is currently predicted to be a Northern Hemisphere object of about magnitude 12–13 and slowly fading during April. Nevertheless, with the exception of Comet Liller (clearly the principal member of the group) the other members have faded out, either prior to perihelion (Tabur) or

shortly thereafter (SWAN). As the new object is intrinsically fainter than the others, survival of perihelion is doubtful.

Another pair

The second object — **C/2019 Y4 (ATLAS)** — was discovered on December 28 at approximately magnitude 19. A very preliminary set of calculations suggested a perihelion within the orbit of Mercury and elements somewhat similar to those of C/1987 B2 (Terasako). There was no possibility of it being the same comet, but an association was suggested. Further observations didn't support this.

An improved orbit did, however, reveal a striking resemblance to that of C/1844 Y1, otherwise known as the Great Comet of 1844 and, unofficially, Comet Wilmot. Once again, there is no possibility of identity (alas!) as the period of both objects is several thousands of years. Furthermore, the intrinsic brightness of the new object is some seven magnitudes (over 600 times) fainter than its predecessor.

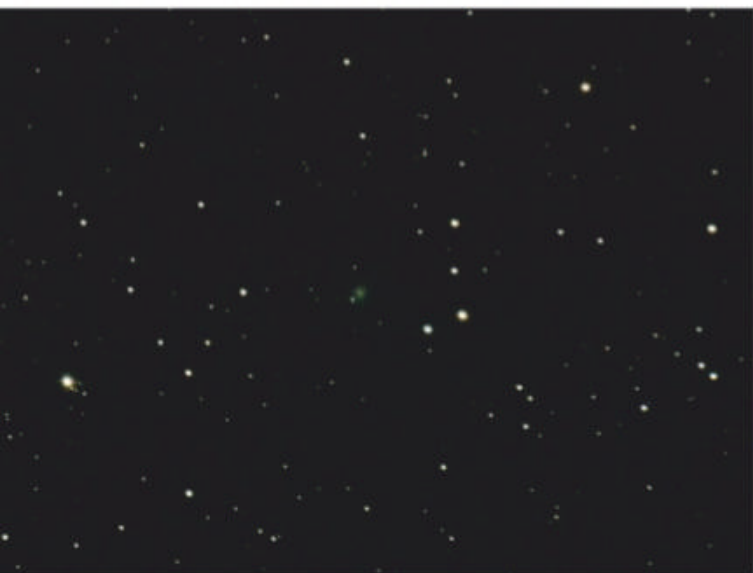
Clearly, this is yet another comet pair, C/2019 Y4 being a small fragment that broke away from the primary sometime in the past. Also confined to

northern latitudes during April, C/2019 Y4 is predicted to brighten to about magnitude 12–13 during April as it drifts toward the evening twilight. Technically, it should emerge for southern latitudes very low in the dawn during June, after passing through perihelion on May 30, but the combination of faint absolute magnitude and small perihelion distance casts strong doubt upon its survival.

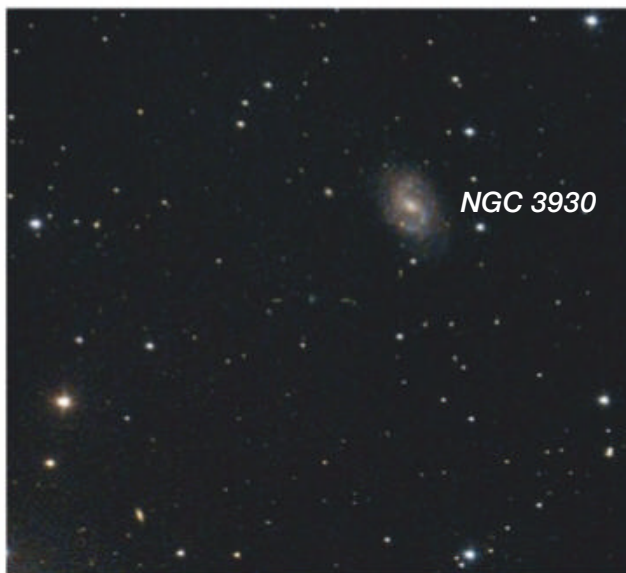
The spectacular comet of 1844 passed perihelion on December 14 of that year and the first sighting was apparently made two days later from South America. Further sightings were made on December 18 by an observer at Cape Town and by P. King at Port Stephens in NSW. The first to officially report the comet was E. Wilmot at the Magnetic Observatory at the Cape of Good Hope, who saw it on the 19th and informed T. Maclear at the Cape's Royal Observatory. Looking toward the western horizon, the latter noted a beam of light extending from behind a bank of horizon cloud, but (unable to see the comet's head) was initially unsure as to whether he was seeing a comet tail or an instance of that twilight light and shadow phenomenon known as crepuscular rays.

Queensland's 'Cometville'

The comet has a small but interesting place in Australian history. On the evening of December 28, 1844, explorer Ludwig Leichhardt was camped on the banks of a creek in central Queensland. Following a thunderstorm, his indigenous companion, Harry Brown, drew the explorer's attention to "a fine comet" visible through a small break in the clouds close to the western horizon. Impressed by the spectacle, Leichhardt named the creek 'Comet Creek'. A later settlement on its banks was named 'Cometville'. Still later, the status of the 'creek' was elevated to 'Comet River'



▲ C/2019 Y1 (ATLAS) appears to be a fourth member of the Liller Group of comets. This image was taken on January 16 by Roland Fichtl.



▲ C/2019 Y4 (ATLAS)'s orbital characteristics are strikingly similar to those of the Great Comet of 1844. Roland Fichtl took this image on January 23.

and the town is today known simply as 'Comet' — a lasting legacy of this spectacular celestial visitor of yesteryear.

Curiously, Leichhardt mentions that he later learned that the comet was first seen on December 1. That must be a mistake, as on that date it was rising after the Sun and setting prior to sunset. The date is probably December 21, which would be in line with the other discoveries. The comet remained visible to the naked eye until the end of the first week of February and was traced telescopically until March 12. An interesting anti-tail was noted in January. Unlike the anti-tails of (for example) Comet Arend-Roland, this could not have been a projection effect as the Earth was not close to the plane of the comet's orbit at that time. It must have involved the genuine expulsion of particles sunward of the nucleus.

Interestingly, if the intrinsic magnitude of the comet before perihelion was similar to that at the time of discovery, it should have been close to magnitude six low in the morning sky during November from the perspective of the Northern Hemisphere. Maybe its brightness surged near perihelion. Some researchers have found evidence of brightness fluctuations during the comet's period of visibility and very high levels of activity have been linked with the formation of the anti-tail. Perhaps new fragments were spawned at the 1844 return which will return as other members of a developing comet group thousands of years hence.

Needless to say, it does not necessarily follow that C/2019 Y4 will show similar behaviour, although this is an interesting thought, as it suggests that the present intrinsic faintness of this comet may be due to a semi-dormant state rather than simply its small size. If so, perhaps there is some hope of it becoming visible in June from southern latitudes.

■ **DAVID SEARGENT** is the discoverer of comet 1978 XV. His book, *Snowballs in the Furnace*, is available from Amazon.com

Betelgeuse is large enough for ground-based telescopes to get a glimpse of its size and shape. This image was taken in 2009 using adaptive optics and the ESO Very Large Telescope.

Red alert for Betelgeuse

A superstar is displaying unusual behaviour.

We last visited the red supergiant Betelgeuse in our December 2011 issue. If you have been following the star since then, you'll have seen that it has faded (see News Notes in this issue). In fact, if you had been following it you might have been the one who discovered the fading event. So if you've not currently monitoring Betelgeuse, why not do so now? — you might be among the first to notice something new. For instance, the red supergiant phase of the star's life is expected to end in a supernova explosion; if and when that happens, Betelgeuse will become so bright it will be visible in daylight.

Also known as alpha Orionis, Betelgeuse is a semiregular variable

with a visual magnitude range of 0.0 to 1.3 (currently 1.5 as I write this), and a period of roughly 2,335 days. At a distance from Earth of 430 light-years, this vast star (15 to 20 times the mass of our Sun) presents a (variable) angular size of 0.055 seconds of arc, meaning it has a diameter of 3.6 a.u. Scientists have detected bright atmospheric convection cells on its surface that are bigger than most stars.

If you want to monitor Betelgeuse, you'll need to bear in mind a couple of things. First, it is not easy to visually estimate its magnitude because its comparison stars are so spread out. The problem is atmospheric extinction; the more air we look through, the fainter a star appears. In fact, on the horizon we look through 38 times as much air mass than at the zenith, so the closer the target and sequence stars are to the same altitude the better. A list of comparison stars is in the table.

To estimate Betelgeuse's magnitude, find two comparison stars that can define the brightness of the target. But beware of the Purkinje effect; when estimating the brightness of red stars, don't stare directly at them. Rather, use quick glimpses from the target to sequence stars.

■ **ALAN PLUMMER** observes from the Blue Mountains west of Sydney, and can be contacted at alan123604@live.com

Comparison stars for Betelgeuse

Star	Mag.
Rigel (β Ori)	0.12*
Procyon (α CMi)	0.36
Aldebaran (α Tau)	0.87
Pollux (β Gem)	1.14
Castor (α Gem)	1.58**
Bellatrix (γ Ori)	1.64**
Alnitak (ζ Ori)	1.79
Alhena (γ Gem)	1.92
Saiph (κ Ori)	2.06

Visual magnitudes, courtesy of the AAVSO.

* Mean mag. — the colour is blue; use with caution.

** Not recommended due to the star's colour.

Located on the western limb, Riccioli and Grimaldi are both mare-flooded craters visible after full Moon.

Riccioli

Grimaldi

Prospecting for helium

The Moon may hold the fuel for Earth's future energy needs.

For thousands of years we've relied on coal and more recently on oil for civilisation's energy needs. Other power sources such as solar, wind, and nuclear fission have entered the energy market in recent decades. An additional potential energy source is nuclear fusion, which has the advantage that it produces no radioactive byproducts, though estimates have continually put fusion 'about 20 years in the future' for the past half century.

The goal of fusion is to merge deuterium (^2H) with tritium (^3H) to create helium-4 (^4He) and one neutron, while releasing prodigious amounts of energy. This process powers the Sun

and other stars. Two problems we've yet to surmount are the technical requirements to build a reactor able to contain the immense heat and pressure that fusion reactions produce and the extremely limited availability of helium-3 (^3He), the ideal fuel. After hydrogen, helium is the most abundant element in the universe, but nearly all helium found on Earth is ^4He , with ^3He being only about one-millionth as abundant.

However, the Moon is a veritable ^3He goldmine. Billions of years of solar wind has deposited ^3He in the lunar regolith. On the Moon, ^3He is available in the order of parts per billion, compared

to the parts-per-trillion paucity here on Earth. Thus, the lunar-exploration programs of China, Korea and other nations are partially focused on finding safe landing sites that have mineable concentrations of ^3He . Kyeong Kim (Korea Institute of Geoscience and Mineral Resources) and colleagues have created a global map of lunar ^3He abundances to determine potential landing-site locations that maximise mining opportunities and minimise landing danger. The most favourable of these sites are visible in backyard telescopes.

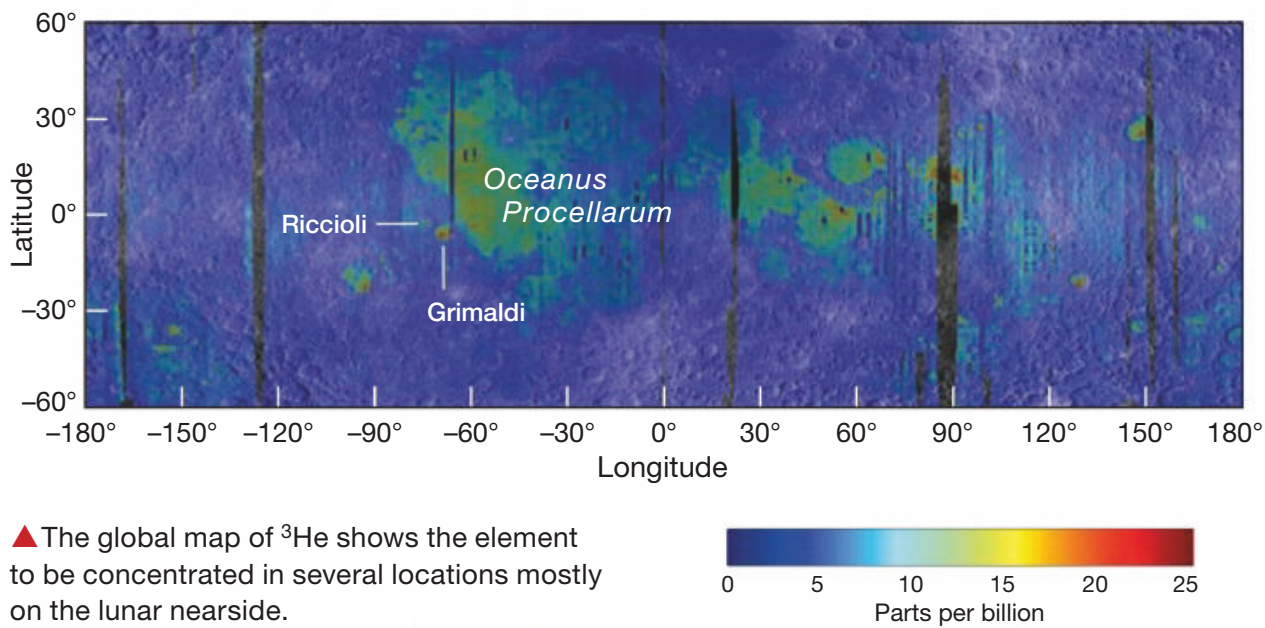
Soil samples brought back during NASA's Apollo missions show that the abundance of lunar ^3He is related to titanium dioxide (TiO_2) content, soil maturity and solar wind flux. The element is found in the iron-rich mineral ilmenite, which efficiently traps ^3He carried by solar wind. Lunar lavas are classified as having high, medium or low concentrations of TiO_2 , with the high titanium lavas having greater-than-average ^3He concentrations. Since ^3He occurs in the regolith or lunar soil, those maria peppered with recent small impact craters have churned the soil more, reducing the concentration of ^3He . The third variable, solar wind flux, or the amount of solar wind that hits a particular area of the Moon, corrects for the fact that the Earth's magnetic field shields various areas of the Moon from solar wind and hence ^3He deposition.

Kim and colleagues used data from the Clementine, Lunar Prospector and Chandrayaan-1 lunar orbiters to construct high-resolution maps of TiO_2 , and to correct for soil maturity as well as solar wind variations to create their ^3He map. They found that the highest abundances occur in the mare patches inside **Grimaldi** and **Riccioli** craters, as well as part of **Oceanus Procellarum**. Similar abundances were detected in Mare Moscoviense, but that lunar farside location would make control of mining operations difficult.

One additional parameter is needed to identify which area of high ^3He abundance is best for safe landings

(as is necessary for commercial use), and that is a site's topographic slope. This was estimated by determining the average slope of the surface at each potential target location using the 2-metre-resolution images from NASA's Lunar Reconnaissance Orbiter narrow-angle cameras. Surfaces sloping less than 10° are considered level enough for safe landing. One final factor affects the site selection. The high ³He abundance must occur over a wide enough area so that landing errors of up to 10-15 km still result in getting the miner into a rich ³He zone. Considering all these requirements, and the fact that crater interior geology is more interesting than mare geology, Kim and coworkers state that Grimaldi and Riccioli are the most promising sites for a future mining operation.

From the point of view of the backyard observer, these two depressions are relatively easy to find. When the Sun is high over this area, dark patches of mare lavas on the crater floors are quite visible against the bright background of surrounding highlands material. More details can be seen just after sunrise, when the grazing illumination reveals Grimaldi's



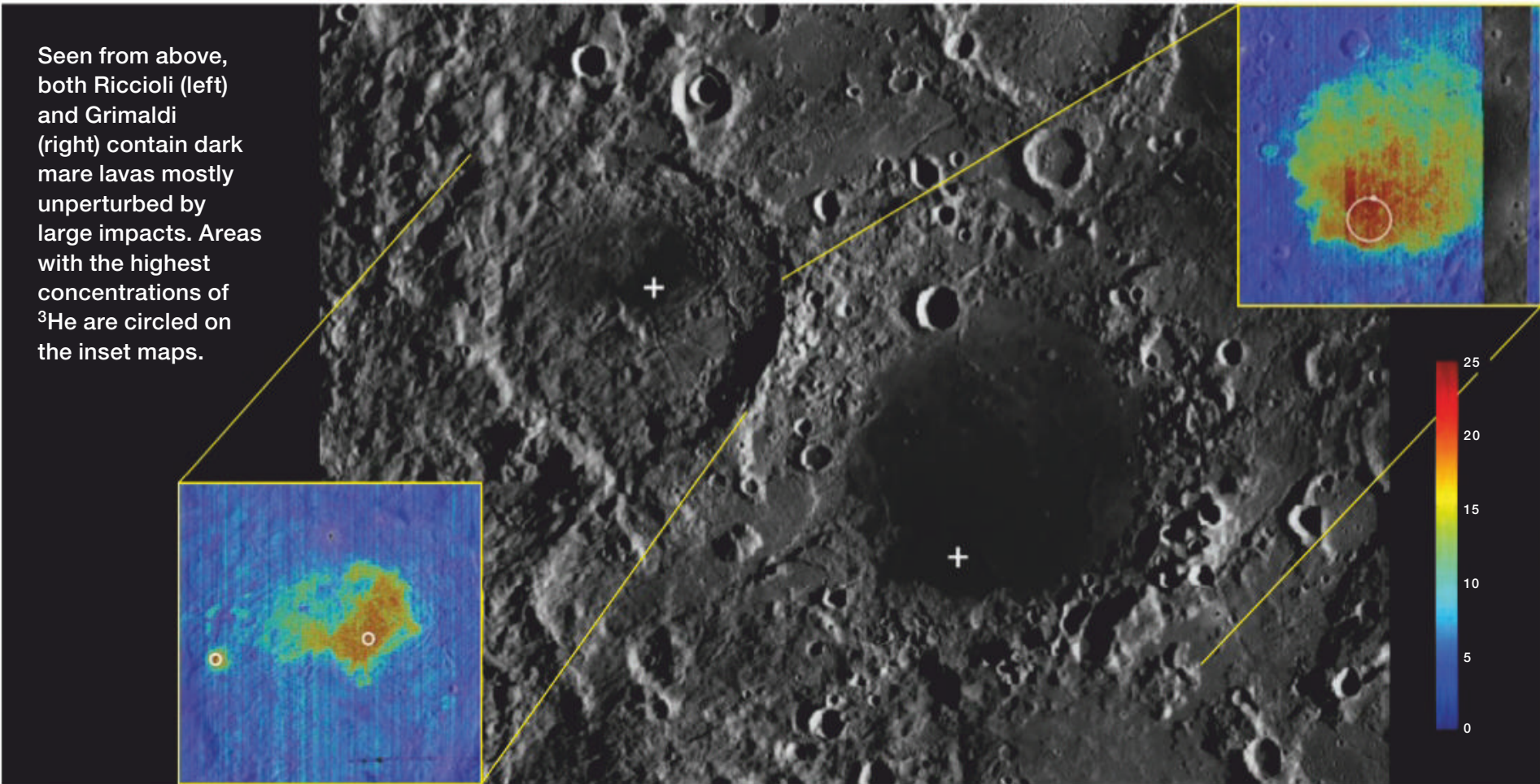
▲ The global map of ³He shows the element to be concentrated in several locations mostly on the lunar nearside.

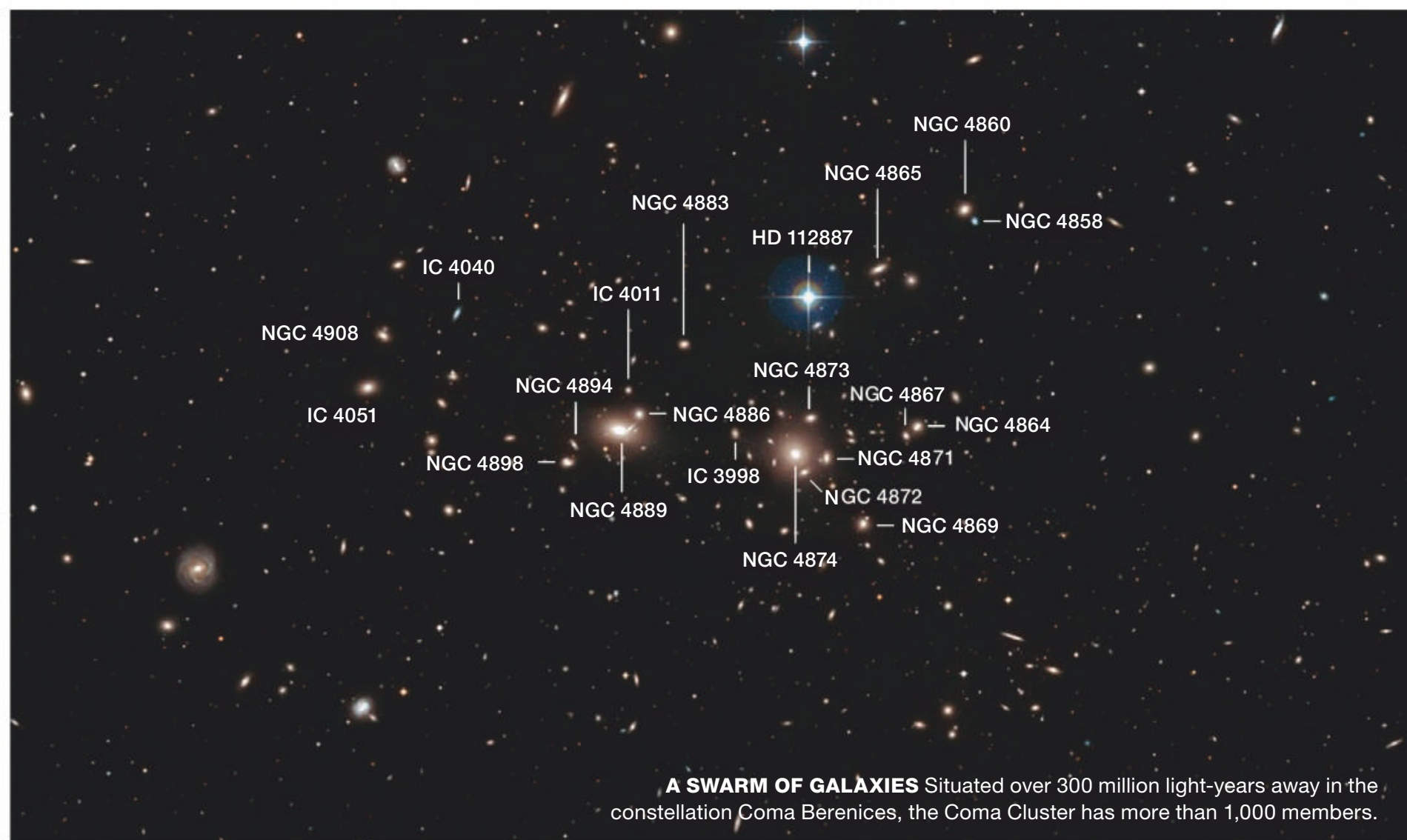
dark floor to be relatively smooth, unbroken by detectable craters, with a flattish dome near the north end of the 145-km-wide mare patch. The highest ³He region is near the southern edge of the dark mare.

Riccioli crater's rim is about the same diameter as the mare material covering most of Grimaldi's floor. But unlike that smooth surface, the majority of Riccioli's floor is covered by ejecta emplaced during the impact formation of the Orientale Basin to the south-southwest. Only a 40-km-long 'pond' of dark lava fills a low area in the northern

half of Riccioli's floor — the greatest concentration of ³He is at the southern end of this small mare patch. The fact that the dark lavas in these two craters are not defaced by ejecta demonstrates that they were volcanically emplaced after that basin's formation about 3.85 billion years ago. The dark floors of Riccioli and Grimaldi show no surface manifestation of the great isotopic wealth that we may someday harvest from those lavas.

■ CHARLES WOOD has been sharing his lunar insights for more than 20 years.





The Coma Cluster

Want to observe a galaxy or two? Point your scope toward the rich cluster in Coma Berenices.

Richer and denser than the Virgo Cluster and containing thousands of galaxies, the **Coma Cluster** (Abell 1656) is a telescopic wonderland that takes its name from its parent constellation, Coma Berenices. More than a hundred visible galaxies are packed into an area only a little greater than 3° in size; as many as 50 are visible through a 40-cm telescope. Exploring beyond its two dominant members is a challenge, though. At almost six times farther than the Virgo Cluster, its members are three or four times fainter. You can enjoy the sample tour I describe here with hardly more than a nudge of your telescope: The objects are contained in a single field of view of less than 1° .

The Coma Cluster lies about 2.5° west of Beta (β) Comae Berenices along an imaginary line connecting

Beta and Gamma (γ) Comae Berenices. The centre of the cluster is about $7'$ southeast of a magnitude-7.2 star (HD 112887). Dominating the middle of the cluster are two giant elliptical galaxies just $7'$ apart, both visible through a 20-cm scope. **NGC 4889** is officially the brightest galaxy in the cluster at magnitude 11.5, but neighbouring **NGC 4874** has a slightly higher surface brightness and appears more brilliant to the eye. Both have significantly brighter cores surrounded by large, luminous halos, with NGC 4889 being noticeably more elongated. The two galaxies each anchor their own group of smaller, fainter companions and stand out strikingly among the many neighbours that cluster around them.

William Herschel discovered both of these galaxies in April 1785. Herschel was the first to explore the cluster,

but several other famous observers, including John Herschel, Heinrich d'Arrest and Guillaume Bigourdan, are credited with discoveries here. And they are each responsible for various errors and ambiguities that John Dryer had to sort out when he compiled the *New General Catalogue*. Modern historians continue working to unravel some of the more puzzling discrepancies, so the pedigree of a few objects remains in contention. For instance, NGC 4889 is equivalent to NGC 4884; the dual designation is due to a second observation of the galaxy by d'Arrest that he mistakenly recorded as a new object.

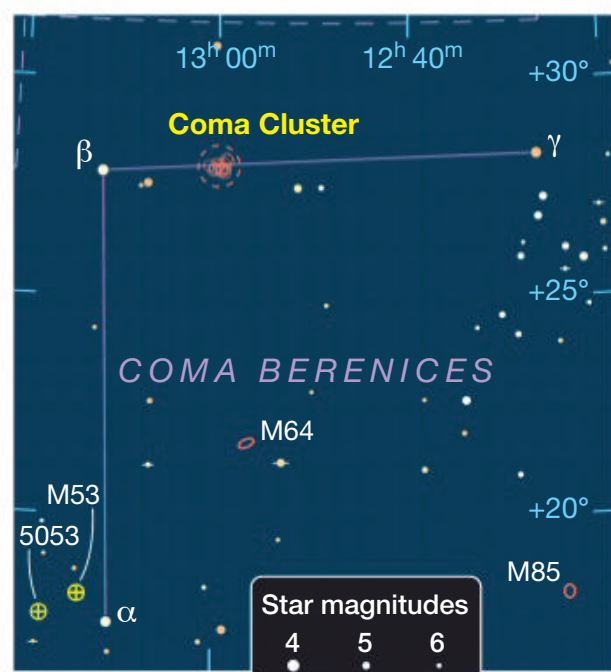
NGC 4886, a smaller elliptical paired with NGC 4889, also has a dual designation (NGC 4882); d'Arrest observed the pair again on a different night, and, not recognising them,

assigned them both new designations. NGC 4886 is round with a bright core and lies at approximately the same distance as its larger neighbour, around 300 million light-years.

Averted vision will reveal a pair of similar galaxies about 2' east-southeast of NGC 4889. **NGC 4898** is an elliptical galaxy that appears round, while **NGC 4894** is a lenticular, a class of galaxies that are intermediate between ellipticals and spirals. NGC 4894 lies about 100 million light-years closer to us than the core of the Coma Cluster. As with most giant galaxy clusters, the centre of the Coma Cluster is populated with ellipticals. The spiral galaxies that are associated with the cluster are typically found in the outskirts, and the lenticular galaxies, such as NGC 4894, are generally intermediate both in morphology and distance from the cluster core. A little more than 1.5' to the north of NGC 4889 is tiny **IC 4011**, appearing as a small round spot of uniform brightness. An elliptical, it is at a distance that puts it near the centre of the cluster.

Northwest of NGC 4889 at a separation of about 4.5' is **NGC 4883**, a small, round, barred lenticular galaxy that has a brighter core.

The western giant, NGC 4874, is surrounded by its own retinue of smaller galaxies that form an oval ring. Lying less than 1' to the southwest is **NGC 4872**, which has a somewhat muddled discovery history. It was most likely missed by William and Caroline



▲ **THE QUEEN IN THE CLUSTER** NGC 4889, an elliptical, is the largest of the galaxies in the Coma Cluster and harbours possibly one of the most massive black holes known to date, weighing in at some 21 billion solar masses.

Herschel and possibly first observed by d'Arrest. Errors in position and an ambiguous description by d'Arrest (his notes could apply to any of three close companions to NGC 4874) muddies the waters. Moving counterclockwise, we find **NGC 4871** a little more than 1' to the west of NGC 4874 and **NGC 4873** about 1.5' to the north. Both are similar lenticular galaxies with small bright cores. **IC 3998**, some 2.5' to the east-northeast of NGC 4874, lies behind the core of the cluster at around 460 million light-years. It appears small, faint and round. A number of small galaxies with PGC designations complete the oval ring of satellite companions, though they will require very large aperture to trace out.

Some 5' west of NGC 4874 lies the close pair comprised of **NGC 4864** and **NGC 4867**. On the night of April 11, 1785, William Herschel described three nebulae in the core of the Coma

Cluster. NGC 4889 and NGC 4874, the two brightest galaxies in the cluster, are certainly two of the three, but the third is somewhat in doubt. Harold G. Corwin speculates that the third nebula might have been the combined glow of NGC 4864 and NGC 4867 along with a superimposed star that lies just southeast of NGC 4864's core. These two galaxies are less than 1' apart.

Corwin notes that the other likely possibility for William Herschel's third nebula might be **NGC 4869**, which lies about 4' southwest of NGC 4874. It is one of the five brightest galaxies in the heart of the cluster and appears round with a bright core.

Some 8' east-northeast of NGC 4889 is one of several concentrations of faint but detectable galaxies that surround the core of the cluster. My 75-cm Dobsonian shows eight galaxies in this quadrant easily enough. The three brightest are **NGC 4908**, a

13.6-magnitude elliptical that has a brighter core, **IC 4051**, a more elongated 13.2-magnitude elliptical, and **IC 4040**, classified as a radio galaxy. Radio galaxies are a type of active galaxy that is very bright at radio wavelengths due to the interaction of powerful jets with the interstellar medium. We can only imagine the violence of the scene; the visual galaxy is very average-looking and reveals no hint of the activity occurring there.

About 3' to the northwest of the bright field star HD 112887 is **NGC 4865**, a foreground lenticular that has a bright core. Some 4' farther northwest is a close pair. The bright elliptical **NGC 4860** is just

38" from its fainter, smaller companion **NGC 4858**. The two are not proximate in space: NGC 4858 is a barred spiral that lies more than 60 million light-years behind its larger neighbour. Both galaxies have bright cores.

Our tour but scratches the surface of this cluster. Several dozen more galaxies lie within this single field, and many more galaxies will come into view with a gentle nudge of the scope in nearly any direction.

A compellingly emotive aspect of visual observing is the sense of reliving the experiences of the famous observers of the past. Exploring a distant galaxy cluster by eye, you are, at that moment,

the last in a line of observers stretching back centuries to the discoverer of the object. Observing the Coma Cluster, we can feel privileged to be sharing a unique moment with William Herschel and Heinrich d'Arrest. No matter how many observers stand between them and you, the visceral impact is undiminished, the view unchanged. Contemplate that incredible fact when next you put eye to eyepiece, and it just might offer you a new perspective and add a touch of awe to your observing session.

■ **TED FORTE** enjoys exploring the deep sky from his home observatory.

Coma Cluster Components

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
NGC 4889	Elliptical	13.3	11.5	2.9' × 1.9'	13 ^h 00.1 ^m	27° 59'
NGC 4874	Elliptical	13.1	11.7	1.9' × 1.9'	12 ^h 59.6 ^m	27° 58'
NGC 4886	Elliptical	12.8	13.9	0.6' × 0.6'	13 ^h 00.1 ^m	27° 59'
NGC 4898	Elliptical	12.0	13.5	0.6' × 0.4'	13 ^h 00.3 ^m	27° 57'
NGC 4894	Lenticular	12.6	15.2	0.5' × 0.2'	13 ^h 00.3 ^m	27° 58'
IC 4011	Elliptical	—	15.0	0.4' × 0.3'	13 ^h 00.1 ^m	28° 00'
NGC 4883	Barred lenticular	12.9	14.4	0.6' × 0.5'	12 ^h 59.9 ^m	28° 02'
NGC 4872	Barred lenticular	12.8	14.4	0.6' × 0.4'	12 ^h 59.6 ^m	27° 57'
NGC 4871	Lenticular	12.6	14.1	0.7' × 0.4'	12 ^h 59.5 ^m	27° 57'
NGC 4873	Lenticular	12.9	14.1	0.7' × 0.5'	12 ^h 59.5 ^m	27° 59'
IC 3998	Barred lenticular	—	14.6	0.6' × 0.4'	12 ^h 59.8 ^m	27° 58'
NGC 4864	Elliptical	12.4	13.6	0.7' × 0.5'	12 ^h 59.2 ^m	27° 59'
NGC 4867	Elliptical	12.8	14.5	0.5' × 0.4'	12 ^h 59.3 ^m	27° 58'
NGC 4869	Elliptical	13.1	13.8	0.8' × 0.7'	12 ^h 59.4 ^m	27° 55'
NGC 4908	Elliptical	12.9	13.6	0.8' × 0.6'	13 ^h 00.9 ^m	28° 02'
IC 4051	Elliptical	13.3	13.2	1.2' × 0.9'	13 ^h 00.9 ^m	28° 00'
IC 4040	Spiral	13.4	14.8	1.0' × 0.3'	13 ^h 00.6 ^m	28° 03'
NGC 4865	Elliptical	12.8	13.7	0.9' × 0.5'	12 ^h 59.3 ^m	28° 05'
NGC 4860	Elliptical	13.3	13.5	1.0' × 0.8'	12 ^h 59.1 ^m	28° 07'
NGC 4858	Barred spiral	13.3	15.2	0.5' × 0.4'	12 ^h 59.0 ^m	28° 07'

Angular sizes and separations are from recent catalogues. Visually, an object's size is often smaller than the catalogued value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Venus skirts the Pleiades

The Seven Sisters welcome a brilliant visitor.

The brightest planet and the best-known naked-eye star cluster join forces on the evening of April 3 for a spectacular conjunction visible just about everywhere. That evening, for observers in Australasia, Venus will tiptoe through the outskirts of the Pleiades and nudge within about 15' of Merope. For those in North America, Venus will pass only $\frac{1}{4}^\circ$ south of the cluster's brightest star, 3rd-magnitude Alcyone. If this very close conjunction feels familiar, it should. A nearly identical one took place on April 3, 2012, and the next will happen on April 3, 2028.

Conjunctions of the cluster and planet aren't unusual — in fact they happen annually — with Venus passing near but rarely *through* the Pleiades. However, every eight years nearly to the day, Venus knocks down the door and strolls right in. What strange clockwork is behind this every-eight-year pattern?

Over many millions of years, the regular and repeated gravitational interactions between Venus and Earth have caused their orbits to achieve what astronomers call a *near resonance*. For every eight Earth years, Venus circles the Sun almost exactly 13 times. This

8:13 ratio means that Earth and Venus return to nearly the same positions in their orbits at eight-year intervals. Venus then repeats its trek across the evening sky, which always includes a special visit to the Pleiades.

Because neither planet's orbit is a perfect circle, the resonance is imprecise. In addition, Venus' orbit is inclined 3.4° to the plane of the ecliptic. These two factors combine to ensure that each Pleiades passage is similar yet unique.

Finding Venus on April 3 will be simple — look in the western sky, starting about half an hour after sunset.

◀ Venus most recently gleamed within the Pleiades star cluster (M45) on April 3, 2012. This 13-second exposure (at ISO 200) was captured with a 92-mm refractor (working at f/4.5) and a Canon EOS 7D DSLR camera. A pair of wires taped in front of the lens produced the diffraction spikes.

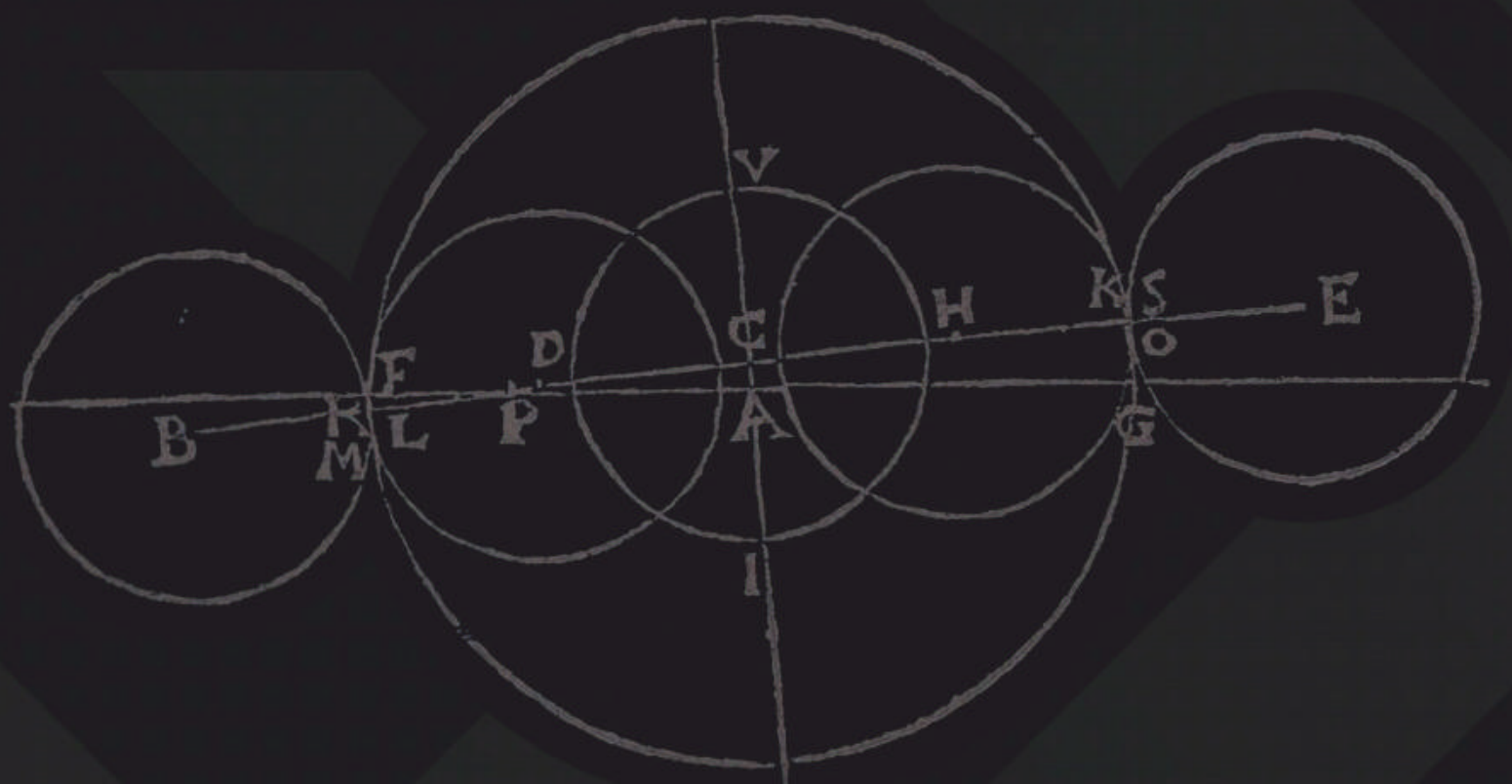
Only 10 days past greatest eastern elongation (which occurred on March 24), the planet will positively dazzle at magnitude -4.6 . You may even notice a few individual Pleiades stars poking out next to Venus as the sky darkens. But the best way to encompass the unfolding drama of laserlike Venus and its temporary retinue of blue-white diamonds is with binoculars or a small, low-power telescope, both of which offer wide fields of view. If ever there were an event for humble equipment, this is it.

Begin observing early and note Venus's position in relation to the brightest cluster stars. After an hour or two, you should be able to detect the planet's eastward motion. Clipping along at 127,000 kph, Venus traverses the Moon's diameter in about 15 hours.

Clouds often have a way of ruining a good conjunction. Not to worry. Venus will shine within 2° of the Pleiades from March 31 through to April 6, more than enough time to appreciate the sweet sight and get a photo. On March 28, the four-day-old waxing lunar crescent will photobomb the scene. Have your camera ready!



▶ In Greek mythology, the Pleiades represent the seven daughters of Atlas and Pleione.



Kepler's Dream, Today's

The great astronomer Johannes Kepler played a central role in the eventual evolution of spaceflight.

WE LIVE IN A WORLD made of our ancestor's dreams, where extraordinary feats have become commonplace. Most people alive today have never witnessed a time when we did not capture exquisite images of planets, stars and galaxies; when we did not regularly shuttle members of our species to a residence orbiting 400 kilometres above Earth; when we did not plunge spacecraft into the depths of the cosmos, scattering them throughout the Solar System and beyond. In the ages before these feats, launching anything into space was mere fantasy, a collaboration of the mind and the pen. Firmly earthbound, we looked up, told stories about far-off worlds, and imagined what it might be like to visit them.

The pathbreaking 17th-century astronomer Johannes Kepler authored such a story — a travelogue, an amalgam of science and fiction, detailing a voyage from Earth to the Moon. His work relates what a journey of this kind entails as

people traverse the expanse of space between the two worlds and the discoveries that await them on the other side. It's titled *Somnium (The Dream)*.

The origins of *Somnium* trace back to Kepler's early life. As a student in 1593, he composed a dissertation in which he speculated about the appearance of Earth from the vantage of the Moon. An advocate of the controversial Sun-centred universe, Kepler intended to support one of the theory's assertions: a rotating Earth. Those who opposed heliocentrism maintained that such dramatic movements would be felt or otherwise obvious to the senses. Kepler hypothesised that the apparent motionlessness of Earth is an illusion; the planet spins unbeknown to terrestrial observers because they partake in the rotation. Meanwhile, those same observers witness the Moon traversing the nighttime sky. Kepler imagined what someone would experience if uprooted from our planet and



Reality

▲ *Above left:* Johannes Kepler was the first scientist to explore in detail how the universe would appear to an observer on the Moon. In this diagram, he shows how a total solar eclipse on Earth would appear from space. *Above right:* On August 21, 2017, NOAA's Deep Space Climate Observatory fulfilled Kepler's prophecy by photographing a total solar eclipse crossing North America.

► This posthumous portrait of Johannes Kepler was engraved by the 19th-century British illustrator Frederick Mackenzie.



Kepler's Antecedents

Johannes Kepler was one of the most original scientific thinkers of all time. It seems likely that he invented the idea of stationing an observer on the Moon all on his own. But he later encountered some similar ideas in the Greco-Roman authors Plutarch and Lucian, which he ended up referencing extensively in *Somnium*.

Plutarch is best known as a biographer, but he also wrote an influential treatise titled *On the Face Which Appears in the Orb of the Moon*. It dissented from the mainstream Greco-Roman theory that the Moon is a perfect sphere — a theory that struggled mightily to explain the Moon's familiar dark splotches. Instead, Plutarch suggested that the Moon is a complex, irregular world much like Earth and is very likely inhabited.

Two or three generations later, the satirist Lucian of Samosata wrote two works describing journeys to the Moon. His *True History* is a sequence of ever-more-whopping tall tales culminating with the hero's ship being swept up by a whirlwind to the Moon, where he joins the lunar army in a war with the Sun for the right to colonise Venus. In Lucian's *Icaromenippus*, the hero flies to the Moon by strapping bird wings to his arms. There he encounters the goddess Selene, who is indignant with all the scientists who claim that she is a spherical body orbiting high above Earth and shining by the reflected light of the Sun. The hero then proceeds on to Heaven, where he is stripped of his wings and escorted back to Earth by the messenger-god Mercury.

Lucian created delightful farces by juxtaposing contemporary science with traditional religion and mocking both. He didn't really care about exploring the cosmos; his genius was for exploring human foibles. But *Icaromenippus* does have one strikingly modern scene in which the hero looks down from the Moon onto Earth and sees how petty we all are in the grand scheme of the universe.

—TONY FLANDERS

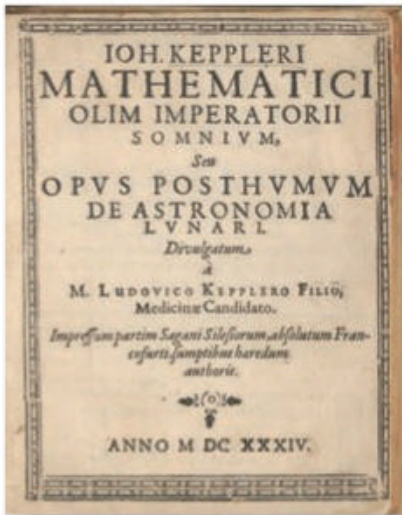
planted on the lunar surface: The motions of the Moon go undetected, while those of Earth are revealed.

Kepler’s dissertation challenged the prevailing Earth-centred model of the universe, and unfortunately for him, the professor in charge of dissertations was deeply entrenched in the geocentric worldview. Typically, a dissertation would have been the subject of public debate, but Kepler’s writing was denied an audience. Wary of protesting this ruling, Kepler fell silent on the matter. He shelved the work, awaiting a time when circumstances would swing in his favour.

When Kepler returned to the dissertation 16 years later, he decided to reframe it as a dream. He believed that in this context, geocentrists could dismiss objectionable material as inventions of his imagination. Thus, if portrayed as fiction, his thoughts on astronomy might evade censorship.

During this period of revision, Kepler also introduced a passage that addresses lunar flight itself. In telling this stage of the journey, he harks back to the ancient Greeks, with whom literary voyages beyond Earth originated. The stories of antiquity were facetious in their treatment of space travel, recounting humans being lofted into the heavens by whirlwinds or transported across space by gods (see the boxed text on the previous page). Kepler follows this precedent; his explorers require the services of a spirit to convey them between worlds. However, amidst this homage to the ancients, Kepler breaks new ground with an earnest discussion of the practical problems of spaceflight.

Kepler speculated that space is permeated with a deadly



◀ The title page of *Somnium* reads as follows: “By Joh. Kepler, formerly Imperial Mathematician, *Somnium*, or *Posthumous Work on Lunar Astronomy*,” followed by publication information.

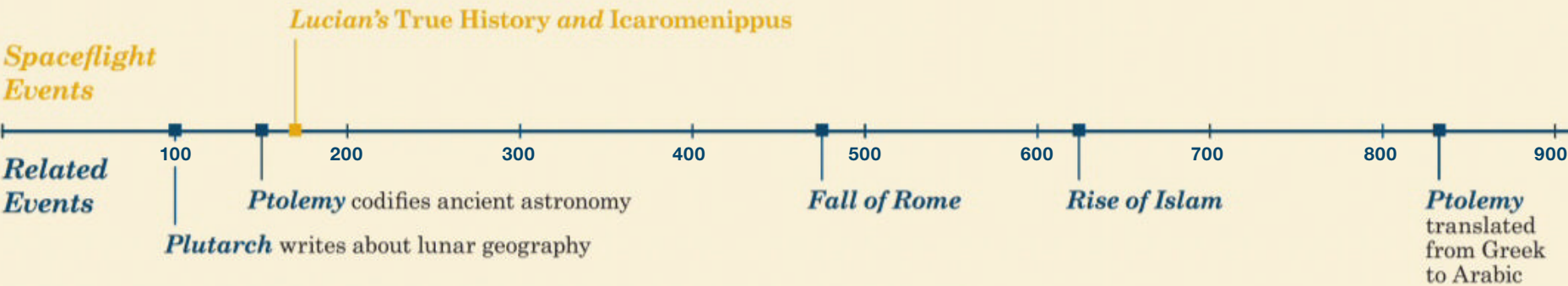
barrage of solar radiation. Therefore, Moon flights must be scheduled for a lunar eclipse, when Earth is situated between the Sun and Moon, generating a shroud of darkness in which the voyagers find safe passage.

The rigours of launch are compared to the detonation of explosives. The ascent so jars the explorer that he requires sedation. His body must be fastened and protected, lest his

limbs be horrifically torn away. But at the end of this torturous episode, the explorer coasts peacefully to the Moon without any further application of force.

A close inspection of the Moon reveals perilous terrain. Here, Kepler indulges in what he called lunar geography. In *Somnium*, he describes the Moon’s features as dwarfing those of Earth. Mountains tower above all earthly peaks, and chasms plummet to depths far below the greatest terrestrial trenches. The climate is no more tame. Each day and night on the Moon causes huge swings in temperature, blistering heat giving way to severe cold.

In time, Kepler proved correct in his assessment of the climate; however, he was wrong about the size of lunar mountains and many other matters, including the presence of life. Kepler populated the lunar landscape with a diverse community of bizarre creatures. He even included a detailed description of how intelligent beings might have built the lunar craters which, he thought, were too perfectly circular



The First Spaceflight Manifesto

While Johannes Kepler was working on the first version of *Somnium*, his great contemporary Galileo Galilei heard of a new device that made distant objects appear bigger. Galileo built his own telescope (as we now call it), turned it to the night sky, and in one year he discovered that the Milky Way comprises innumerable faint stars, confirmed Petrarch’s theory of complex lunar topography as shown in the sketches on the facing page, discovered Jupiter’s four bright moons and observed their changing patterns. That was a severe blow to the geocentric theory, because

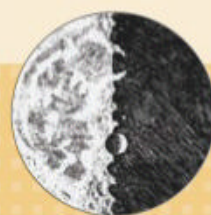
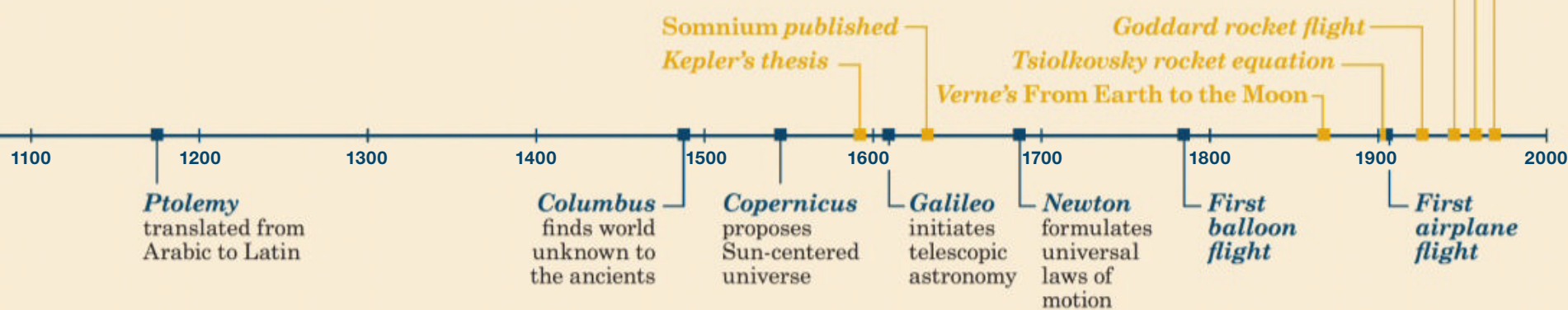
it proved that at least four objects orbit something other than Earth! He published these results in 1610 in a short pamphlet entitled *Sidereus nuncius* (*Starry Message* or *Messenger*) that electrified the scientific community.

Kepler was thrilled by the pamphlet. He wrote an open letter to Galileo titled *Conversation with the Starry Messenger* that discusses the new revelations in detail. Toward the end, he mentions the possibility that both the Moon and Jupiter are inhabited and proceeds to say, “But as soon as somebody demonstrates the art of flying,

Kepler correctly stated that the most beautiful sight on the Moon's nearside is Earth, which rotates, waxes and wanes, but always stands in the same spot in the sky. In this photograph, NASA's Lunar Reconnaissance Orbiter captured Earth appearing around the curve of the Moon's surface.



Bootprints on moon
Sputnik in orbit
V2 rocket reaches space



settlers from our species of man will not be lacking.” And then he proposes that he and Galileo prepare the charts to be used by these explorers.

This appears to be the very first time that anyone wrote about colonising other worlds not as a fantasy or satire, not even as an interesting possibility, but rather as something that is destined to happen.

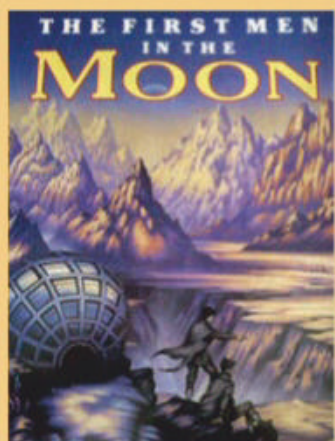
Many people wrote about spaceflight and alien life after *Sidereus nuncius*, drawing parallels with the New World discovered 118 years earlier by Christopher Columbus. It's a testament to Kepler's unique genius that he was thinking about visiting alien worlds when he was a student, 14 years *before* the telescope was invented.

—TONY FLANDERS

Kepler's Legacy

Like almost all scholarly works of the 17th century, Kepler's *Somnium* was written in Latin, making it inaccessible to the general public. But the small community of scientists interested in alien life and spaceflight took note of the book from the moment that Kepler first circulated his manuscript among his colleagues.

John Wilkins's 1638 book *The Discovery of a World in the Moone* is sprinkled with references to Kepler, including a short discussion of spaceflight at the end. Internal evidence suggests that he heard



about *Somnium* secondhand rather than reading one of the rare copies that had been published just four years earlier.

In 1640 Wilkins expanded his brief note about spaceflight into a discussion of its problems and possible solutions, far more detailed

and sophisticated than anything Kepler attempted. It ends with a clarion call to fly to the stars “despite those who choose to crawl on their bellies like reptiles”. Written in nontechnical terms for a lay audience, *The Discovery of a World in the Moone* provoked a brief and wildly premature burst of spaceflight enthusiasm.

Jules Verne and H. G. Wells, the fathers of modern science fiction, both mention Kepler's theory of an inhabited Moon. And an offhand reference to “Kepler's sub-volvani” in Wells's 1901 book *The First Men in the Moon* makes it clear that Wells took the idea of selenites sheltering from extremes of heat and cold in a honeycombed Moon directly from *Somnium*, though he channeled Kepler's vision into a much deeper and more disturbing narrative.

All the early rocket pioneers cited Verne or Wells as having inspired them to investigate spaceflight, so the causal chain linking Kepler to real-life space rockets is surprisingly short. And through Verne and Wells, Kepler's influence on popular culture is incalculably huge.

—TONY FLANDERS

to have been formed by nature. He was unaware of the rocky debris bombarding the Moon, excavating the circles.

He speculated that the inhabitants shelter in caves to protect themselves from extremes of heat and cold, especially on the Moon's farside, where the long lunar night is unrelieved by Earth's glow.

Recalling the hostility that he encountered in his youth, Kepler entrusted the manuscript of *Somnium* to various colleagues for review. He sought to understand how his writing would be received. This decision, he believed, prompted the hardships that soon visited his family.

Kepler's mother, Katharina, was argumentative and temperamental. She quarreled with neighbours and local authorities. Elderly, alone and the object of public contempt, Katharina was susceptible to the storms of superstition that raged in 17th-century Europe (and America). She was arrested on charges of witchcraft — taken in the night and whisked away in a linen chest.

Kepler came to his mother's defense, entangling himself in a grueling campaign to prove her innocence. He worked diligently to reveal the natural forces underlying the supposed evidence of witchcraft. After six long years, Katharina was acquitted and exiled, warded off by the promise that her return would mean her death.

A grief-stricken Kepler reflected on his mother's arrest and the ordeal that followed. He imagined that a copy of *Somnium* had escaped his colleagues and had been read by one of his mother's enemies. Parts of the text are blatantly autobiographical; for instance, the explorer, like Kepler, was apprenticed to the Danish astronomer Tycho Brahe. Kepler suspected that his mother was, correspondingly, likened to the explorer's mother — a mysterious vendor of drugs and a friend to spirits. So, Kepler feared, it was *Somnium* that had aroused suspicions of sorcery and cries of witchcraft.

The case for Kepler's culpability is tenuous. It seems much more likely that Katharina was just another innocent victim of the paranoia and fear that were rampant in her time. However, Kepler blamed himself, convinced that he had penned the very evidence that locked her away. He assumed a



Appropriately enough, the bright young lunar craters Kepler and Copernicus have overlapping ray systems. Johannes Kepler thought that craters were artificial constructs.

► The Kepler spacecraft, shown here launching in 2009, discovered more than 2,600 exoplanets in its nine-year lifespan. Carl Sagan, among others, insisted on naming it after the great 17th-century advocate for exploring alien worlds.

responsibility that was not his and was plagued by guilt for the rest of his life.

When Kepler returned to *Somnium*, he set out to dispel the misrepresentation of his work and mischaracterisation of his mother. Accordingly, he supplemented the manuscript with footnotes containing elucidations of lunar geography, discussions of telescopic observations, and rebukes of those who (he believed) had weaponised his words against an innocent woman. The remarks — 223 in all — are many times longer than the main text, and required a decade to complete.

Kepler's *Somnium* was a lifelong exercise in scientific investigation, imagination and patience. But illness struck him down before the manuscript made it to print. His son Ludwig took charge of it, which was finally published in 1634, four years after Kepler's death.

Combining a mystical framework, a weak narrative and a profound but rambling scientific treatise, *Somnium* is not an easy read. While the book had a deep effect on some of Kepler's contemporaries (see the discussion on the facing page), others were confused, and most were probably unaware of its existence. Not until the mid-20th century was *Somnium* studied in earnest. We now recognise it as the first modern contemplation on lunar geography and spaceflight.

A far cry from the doctoral dissertation from which it sprang, the completed *Somnium* is more than an effort to promote and popularise the Sun-centred universe. It's a prophecy about the potential of science and the promise of our species. Kepler believed that space travel was indeed possible, that someday humanity would construct ships suited to the cosmic seas and sail for uncharted worlds.

More than three centuries elapsed after Kepler's death before humans attained spaceflight — before they propelled themselves into the heavens, braving that dangerous expanse, destined for the Moon. Then, far from home, those voyagers beheld Earth from aloft — its lands adorned by vibrant hues, its oceans peeking through wispy clouds — and darkness stretching in every direction. But marooned in a time long past, Kepler was never to know of humanity's rendezvous with the Moon and the bootprints impressed in its surface.

While our capabilities and technologies far surpass those of Kepler's time, our fundamental situation remains the same. We reckon with the blank regions on our maps — all that lies outside our line of sight and beyond our reach. We stare out at the universe through a pinhole, fated to know hardly any of it — just our little corner, perhaps, and a few remote fragments, here and there. We try mightily to force a retreat of the boundary separating knowledge and ignorance.



Yet when we cross one frontier, we discover a new one. So we do what we can, in the time we have, to light up the darkness in which we live, and bequeath a universe a little less unknown.

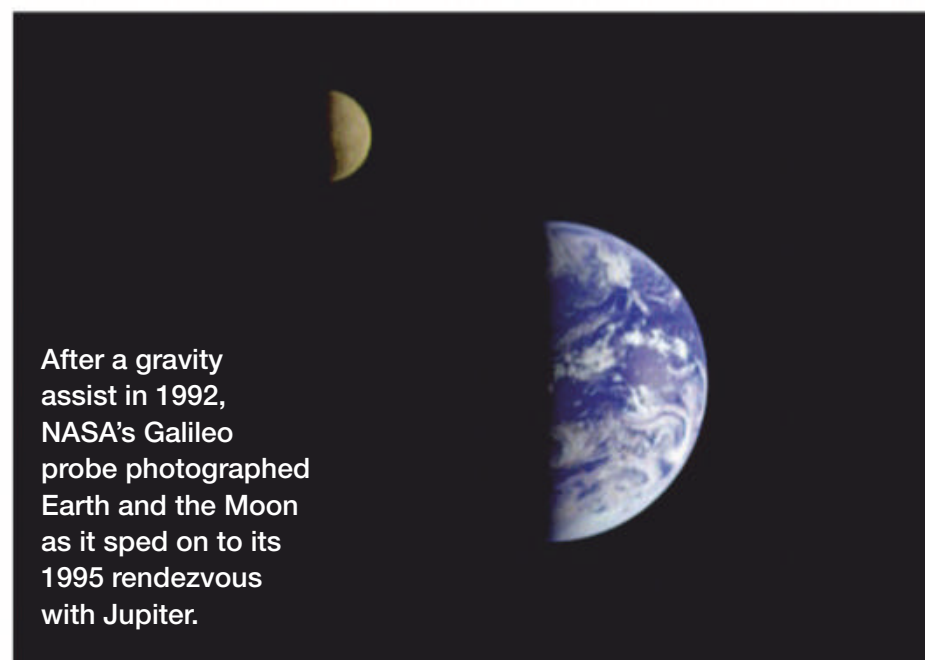
Each generation that follows us will gaze up with wide eyes and see the universe for the first time. Our successors will access perspectives yet unseen, behold wonders yet unimagined, and reveal the cosmos as it has never been known to us nor any human before. And we, islanded in our own time, reach into theirs, helping to create a future that we

cannot live to experience directly.

Space travel is an endeavour owed to the labour of multitudes — to the generations past who developed the technology and garnered the scientific know-how to propel us into the universe. Now, the time is ours to carry on this remarkable undertaking. Today, it is we, the most recent iteration of humankind, who make the unthinkable plausible and the extraordinary commonplace. We are the next chapter in a story far greater than ourselves — a story spanning from the distant past to distant worlds. With every voyage beyond Earth, we fulfill the dreams of our ancestors and set the stage for our descendants to venture farther than we ever will.

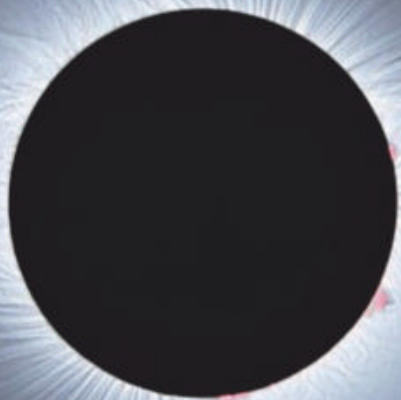
■ **JAKE ROSENTHAL** is an aerospace engineer at NASA's Goddard Space Flight Center. He was born a quarter-century too late to witness humankind's first "giant leap," but at the right time to take part in the next.

FURTHER READING: The standard English translation of Kepler's *Somnium*, with ample commentary, is by Edward Rosen, Dover Publications, 2003. Marjorie Hope Nicolson's *Voyages to the Moon* (Macmillan Co., 1948), sadly long out of print, is a superb synopsis of spaceflight stories from ancient Greece to the first balloon flight in 1783.



After a gravity assist in 1992, NASA's Galileo probe photographed Earth and the Moon as it sped on to its 1995 rendezvous with Jupiter.

Capturing the entire brightness range of a total solar eclipse in a single exposure is beyond the capability of digital detectors. You can circumvent this by recording progressively longer exposures and then stacking the results. This image of the eclipse of August 21, 2017 uses 91 exposures shot in 13 bracketed groups of 7 images each at ISO 100. The author used a Canon EOS 70D DSLR and Tele Vue Pronto refractor at f/5.3 riding on a Sky-Watcher Star Adventurer Mini tracking head.



REVEALING TOTALITY IN

HDR

This innovative technique can pull out stunning detail in the solar corona.

PHOTOGRAPHING SOLAR ECLIPSES is one of the most challenging forms of astroimaging. It requires a great amount of advanced planning, from organising the equipment you tow along on your voyage towards totality, to recording a series of exposures that capture the huge range of brightness displayed by the Sun's ethereal corona. It's even trickier if you hope to reveal complex magnetic loops that are hidden within the corona. Fortunately, digital photography has made this type of high-dynamic-range (HDR) imaging a bit easier. Here's a technique I use with *Adobe Photoshop* that works on solar eclipse photographs taken through almost any lens or telescope.

A good plan

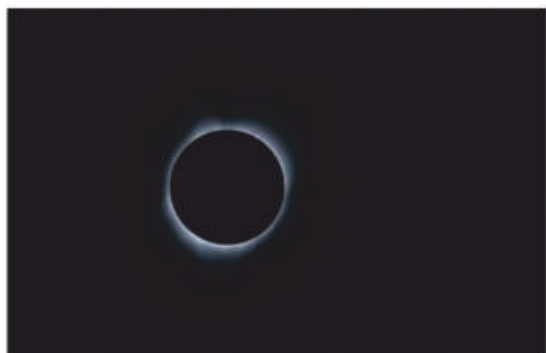
Part of the trick for revealing the entire dynamic range of the solar corona is to shoot bracketed exposures. Because the corona spans an extremely wide range of brightness, it's impossible to record all the coronal detail in a single exposure. Prominences visible along the eclipsed Sun's limb are best captured in very short exposures of typically $\frac{1}{500}$ second or less in an f/5 optical system, whereas photographing the outermost extent of the corona requires keeping the camera's shutter open for up to 1 or 2 seconds, completely overexposing details within the inner corona.

Recording the full range of the corona's brightness requires shooting a rapid-fire sequence of bracketed exposures spanning the two extremes and then combining the shots into a single, HDR image with image-processing software. There are several good ways to shoot the bracketed exposures, but the most efficient is to either employ a camera that has built-in auto-exposure bracketing (AEB), or use a laptop computer with camera-control software such as *Eclipse Orchestrator* (<https://is.gd/EclipseOrchestrator>) to make the exposures. A helpful list of cameras that include auto bracketing is available at <https://is.gd/cameraAEB>.

My best results so far have involved a set of at least seven separate exposures ranging from around $\frac{1}{500}$ to 1 second. The more exposures in a bracketed set, the smoother the transition between the individual exposures will appear in the final result. It's also better when you shoot many of these bracketed groups of exposures during totality so that you have lots of images to combine, greatly reducing noise in your final result.

I highly recommend tracking the Sun while you're shooting. Much like when stacking deep sky astrophotos,

► The individual exposures as captured range from $\frac{1}{500}$ to 1 second.



ALL IMAGES PROVIDED BY THE AUTHOR

alignment of your individual exposures is key to producing the best results. Aligning untracked eclipse images is time consuming because it can be difficult to find precise reference points such as background stars in all the images, particularly the shortest exposures. No software I've tried can automatically detect stars and align solar-eclipse pictures. Shooting with your camera on a well polar-aligned tracking mount makes it much easier to nudge your individual exposures into alignment.

Stacking brackets

Let's assume your images are all well-tracked and are ready to stack together. There are several specialised HDR image-processing programs for doing the stacking that I've described in the past. But stacking aligned images is also relatively quick and easy in the current version of *Adobe Photoshop*.

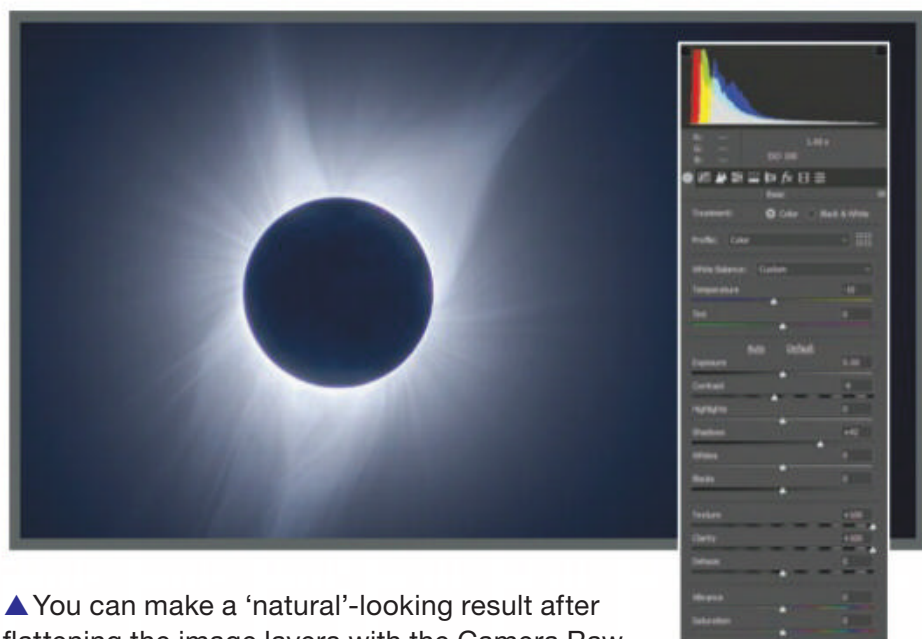
Start by opening the program and selecting File > Scripts > Load Files into Stack from the dropdown menu. The Load Layers window opens, where you'll click the Browse button at right and navigate to your first bracketed set of exposures. Select them all (you can stack almost any format image files, including RAW camera files). When you click OK, in a few moments your images will be layered one atop the other sequentially in the order you shot them, either shortest to longest or vice versa. If you don't see the Layers window, open it using the dropdown menu Window > Layers. Any layer that needs additional alignment can be moved by selecting the Move tool, clicking the layer in question, changing the blending mode to Difference, and nudging it into place using the arrow keys on your keyboard.

To smoothly combine all the layers, you need to change the Opacity setting of each layer so that they collectively contribute to the final visible image sequentially from the bottom layer to the top. For my stack of seven exposures, I changed the opacity setting of layers 2 through 7 at the top-right of the Layers window to 50%, 33%, 25%, 20%, 17% and 14%, respectively, leaving the bottom layer set to 100%. This should produce a smooth image that shows everything from the Moon's faintly illuminated surface to prominences, extended coronal streamers, and even some of the brightest field stars. Simply choose Layer > Flatten Image and save the result as 'group 1.tif'.

If your goal is a natural-appearing image of totality, a great result can be had by just tweaking this stacked image using *Adobe Camera Raw* (Filter > Camera Raw Filter). This filter

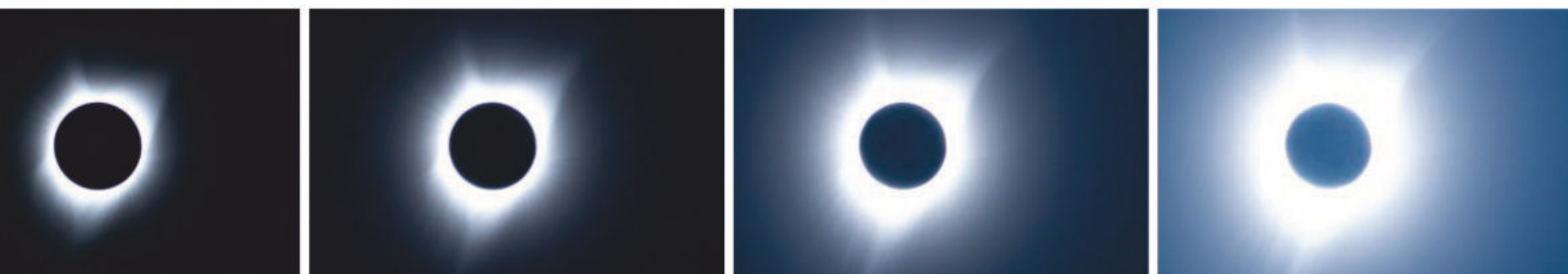


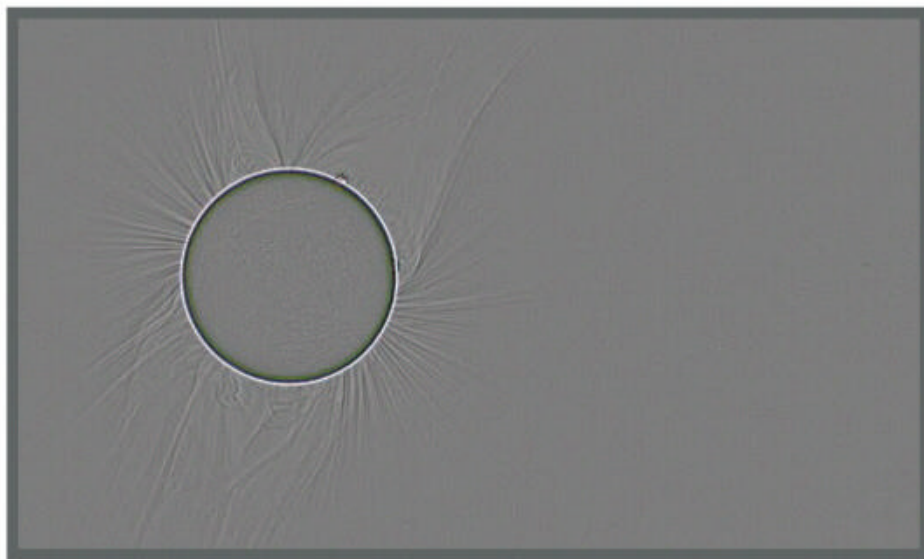
▲ After importing a group of bracketed exposures into *Photoshop*, you change the opacity of each layer to reflect how much that image will contribute to the final stack based on its position in the stack, thus ensuring a smooth transition between the individual exposures.



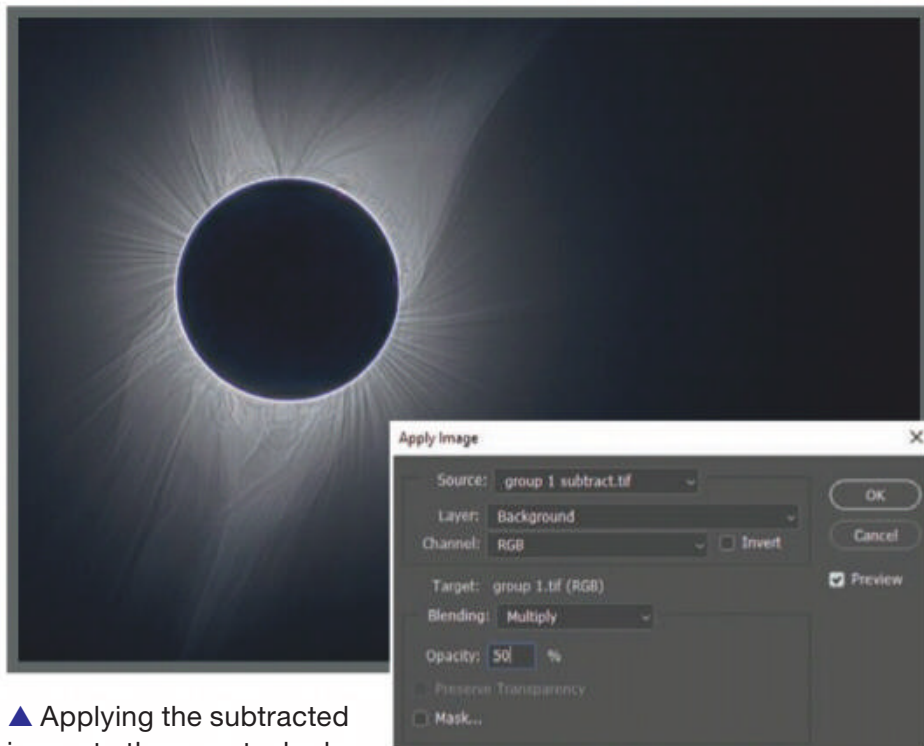
▲ You can make a 'natural'-looking result after flattening the image layers with the Camera Raw Filter by maximising the Texture and Clarity sliders, and increasing the Shadows. This produces an excellent image that resembles the naked-eye appearance of an eclipse.

lets you adjust the colour balance, increase the texture and clarity, and also increase the shadow detail until you start to see some features in the inner corona as well as the Moon's surface. Setting both the Texture and Clarity sliders to 100 and the Shadows to 50 produces an eye-catching result that is very close to what the eclipse looks like to the unaided eye. Adjust the colour balance, save the result with a new file name (group 1ACR.tif), and you'll have a great image of the event. But you can do much more with your bracketed set.





▲ Applying the blurred image to its corresponding image stack using the Subtract blending mode produces a detail map that is then stretched to reveal low-contrast details within the solar corona as well as some lunar features.



▲ Applying the subtracted image to the raw stacked image using the Multiply blending mode produces a detailed, though noisy, picture. Reducing the opacity of the target between 50% and 75% can achieve a more pleasing result.

Revealing coronal loops

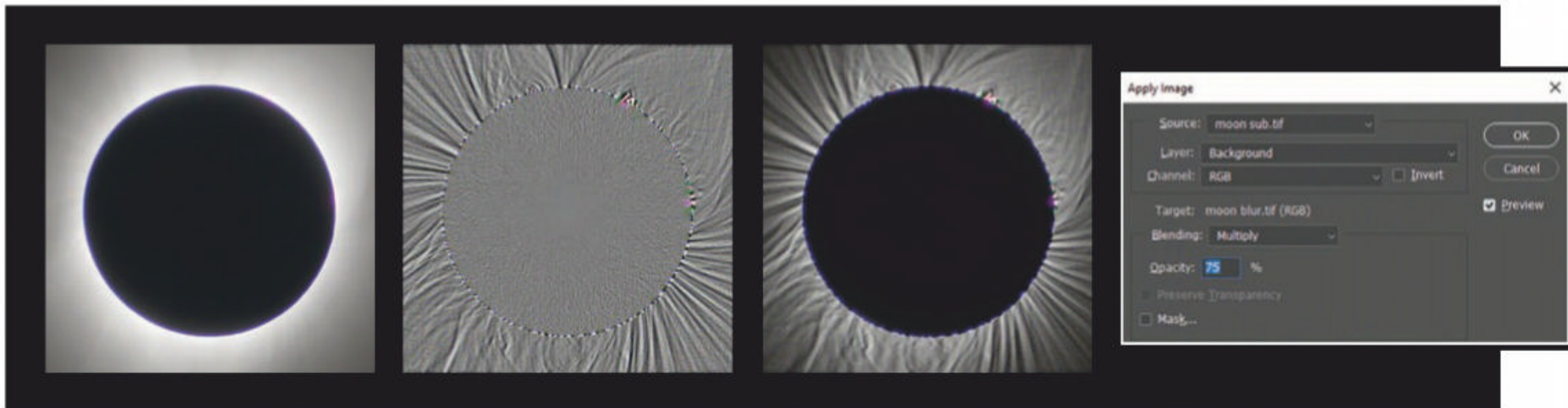
To bring out additional fine detail in the corona, open the first stacked image (group 1.tif) and blur it using the Gaussian Blur filter (Filter > Blur > Gaussian Blur). In the filter window, change the Radius to 3 or 4 pixels (the larger value will add more contrast to your completed photo, though at the cost of suppressing the smallest-scale features), depending on the focal length of the optics you shot with. Save this image with a name that reflects the process used, such as 'group 1 blur.tif'.

Keep this blurred image file open and reopen the original stacked image (group 1.tif). Next, apply the blurred image to the original by selecting Image > Apply Image from the dropdown menu. In the Apply Image command window, first change the Source from group 1.tif to group 1 blur.tif. In the Target section, change the Blending mode to Subtract, and increase the offset to 128. Click OK, and a very low-contrast map of small-scale differences between your original image and the blurred version remains, though it will appear grey with a dark ring where the limb of the Moon is located. We need to significantly compress the dynamic range of this image by opening the Levels tool (Image > Adjustments > Levels). In this window, change the low value slider at left to 126, and the high value slider at the right to 130, and click OK.

This mapped image should now display the edges of coronal loops and streamers, and some background stars, albeit with a lot of noise. Save this image as 'group 1 subtract.tif'.

Next, you need to apply this detail map to the original stack. Open group 1.tif and again select Image > Apply Image from the dropdown menu. Here you have several options depending on how aggressive you want the processing to appear. Change the Source to group 1 subtract.tif and the blending mode to Multiply. Immediately, you'll see lots of high-contrast loops within the corona, though it will be extremely noisy and rather 'overcooked'. When applying this process, I prefer to lower the Opacity to about 75% before clicking OK.

This result displays a lot of coronal detail but is very noisy. You can reduce the noise by opening the Camera Raw Filter again and dropping the Texture slider to -50.



▲ *Left:* To correct the sharpening artifact around the lunar limb, return to the original stacked image and crop it with the Moon centred. *Middle:* Create a blurred image using the Radial Blur filter set to Spin at 3 pixels, then apply it to the cropped Moon picture and stretch the result using the Levels tool. *Right:* Applying the radial-blurred subtraction map to the cropped Moon image with the same settings used for the full eclipse stack results in an image showing coronal detail right to the limb of the Moon.

If I have only one set of bracketed exposures, the only things left to do are to adjust the colour balance and fix the Moon as well as the over exposed ring around its limb, which is an artifact of this extreme sharpening method. I find that stacking several sets of bracketed exposures reveals crisper details in the corona without needing to employ aggressive noise-reduction methods on the final result. The results of stacking multiple bracketed sets are superior, though the Moon becomes slightly smeared as it moves across the solar disk on each progressive set of images.

Combining several stacked and aligned sets of processed exposures is done the same way as stacking the initial sub-exposures using File > Scripts > Load Files into Stack. As before, change the opacity of each layer so that together they progressively contribute to the final view. When you're pleased with the result, flatten the layers by selecting the dropdown menu item Layer > Flatten Image.

The last step is to layer the Moon back in and address the bright artifact around its edge. I find this requires two versions of the same image processed slightly differently. First, open your stacked but unprocessed image and crop it as a square around the Moon. Be sure to leave about 50 pixels or more beyond the lunar limb, and save the result at 'moon.tif'.

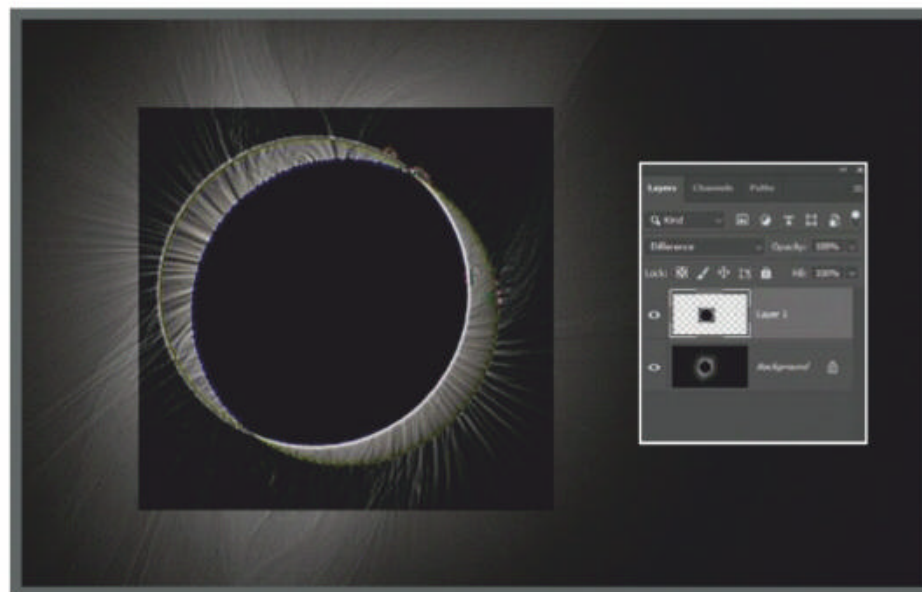
Let's blur this image but in a slightly different way using Filter > Blur > Radial Blur. In this new window, select Spin as the Blur Method, Quality Best, and change the Amount to 3 and click OK. Save this as a new file titled 'moon blur.tif'.

At this point, you process the Moon image just as you did the full stacked eclipse image by first applying the radial-blurred image to create the subtracted difference map. Then compress the levels, save the result, and apply it to the Moon picture again using the Overlay blending mode (and reduce this to 75% opacity). The resulting Moon image will have the coronal details visible almost to its limb, but the Moon itself will appear odd due to the radial blurring.

Now copy this sharpened lunar image (Select > All, Edit > Copy), open up your single stacked and processed eclipse image, and paste this new processed Moon image as a new layer. To align it to the base image, change the layer Blending Mode in the Layers window from Normal to Difference. Using the Move tool, move the top layer until the majority of the two images cancel each other out and turn black, except for the ring around the limb of the Moon. When you're satisfied, make a circular selection with the Elliptical Marquee tool that includes the Moon and the ring artifact. When you've circled it all, choose Select > Inverse from the dropdown menu and hit the backspace key on your keyboard. When you change the layer blending mode back to Normal, the bright ring should be reduced to a thin line.

At this point, I open the stack I saved that was processed using the Camera Raw filter (group 1ACR.tif), select the

► Select the Moon from the Camera Raw-filtered image and paste it onto the final stack. Once aligned, flatten the layers and perform any final colour correction or noise reduction.



▲ After pasting the processed Moon limb image into the full eclipse picture, change the layer blending mode to Difference and nudge the layer into place. When aligned, the majority of the Moon layer will become black, with only the ring artifact and some coronal details being visible.

Moon, and then paste this into the stack. After aligning the final Moon layer, flatten the image and perform any final adjustments such as noise reduction and colour balance.

The end product is an image showing the entire range of brightness and detail captured in your images. If you're planning on imaging an upcoming eclipse, it wouldn't take much to add bracketing into your routine. Images like these allow us to see extremely small tonal variations, as well as stars much fainter than were noted during the event. Good luck!

■ **SEAN WALKER** processed photographs from solar eclipses for decades before witnessing one in person.





Sky-Watcher's Esprit 150mm APO refractor

Here's a large apochromat that produces a big bang for your buck.

Sky-Watcher Esprit 150-mm ED triplet refractor

US price: \$6,399 (includes case, rings, dovetail bars, 2-inch dielectric star diagonal, finderscope, and 2-inch field flattener)
skywatcheraustralia.com.au

What we like

Imaging performance with included field flattener
Excellent optics

What we don't like

Mounting plate (dovetail bar)
Finder mount

WHEN I WAS MUCH YOUNGER than I'd care to relate, I spent lots of time eyeing ads for 15-cm Unitron refractors. Surely, I thought, that large (and long) refractor would be the perfect telescope. And on a cloudy night I could kick back and just gaze at the scope itself. While I've had glimpses through large APO refractors at star parties, the lure of these classical instruments always was just beyond my grasp. When I was presented the opportunity to review the Sky-Watcher Esprit 150mm ED triplet refractor, I finally had the chance to realise my expectations.

▲ The Sky-Watcher Esprit 150-mm ED Triplet Refractor is the largest aperture offered in the company's Esprit line of premium apochromatic telescopes. This hefty piece of glass will require a solid, medium-to-heavy-duty mount to fully realise its imaging potential.

The Esprit 150ED on loan from Sky-Watcher USA arrived in a single, large box, and when removed from its rugged, fitted carrying case the scope is compelling just to look at. Though 2 mm shy of a 15-cm aperture, its smooth, glossy white finish and massive 3.4-inch focuser immediately convey that this is a quality instrument.

Fit and finish

The Esprit 150ED comes with a top-notch carrying case, although 'footlocker' might be a better description. The hinged 104 × 42 × 33-cm case is covered in plastic laminate with metal-reinforced edges and corners. One end has two permanently mounted 75-mm-diameter hard rubber wheels, while the opposite end includes sturdy handles enabling a single person to roll the case across smooth surfaces. Inside is custom-fitted, high-density foam to accommodate the Esprit 150ED tube with its mounting rings and dovetail bar attached. A row of seven additional cutouts provide storage for the finderscope, field flattener, and other accessories. The case alone weighs 16.8 kg. With the scope and accessories within, it tips the scales at more than 32 kg, so those wheels are certainly useful.

Since the Esprit 150ED with its supplied 2-inch diagonal, finderscope, and a 2-inch 28-mm eyepiece weighs 14.5 kg, it is a hefty load that may tax some medium-duty mounts. The tube assembly is rather front-heavy even with its massive 3.4-inch focuser. The three-element objective has two lenses made of BK7 glass and one of extra-low dispersion (ED) glass to eliminate colour fringing. A metal lens cap slips onto the objective cell to protect the lens when not in use.

The scope includes a pair of heavy, cast-aluminium mounting rings, each with four ¼×20 threaded holes on their top side. The rings are spaced 30 cm apart when attached to the supplied dovetail bar. These threaded holes allow for mounting additional accessories such as a guidescope or even a small computer.

I was looking forward to using the

scope with my 25-year-old Losmandy G-11 German equatorial mount but encountered a problem. The Esprit 150ED's Losmandy-style D-rail dovetail bar was too narrow for my G11's saddle. Tightening the clamps all the way down still allowed the dovetail bar to slide freely in the saddle. The D-rail was almost a millimetre narrower than the Losmandy mounting bars I had on hand. I switched the Esprit 150ED's tube rings to one of my Losmandy plates and was back in business. Note that users with Sky-Watcher and other mounts with the Losmandy D-system may not experience this issue.

The large focuser is rotatable by loosening a large metallic 'captain's wheel' collar with four 19-mm machined pegs spaced 90° apart to help your grip. A mounting shoe for the supplied 8×50 right-angle finder attaches to the left side of the focuser.

The Esprit's dual-speed, rack-and-pinion focuser has very smooth motion with almost no backlash. A 2-inch compression-ring accessory adapter threads onto the end of the drawtube. Locking the focus position is done by pulling out a small lever located on the front of the focuser's gearbox, which was a little awkward in practice.

The supplied 2-inch dielectric mirror

star-diagonal, as well as the 2-to-1¼-inch adapter, also incorporate non-marring compression rings secured with a thumbscrew.

One nice feature of the Esprit 150ED package is that the purchase price includes a zero-power, two-element field flattener to correct for field curvature when imaging with large-sensor cameras. It attaches to the scope in place of the 3.4-to-2-inch adapter on the focuser drawtube. A camera connects to the flattener using M48 threads.

This rigid, threaded connection between the focuser, flattener, and camera virtually eliminates potential weak points that can tip the camera and distort stars across the imaging plane. However, orientating the camera around the optical axis isn't as convenient as it would be with thumbscrews and a compression-ring-secured coupling. The desired camera orientation can be achieved by rotating the focuser or the telescope within its mounting rings, but doing either rotates the finder position. In some positions the finderscope's view was blocked by the guidescope I had mounted on the tube rings. Several times when imaging with the Esprit 150ED I wished that the finder wasn't mounted directly to the focuser, or the bracket could at least be



▲ The telescope's 150-mm f/7 (1,050-mm focal length) air-spaced, three-element objective incorporates one element made with FPL-53 extra-low-dispersion glass and two BK7 elements. Its retractable dewshield is secured with two thumbscrews.

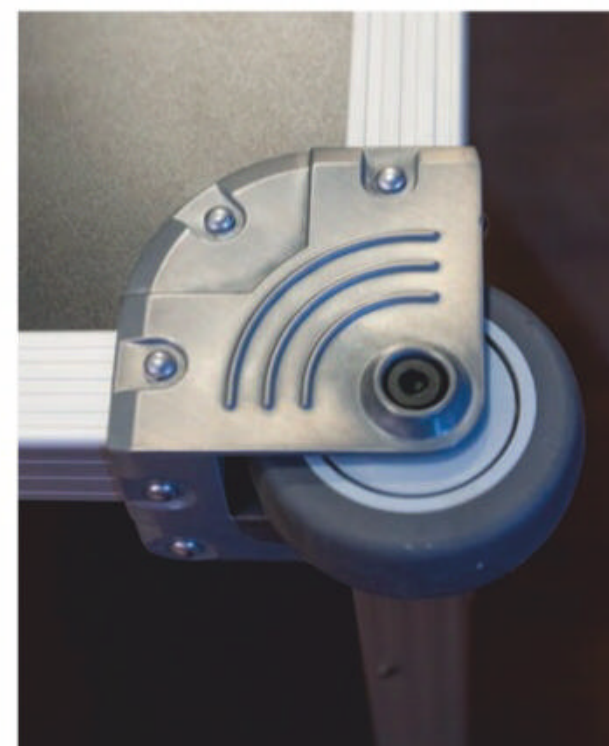
moved to the other side of the focuser.

While the scope's US\$6,399 price tag is very attractive for such a large triplet apochromatic refractor, the finderscope fell a little short of my expectations. It's an inexpensive 8×50 right-angle finder with a solid mounting bracket, but it has a narrow field of view and lacks any provision for illuminating its crosshairs.

Visual impressions

The Esprit 150ED is an outstanding visual performer on a variety of objects. Star images were tiny and sharp to

▼ *Left:* A heavy-duty case included with the scope uses high-density foam with several recessed holes containing blue rubber balls. These nestle the telescope tube on all sides and allow room to reach around the scope to lift it from the case. *Right:* Weighing in at about 32 kg with scope and accessories in tow, the case's hard rubber wheels enable one person to transport the scope over most surfaces.





▲ *Left:* The telescope's solid 3.4-inch rack-and-pinion focuser and mounted 8×50 right-angle finderscope are rotatable by loosening the large metallic 'captain's wheel' ring with machined spokes. *Right:* A millimetre scale to aid in repeating focus positions is printed on the focuser drawtube. Also visible is the 10:1 fine-focus knob.

the edges of the field using a variety of eyepieces. There were no bluish or violet halos around bright stars, and the sky background was very dark, producing high-contrast views on deep sky objects and double stars. Stellar Airy disks were clearly surrounded by an unbroken first diffraction ring and stood out vividly during periods of good seeing. With a Barlow to increase the scope's effective focal length, both Jupiter and Saturn revealed lots of fine detail and no distracting false colour. Even pushing the magnification above 20× per cm of aperture with short-focal-length

Tele Vue Nagler and Delos eyepieces, planetary views were still sharp and contrasty. Views of both planets were consistently better than those I saw through my 11- and 14-inch Schmidt-Cassegrain telescopes.

Lunar views were equally impressive. The scope was free of any troublesome off-axis scattering or reflections no matter if the Moon was placed in the centre of the field or near the edge. The Esprit 150ED's tube uses six internal baffles, which no doubt contributed to the lack of contrast-robbing scattered light.

White-light views of the Sun with a Baader Astro-Solar Safety Film filter gave great views of the photosphere's surface granulation that easily snapped into sharp focus, though no sunspots were visible during my testing period.

With all my visual tests, the focuser's movement was smooth and positive. All eyepieces I used during my tests reached focus with the included dielectric mirror star diagonal without the need for any extension tubes.

Imaging performance

Many purchasers will see the Esprit 150ED as an imaging scope with included field flattener and relatively fast f/7 focal ratio.

Sky-Watcher included a T-ring adapter with M48mm threads for me to use with my Nikon D750 camera, and I was really looking forward to how the combination performed. The scope is advertised as having a corrected image circle 43-mm across, and my Nikon D750 full frame DSLR camera body with its 24 × 36-mm sensor has a diagonal measurement slightly greater than 43 mm. Even so, star images in the extreme corners were still tiny and round. There was some vignetting in the very corners and also a narrow strip of mirror-box vignetting along the bottom edge of the D750 frame, though flat-field calibration easily corrected these minor issues. Users with smaller detectors shouldn't

▼ A 2-inch dielectric mirror star-diagonal with non-marring compression rings is included with the scope, as is a 1¼-inch adapter (not shown).





▲ With the included field flattener, stars appeared about as round and sharp in the corners of the author's Nikon D750 DSLR frame as they were in the centre of the field, as revealed by this image of the Lagoon Nebula with enlargements of the extreme corners.

► The Esprit 150ED includes a dedicated field flattener to improve star images near the edges of the field of view on full-frame cameras. The flattener replaces the focuser's 2-inch accessory adapter, screwing onto the exposed threads.



experience vignetting at all.

To see how flat the field is, I focused a star near the centre of my camera's field by evaluating the star's full width at half maximum (FWHM) diameter using *Backyard Nikon* software.

Moving the star from the centre of the frame to near the edge produced very little difference in the FWHM value, attesting to the Esprit 150ED's well-corrected field.

No focus change due to temperature variations was evident during my imaging tests. The 3.4-inch focuser had no problem keeping my camera aligned to the imaging plane no matter where in the sky the scope was pointed, and the focuser's locking mechanism, though a little awkward to access, held focus throughout every exposure.

In conclusion

It's hard to imagine a purchaser being disappointed with any performance aspect of the Sky-Watcher Esprit 150ED. Visual observers will enjoy textbook star images across a wide field, and imagers will delight in its tight corner-to-corner star images across large imaging chips.

The weight and length of the scope will be an important consideration for mounting. The scope worked well with my Losmandy G11, but one should probably consider this the minimum in mounting options for the heavy Esprit 150ED, especially if one adds on a large camera, filter wheel, and guidescope.

The scope gave me many memorable views of deep sky objects, the Moon, and planets. Hooking a camera to the scope with the included field flattener resulted in exciting images of deep-sky objects with textbook star images across the entire field.

■ Contributing Editor **JOHNNY HORNE** still fantasises about owning a large apochromatic refractor.

► The Esprit 150ED excels at imaging nebulous deep sky objects and handles bright stars well. This shot of the Pleiades (M45) is a stack of thirty 5-minute exposures with a Nikon D750 DSLR camera showing bright stars free of reflections or large, distracting halos.



◀ Views of the Moon with the Esprit 150ED are sharp, with neither a hint of colour fringing visible on the lunar limb, nor any scattered reflections even when placing the Moon outside of the field of view. This image centred on Sinus Iridium was recorded with a ZWO ASI290 high-speed video camera at the telescope's native f/7 focal ratio.

▼ This uncalibrated image of M31 — taken with a full-frame Nikon D750 and a 48-mm T-adapter — displays minor vignetting in the extreme corners of the field. Flat-field calibration reduces this to imperceptible levels.





Image courtesy Dr. John Carver (50 megapixel MicroLine ML50100 camera)

Kepler CMOS: Paradigm Shift

It is no surprise that the CCD's best performance is with a single long exposure. What may be surprising is the Kepler KL4040 CMOS camera has a better signal-to-noise ratio than the PL16803 even with a single long exposure. The signal-to-noise ratio of the KL4040 is better than the PL16803 even when using short exposures that are stacked!

The benefit of taking multiple short exposures is the option to discard a bad exposure ruined by satellite trails, tracking errors, or bad seeing (etc.). Incredible low-noise images are now possible with a single long exposure or many stacked short exposures. The KL4040's superior performance allows it to be used for a wide range of applications and requirements.

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Art Gamble's 'final' masterpiece

A veteran telescope builder achieves his own personal Nirvana.

WHEN ART GAMBLE sent me a photo of his latest telescope, he wrote, "Please, please, know that I am not campaigning to have more of my gear featured in AS&T. I feel pretty sure that your readers have seen more than enough of my low-tech, funny-looking telescopes." I wasn't even tempted to obey his wishes. This telescope was simply too amazing not to write about it.

First off, that beautiful wood-grain-looking tube and pier isn't wood at all. It's fibreglass. In fact, it was a reject from a local manufacturer, probably because of the very colour and texture that makes it so beautiful. And it's a perfect fit for the 1985-vintage Jaegers 15-cm f/5 achromat objective lens. Art chose not to paint it for two reasons: "First, it's so durable I don't have to worry about damaging a paint job every time I carry it in and out of the house. Second, I like the look of the fiberglass. So I sanded it smooth and left it like that."

The tube is not the only thing here that's interesting. Take the diagonal and focuser, for instance. Most refractor builders put the focuser in front of the diagonal, but Art thinks outside the box, and inside the tube. Since there's no worry about image obstruction with a refractor, he simply put a 75-mm diagonal partway down the tube and stuck his focuser on the side. The result: a dramatically shorter telescope than if he'd done it the traditional way.

Then there's the altitude and azimuth bearings. One of the

common problems with homemade mounts is that the mating surfaces are often so small that any play translates into unacceptable vibration at the eyepiece. Not a problem with 30-cm lazy Susan bearings! Many ATMs use them for azimuth bearings on Dobsonian scopes; Art reasoned that they would work just as well for altitude bearings, and they do. Except for one problem: Lazy Susan bearings are too smooth to allow for eyepiece changes. So he installed a bolt and a wingnut in the centre of the altitude bearing to let him adjust the tension.

You'd expect the scope to be a bit side-heavy with the tube offset like that and no counterweight, but Art solved that problem with simple over-engineering: long, beefy legs made of 5 × 15-cm pine.

While you're admiring this scope's legs, take a moment to admire the tracking mechanism. Yes, that's a strap hinge and a screw with a long, flexible shaft that lets you turn the screw while you observe. Art calls it his 'G-Tracker'.

Lastly, check out the finder. That's a standard Telrad, but with an Art Gamble twist: a bicycle rearview mirror suspended at a 45° angle in back of the glass window lets him look through the Telrad without bending down. Given how my back aches after a long night



Art Gamble's latest telescope uses a fibreglass tube and lazy Susan bearings to achieve a masterpiece of form and function.

of leaning sideways to look through a finder, I think this may be the biggest stroke of genius on this whole project.

Overall, Art is very happy with this scope. In fact, he says, "I started grinding mirrors and building telescopes in the mid-'80s. This is mount number eleven. I feel sure this will be the last. Out of all the telescope mounts I've built, this is the only one that has truly exceeded my expectations. It's heavier and bulkier than I had planned, but it is silky smooth and rock solid. It's a joy to use. There is always compromise; I'm never 100% satisfied with my telescope optics or mounts, but I think I am as close as I'll ever get with this one. I'm stopping here."

For more information, contact Art at artgam1946@gmail.com.

JERRY OLTION has built a couple of fibreglass scopes, too, but none as beautiful as this.

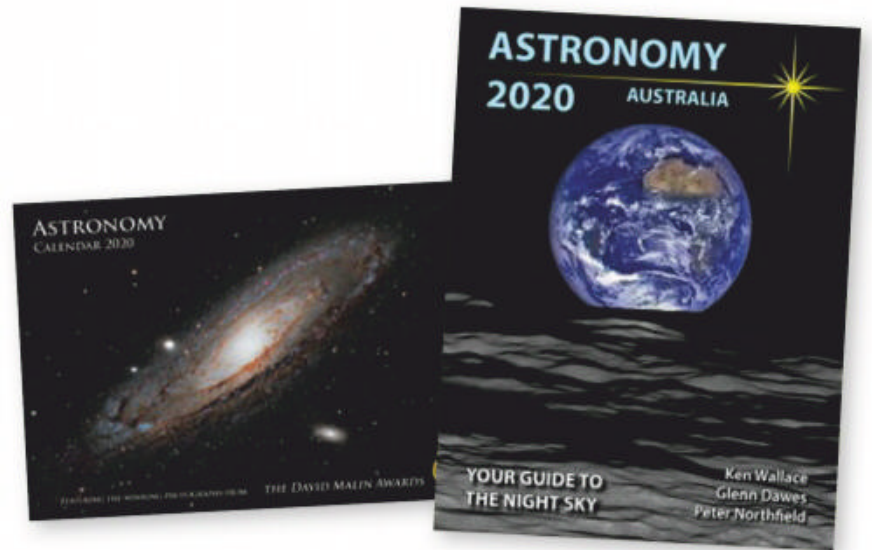
► Two 30-cm lazy Susan bearings provide smooth, rock-steady altitude and azimuth motions. Note also the mirror behind the Telrad.



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Amateur and pro astro activities

The nights are becoming longer, so it must be star party season.

Our region's two major amateur astronomy conferences are only one and two months away, respectively, being the National Australian Convention of Amateur Astronomers (nacaa.org.au) – to be held in Parkes, NSW, on April 10–13 – and the Royal Astronomical Society of New Zealand's annual conference (rasnz.org.nz), to be held in Wellington on May 8–10. Both events will see many experienced (and novice) amateurs gather to share their knowledge and experience through presentations and workshops, and meet up with friends old and new. If you've not been to either event and you have the opportunity to go, you won't be disappointed if you turn up and take part.

Those two events will be backed up over the following months by several astrofests and star parties: the Astronomical Society of NSW's annual South Pacific Star Party (May 21–24, asnswnz.com/spsp) at the Society's dark sky rural site; the Central West Astro Fest (July 18–19, cwas.org.au) at Parkes, NSW, along with the David Malin Awards for astrophotography

(this year's theme is smartphone imaging); and the Queensland Astrofest at Camp Duckadang (August 14–23, qldastrofest.org.au). All three events are great occasions to meet other amateurs, check out the latest telescope gear (both commercial and homemade) and do some serious observing.

Star Stuff (starstuff.com.au) returns to Byron Bay, NSW, in July following a year's sabbatical in 2019. Now a one-day event, it will be a celebration of all things astronomical with a stellar line-up of guest speakers.

Rounding out July will be two major professional events happening in Perth from the 6th to the 10th. There will be the annual meeting of the Astronomical Society of Australia (asa.astronomy.org.au) – the nation's body of professional astronomers – and, running concurrently, the Asia-Pacific Regional IAU Meeting (aprim2020.org). The IAU is the International Astronomical Union, the world's primary society of professional astronomers. Both events will be hosted by the International Centre for Radio Astronomy Research.

2020 CALENDAR

NACAA XXIX

April 10–13, 2020

Australia's major biennial amateur astronomy convention.

nacaa.org.au

Yuri's Night

April 12, 2020

Worldwide celebration remembering Yuri Gagarin's spaceflight.

yurisnight.net

RASNZ Conference

May 8–10, 2020

New Zealand's national amateur astronomy conference.

rasnz.org.nz

South Pacific Star Party

May 21–24, 2020

Annual star party of the Astronomical Society of NSW, at a dark sky site.

asnswnz.com/spsp

Asteroid Day

June 30

A global day of education to help protect Earth from asteroid impacts.

asteroidday.org

CWAS AstroFest 2020

July (date TBA)

Annual gathering at Parkes, NSW, and venue for the David Malin Awards.

cwas.org.au

Star Stuff III

July 18

Festival of astronomy in Byron Bay, NSW.

starstuff.com.au

Queensland Astrofest

August 14–23, 2020

Held since 1993, the dark skies of Camp Duckadang, Linville, attract lots of amateur astronomers.

qldastrofest.org.au

International Observe the Moon Night

September 26

Annual event to encourage observation and understanding of our Moon.

moon.nasa.gov/observe-the-moon/annualevent/overview/

WHAT'S UP?

Do you have an event or activity coming up? Email us at editor@skyandtelescope.com.au



Stephen Russell with his homebuilt 33-cm Dobsonian.

from these days: a 72-mm refractor, a C5, C6, 20-cm Schmidt-Newtonian and a 25-cm carbon truss Newtonian. Not counting solar eclipses, I haven't set up a telescope to do any observing for some time. What I like to observe are asteroidal occultations, and I'm hoping to get into photometry in the future.

What has been your favourite stargazing moment?

Any cloud-free solar eclipse! There have been lots of other special moments. Two that come to mind are watching the impact sites caused by Shoemaker-Levy 9 appear around the edge of Jupiter in 1994. That same year I was in the Andes in northern Chile, on the southern limit of the solar eclipse, and watched the shadow cone approach over the coastal cloud from the north-west. It was so fast!

What has been your proudest moment in astronomy?

Winning a special mention in the inaugural David Malin Awards for an image of the 2002 eclipse in South Australia. I marvel at the quality of the latest Award images. Amazing.

What's on your astronomy 'to do' list?

I plan to build an observatory in my backyard to house the Newtonian. So far, no progress on that project. What's been keeping me busy is working on the program for the 2020 NACAA. I've been involved with NACAA forever, and helped set up the 'new' NACAA in time for the 2008 event in Penrith. It's been hard work at times, but I think 2020 will be one of our best.

As for stargazing, I'm looking forward to upcoming solar eclipses such as the one in Chile later this year. We are lucky that there will be five eclipses in Australia starting from 2023; I'll be able to do 2028 from my backyard. And one day I might restart the 45-cm telescope project, but with a completely new design. I just have to find the time!

Stephen Russell

Stephen Russell has been engaged in Australia's amateur astronomy scene seemingly forever. An avid eclipse chaser, he's also been heavily involved in organising the biennial NACAA conferences and is chair of the next one, to be held in Parkes in April this year.

What got you into astronomy?

I was a kid during the Apollo lunar missions, and because of them became very excited by space exploration. At the age of 10, my neighbour took me along to the local astronomy club (the Illawarra Astronomical Society, IAS), in which I became actively involved for many years, even after I moved to Sydney. The IAS hosted the 1970 National Australian Convention of Amateur Astronomers (NACAA), which started another long story for me. I've been to all but two of the events since then — 50 years!

What was your first telescope set-up?

It took me a long time to get my first telescope. In the early 1990s, I built a portable 33-cm Dobsonian,

which got a lot of use at star parties and monthly club viewing nights. It even won an award at a Queensland Astrofest. I then started work on a 45-cm motorised scope, but that project stalled several years ago. Work and travel keep getting in the way.

What sort of gear do you use now?

I have a bunch of telescopes to choose



One of Stephen's eclipse images was singled out for a special mention in the inaugural David Malin Awards.

Astrophotos from our readers

ORION'S GLORY Benjamin Marks

The Great Nebula in Orion, seen through smoky skies in Brisbane in mid-December. Ben used a Sky-Watcher Black Diamond ED80 scope, ZWO ASI1600MM Pro camera and LRGB filters.



HORSEHEAD #1 Brian Sengstock

Brian made this shot of the Horsehead Nebula with multiple exposures over four nights in November and December 2019 using a Sky-Watcher Esprit 120 scope, an Atik One 6.0 camera and Ha filter. Total time was 18 hours.



◀ RING OF FIRE Chee Guan Chan

Last December's annular solar eclipse was seen throughout Asia. Chee Guan Chan captured this shot amongst Singapore's skyscrapers using a Sony A7 camera and Sony FE 16-35 mm f/4 lens.

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GALLERY

CROWN JEWELS Fernando Menezes

The Corona Australis Molecular Cloud is a complex region encompassing bright reflection nebulae and star clusters. Just across the border in Sagittarius is the globular cluster NGC 6723 (right), but it's not part of the Cloud — it's about 30,000 light-years further away. Fernando used a 80-mm refractor and ZWO ASI1600MM camera.



◀ COSMIC SCULPTURE

Stamatios Tsigos
The Sculptor Galaxy (NGC 253), also known as the Silver Coin or Silver Dollar galaxy, is a barred-spiral more than 11 million light-years from Earth. Stamatios used a Sky-Watcher 80ED scope, ZWO ASI1600MM camera and LRGB filters. Approximately 4 hours total exposure time.



HORSEHEAD #2 Petar Milevski

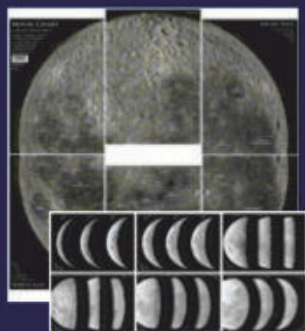
Another shot of the Horsehead, this time in colour. Petar used a Takahashi FC-100DF scope and QHY163 one-shot colour camera.

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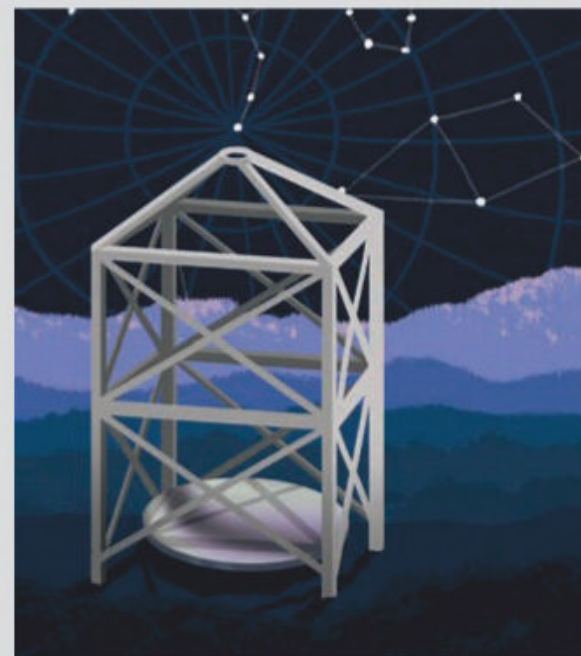


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Liquid telescopes

Forget lenses and silvering — scientists are turning to spinning mirrors made of mercury to study the universe.

Seeing a black hole's jet

Join the author on his quest to observe the jet in the giant galaxy, Messier 87, using scopes of up to 2 metres aperture.



The classic Dobsonian

A long-neglected relic of the 1970s finally sees the light, complete with psychedelic colour scheme.

Test report

We check out Canon's EOS R mirrorless cameras, including the new 'Ra' model made for astrophotography.

Plane amazing

*Chances were slim that day in a nearby park,
but the wish of two young observers came true.*



MY CITY HAS A SECLUDED park that attracts many visitors to admire its colourful flowers and to picnic on its well-tended lawns. It's also a magnet for artists and photographers.

Sometimes, mainly when sunspots are present, I'll set up my 75-mm refractor in the middle of the park and invite passersby to safely view the white screen on which the telescope projects an image of the Sun — the ultimate nourisher of all those gorgeous flowers.

I bought the 75-mm in 1978 for nighttime observing. When it arrived with a bracket and screen accessory for solar projection, I felt I'd been conned into paying for something I'd never use. In 1981 I purchased a Meade 20-cm Schmidt-Cassegrain for nighttime use and, later, a Tuthill Solar Skreen filter for observing the Sun. My 75-mm went into a cupboard.

Eventually I began specialising in public viewing, and it slowly dawned on me that for solar observing by groups, especially in school venues, projection with the 75-mm would be a far superior way of sharing views of the Sun than having everyone peering individually through an eyepiece. So, using red stick-on letters along its tube, I

christened my 75-mm the Sunscope and have now used it dozens of times for solar observing, including for sunspots, partial eclipses and two transits of Venus.

One Sunday afternoon in the park, two boys came over to my scope. Probably brothers, they looked to be about eight and ten years old. As they gazed at the Sun's round image on the screen, across it glided the silhouette of a high-flying bird. The sight excited them considerably, whereupon I said, "Sometimes an aeroplane flies in front of the Sun". Instantly, they decided to stay put until they saw an airplane fly across our star. I warned them that the chance of its happening was very slim, but they were determined.

Maybe 30 minutes had passed when one of the boys pointed skyward and shouted, "There's an aeroplane!" It was there alright, the tiniest speck just above the distant treeline. I once again warned of the improbability of its passing in front of the Sun and then joined them in watchful waiting. Gradually, the plane grew closer and larger and at least seemed to be coming in our general direction.

A few moments later I realised, if

▲ Capturing an aircraft crossing the face of the Sun, such as occurred on this occasion on April 13, 2016, is a true treat — especially when unplanned.

nothing else, this was going to be a close call! I instructed the boys, "Don't take your eyes off the screen. I'll watch the aeroplane." Seconds later the nearly unimaginable happened: A giant airliner shot across the Sun's projected image, leaving in its wake a silhouetted trail of dark, writhing engine exhaust.

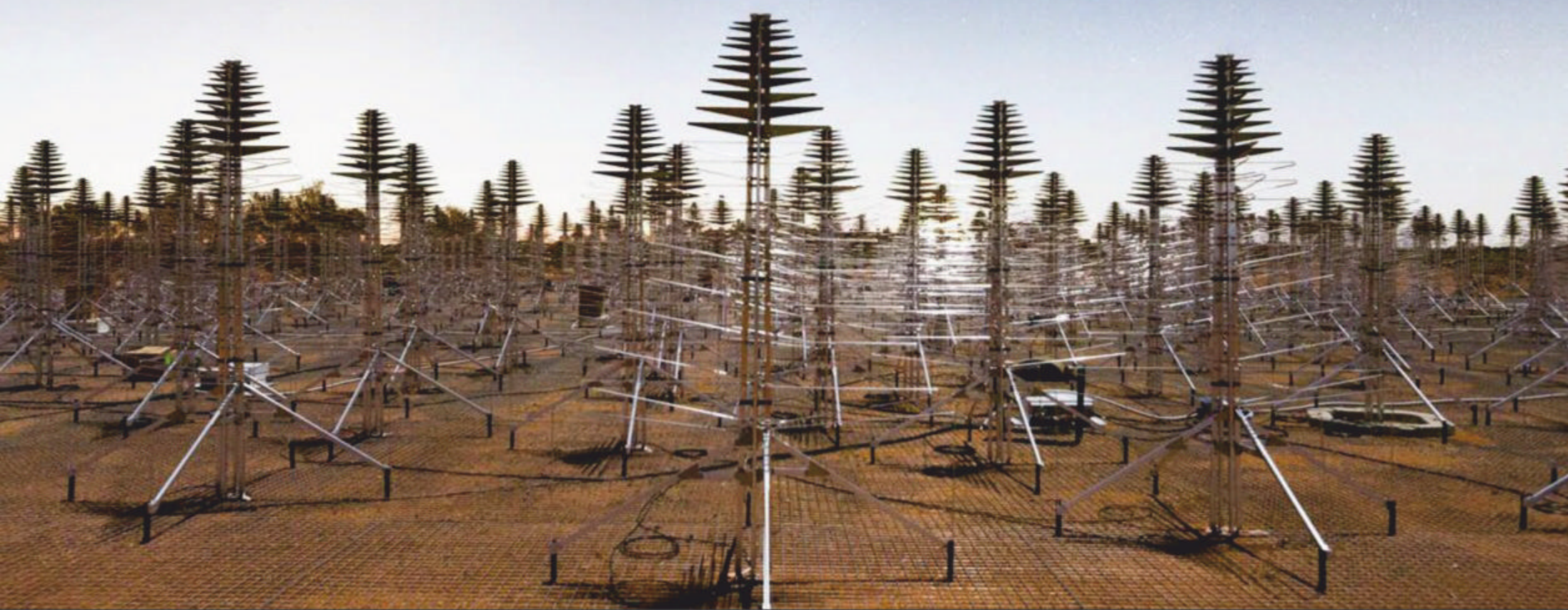
The brothers never looked back. They darted off to tell their parents of the incredible sight they'd just witnessed. I last glimpsed them standing beside two adults, excitedly gesturing in my direction.

While it's been at least five years since the incident, I'm sure the brothers haven't forgotten their elation at seeing an airplane fly over the Sun — I certainly haven't. Indeed, I've had the pleasure of retelling the story when I'm out with my sunscope and, as sometimes happens, a pedestrian is surprised by seeing a bird, plane or even a child's escaped balloon pass across the Sun's image on my screen.

■ **HERMAN HEYN** recently retired from street-corner astronomy after 31 years.

Join us in Perth for the Asia-Pacific Regional IAU Meeting

Image by Michael Goh / www.astrophotobear.com



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