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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MARCH 2025

Comet Tsuchinshan-ATLAS Shines

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THE ESSENTIAL GUIDE TO ASTRONOMY


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Comet C/2023 A3 over Osoyoos, Canada, on October 13, 2024
PHOTO: DEBRA CERAVOLO

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Continuing the Journey

TO SAY THAT I'M HUMBLED by my appointment as editor in chief of this magazine would be an understatement of several orders of magnitude. I'm fully aware that I'm standing on the shoulders of giants — not only my forerunners in this role but also all the people who have made *S&T* what it is.

My predecessor, Peter Tyson, penned a gracious editorial in the February issue introducing me to you, our dear readers. I've been at *Sky & Telescope* for more than seven years now, in the capacity of observing editor (the first issue I worked on was December 2017). If you read Peter's editorial, you'll know that I transitioned to the wonderful world of astronomy magazines from that of scientific research. I've learned *a lot* in the time I've been here, and I feel truly privileged that I had the opportunity to embark on a new career.

At *S&T*, I've witnessed from a front-row seat the diligence, accuracy, and passion with which my colleagues approach their work every day. They've been so patient and supportive as I learned to navigate the ins-and-outs of the editorial business. I'm still learning from them and drawing inspiration from them every day. (And they're still ever-patient.) Their encouragement throughout this hiring and promotion process has meant the world to me: One could not ask for better cheerleaders.

Of course, what with me sliding into the editor in chief's role, my former position is now vacant. As of the time of this writing, we're advertising for an associate editor to join our team in lovely Cambridge, Massachusetts. We'll hopefully have good news to share with you all early next year.

In the midst of all this, we all — amateurs and professionals alike — continue doing astronomy, fueled by our passion for the subject. If it weren't for that passion, some of us may have abandoned the adventure years ago. But it is precisely that passion that drives us all here at *Sky & Telescope*, under the aegis of the American Astronomical Society, to do the very best we can to bring you top-notch content. We'll continue to cover all aspects of the science and hobby of astronomy — whether it be in the form of observing and equipment guides, historical tales, or cutting-edge stories from the world of astronomical research. And we'll keep bringing you these stories both in the magazine and on our website, all deftly designed and illustrated by our talented art and digital team.

I promise you that I will endeavor to continue the legacy that sparked into existence in 1941. I know that with the team spirit that infuses everyone at *Sky & Telescope*, we can shepherd that legacy into the future. I'm looking forward to this journey — I hope you'll come with us.

Diana

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Tour the Sky

Thank you so much for all the information you provide to help us enjoy the night sky. A special thanks to the October episode of Kelly Beatty's *Sky Tour* astronomy podcast (**https://is.gd/SKYpodcast**), which outlined how we could locate Comet Tsuchinshan-ATLAS (C/2023 A3). We were able to see the comet both with the telescope and our naked eyes. It was a very exciting evening. Without the specifics that Kelly Beatty provided, I'm not sure we would have found it.

Mike Bliziotes and Iris Walling
Lake Oswego, Oregon

Comet Tsuchinshan-ATLAS cuts across the sky above Great Sand Dunes National Park on October 12th.

PATRICK MYERS/ NPS

Seeing Red

As a non-astronomer but curious lover of astronomy, I would like to thank Monica Young for the beautiful article "What Is Redshift" (*S&T:* Oct. 2024, p. 76). It was concise, easy to read, and wonderfully explained.

However, her statement that "galaxies aren't flying through space — it's the space between us and them that's expanding" is quite difficult to understand. Could she clarify this statement?

Einar A. Berger
São Leopoldo County, Brazil

Monica Young replies: *These concepts are not intuitive and can be quite difficult to wrap one's head around. The typical analogy given for the expansion of space is a rising loaf of raisin bread. The raisins are the galaxies, and the dough is the space between them. As the loaf rises, the raisins appear to move away from one another. However, the raisins themselves are not moving through the dough — it's the dough between them that's expanding.*

I was puzzled while reading the redshift explanation in the October issue. Young says "But really, redshift is a measure of velocity. Yes, velocity . . ."

If I'm applying the redshift equation correctly, a redshift of 1 is reached at 60% of the speed of light.

At much higher velocities, an increase of 1 mph would also add 1 to the redshift. And even closer to the speed of light, an additional inch-per-hour would add 1 to the redshift as well, and so on.

Redshift must vary with velocity, but not directly. Help readers like me understand how and why the redshift varies as it does.

Richard High
Via email

Monica Young replies: *When you measure the redshift of a relatively nearby object, you measure that object's physical velocity through space. One example of this given in the October Beginner's Space column is the motion of binary stars in mutual orbit. Assuming their orbit isn't exactly in the plane of the sky, then one star will be physically moving in Earth's direction by some amount as the other moves away, and we can measure that motion by the redshift in the stars' spectral lines.*

However, when it comes to cosmological redshift, you're no longer measuring the object's motion away from you in terms of its velocity through space. Instead, you're measuring the velocity an object appears to be moving away from us due to the expansion of space itself. That relationship is linear for relatively nearby galaxies (as shown for redshift-lookback time on page 76 of the October issue). However, it quickly becomes nonlinear at greater distances because the universe hasn't expanded at a constant rate over its history.

While I don't have a redshift-velocity graph handy for you, I think you might find this Physics Stack Exchange forum interesting: **https://is.gd/redshift_velocity**.

Defending Home Base

Emily Lakdawalla's "Asteroid Impact: The Aftermath" (*S&T*: Oct. 2024, p. 14) is both thrilling and informative. However, there is mention of one matter in passing, which has been the fly in the ointment of many an otherwise excellent account of planetary defense. "At 160 m, the moon Dimorphos was . . . large enough to represent the class of asteroid that poses the greatest impact risk, because astronomers predict that almost half of the objects in this size range remain undiscovered."

The quoted statement implies that an object that could only wreak regional damage presents a greater risk than an object the size of the one that wiped out most life on Earth 66 million years ago. Why? Because we have already discovered most of the latter and know that none of them is on a trajectory to do so in the next century.

But this perspective overlooks the fact that risk is not just the probability of a single event — it is the multiple of probability and potential damage. The DART mission was a triumphant proof-of-concept for planetary defense. But the only way to reduce the risk of a catastrophic impact is to prepare in advance for the worst-case scenario, even though it might never happen. Currently we do not have such a policy. Therefore, I submit, we humans are creating a greater risk than any unknown impactor is, since we are fully capable of rendering a large object harmless with the proper infrastructure and yet are ignoring the need to develop a plan to do so.

Joel Marks
Milford, Connecticut

To Each Their Own Color

Mathew Wedel's "Star Crossed" (*S&T:* Oct. 2024, p. 43) is a great binocular highlight. I have trouble discerning the color of TX Piscium in my 7×50 binoculars, but it's a well-balanced challenge. To my eyes, it's a very reddened orange at 51× in my 12.5-inch scope. The chart scale used by the article was perfect.

Thank you, *Sky & Telescope*, for your continued good work with this, the most helpful Comet Tsuchinshan-Atlas article, and your many observing and photographic articles.

Ted Harp
Tuttle, Oklahoma

Mathew Wedel replies: *Thank you for the kind words! I find the colors of stars are more intense in smaller instruments. In a 12-inch Dobsonian even the carbon stars are brightened up to maybe orange at best.*

But then I'm always amazed at how color perception of stars varies among observers — another prod, if any were needed, for everyone to get out and see these things for themselves.

Reaching for the Stars

Corey Burrell is a star! It's wonderful that he shared his passion for stargazing with the readers of *Sky & Telescope* in "The Gift of Stargazing" (*S&T:* Oct. 2024, p. 84)!

I once read a book (a true story) about a family whose parents were so poor that the father would give his children each a star on their birthday. And, when I read that his parents gave him a telescope for his 7th birthday, I thought, *How great is that!* With their love, he could see Mars and Jupiter.

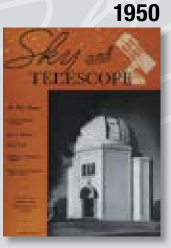
I can feel that his dream of visiting Zion National Park, Bryce Canyon, and Monument Valley will happen soon. After all, "One shouldn't go through life without visiting them!" to observe the night sky.

Caroline Robicheaux
Patchogue, New York

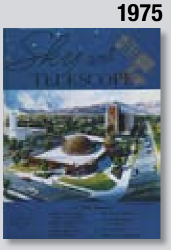
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

1950



1975



2000

March 1950

Remote World "[Seemingly] Pluto is a much larger body than the moon or Mercury. According to the best evidence available, the mass of Pluto is 0.9 or 0.8 times the mass of the earth . . . One would expect that such a body would have an atmosphere. Since a dense atmosphere would correspond to a high albedo, it cannot have a dense atmosphere. It is impossible to account for the faintness of Pluto except by making it almost black. . . .

"In view of the apparent absence of an appreciable atmosphere, . . . it is important to ask with what degree of certainty the mass of Pluto has been determined."

Yale astronomer Dirk Brouwer already suspected flawed data. Now known to be much smaller, Pluto was reclassified as a dwarf planet.

March 1975

Winking Star "On the evening of [January] 23rd, Eros passed directly over the 3.6-magnitude star Kappa Geminorum — the first case in history of a well-observed occultation of a star by an asteroid. [Along with] three positive observations [from Massachusetts,] six more and perhaps a seventh have been reported from Connecticut. . . .

"[Near] Avon, Connecticut, Dr. D. R. Morrison was not thinking of the occultation, but was endeavoring to locate Eros with 8 x 42 binoculars. He was startled to see Kappa Geminorum suddenly and completely vanish, and return just as abruptly about two seconds later. . . .

"Since Eros was at minimum brightness in its rotational cycle . . . it was presenting its smallest cross section . . . Tentatively, the occultation results indicate a diameter of about 14 miles . . ."

March 2000

Silent Menace "The Sun's sometimes deleterious effect upon our technology is an old story that begins with the invention of the telegraph and telephone. Electrical currents induced during geomagnetic storms in the 19th century were at times so powerful that telegraphers often didn't need battery power to send their dits and dahs down the line. . . .

"Like telephone wires, power lines make excellent conductors for the currents created by geomagnetic storms — after all, power lines are *supposed* to carry electric current. The problem is that the storms produce direct current (DC) while the lines are meant to carry alternating current. Induced DC loads cause the windings of transformers to overheat; insulation can then break down and transformers fail . . . On August 2, 1972, a 230,000-volt transformer in British Columbia exploded. Near the peak of the last sunspot cycle on March 13, 1989, the Hydro-Quebec power grid failed, plunging large portions of Quebec into darkness for nine hours."

Sten Odenwald worried that we are now less prepared than ever for such catastrophes.

TELESCOPE

Arecibo's Powerful Radar May Have Contributed to the Telescope's Demise

Aerial view of Arecibo Observatory in 2019

THE RADAR SYSTEM at the Arecibo Observatory in Puerto Rico was once the most powerful source of electromagnetic radiation on this planet, enabling the mapping of Venus, the Moon, and near-Earth asteroids. Then, in 2020, support cables for the giant dish's observing platform failed, resulting in the collapse and permanent closing of the storied telescope (*S&T:* Mar. 2021, p. 8). Now, an inquiry has found those very radar transmissions may have helped trigger the collapse.

Arecibo consisted of a 1,000-foot-wide dish mounted over a natural sinkhole; three concrete towers suspended a 900-ton receiver and transmitter platform above the dish. To hold the radar platform's support cables in place, molten zinc was poured into tapered steel sockets — a standard method used for well over 100 years in a wide variety of industrial settings. Yet a committee formed by the National Academy of Sciences and sponsored by the National Science Foundation concludes that those zinc sockets might have weakened unexpectedly in a phenomenon called *zinc creep*. The raging winds of Hurricane Maria in 2017 provided additional stress that ultimately led to the telescope's demise.

▼ In a photo taken on December 8, 2020, the damage is visible a week after the telescope's collapse. The remains of the instrument platform are visible on the telescope's dish.

Initially, the collapse made little sense. "As far as we know, there is no recorded case of a cable that has stood the initial loading, and then over time pulls out at loads that are lower than the initial level," says Habib Tabatabai (University of Wisconsin-Milwaukee), a civil engineer who served on the committee. The pattern of cable pullouts were also puzzling, he notes. The cables pulled out more at the tower level than at the platform, and some newer cables failed before older ones did. That pattern didn't match weakening from hurricane winds alone.

After some digging, the team found a 1963 study that documented zinc creep when high currents were applied over a short period of time, such as during manufacturing processes. But the panel realized that if currents had been induced that were orders of magnitude lower but sustained over longer periods, the same effect could occur.

The likely source of those currents: the telescope's powerful S-band planetary radar system, added to the facility in 1997. Its emissions could have induced surface currents in the steel cables that would have flowed through the sockets, weakening the zinc there. While this scenario isn't proven, Tabatabai cautions, it would explain why the cables on the towers, within the beam of the radar emissions, were the ones most affected.

While the phenomenon was unanticipated, the report nevertheless notes that clear danger signs were missed. After Hurricane Maria, inspections showed that cables were pulling out of their sockets by more than an inch. Major steps should have been taken to improve the supports at that time, and a much more rigorous program of inspections and maintenance should have been in place for such an important facility.

"We hope that our report can at least shed some light on what happened," Tabatabai says, "and guide the way for the future."

■ DAVID L. CHANDLER

ARECIBO: UNIVERSITY OF CENTRAL FLORIDA; ARECIBO DAMAGE: MICHELLE NEGRON / NATIONAL SCIENCE FOUNDATION

SOLAR SYSTEM

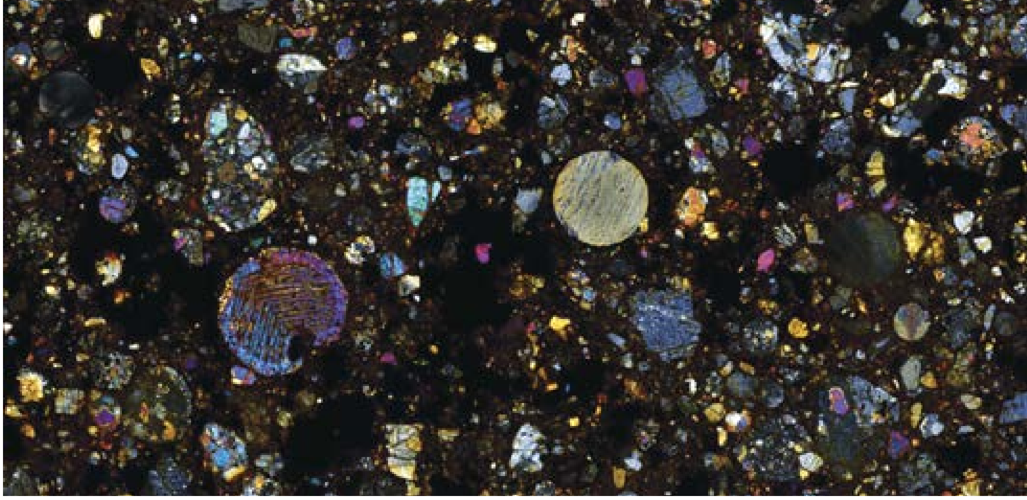
Sources of Most Meteorites Identified

TWO TEAMS PUBLISHING in the October 17th *Nature* have traced 70% of meteorite falls to specific collisions in the main asteroid belt.

The origins of even the most common meteorites, known as *H chondrites* and *L chondrites* (which together make up some 70% of meteorite falls), has long remained elusive. To track down their sources, a team led by Miroslav Brož (Charles University, Czech Republic) gathered data on major main-belt *asteroid families*, members that were once part of a larger body. After a collision splits a body apart, the fragments' initially similar orbits spread out over time. The researchers simulated the evolution of those orbital motions, including the effects of exposure to solar heating, cosmic rays, gravity, and other forces.

Brož's team found that H and L chondrite meteorites originate primarily from three families produced in recent collisions: Two of these occurred 7.6 million and 5.8 million years ago, respectively, and a third happened within the last 40 million years.

In an accompanying study in the same issue of *Nature*, a group led by Michaël Marsset (European Southern Observatory) traced an additional source of L chondrite meteorites back to a collision that occurred some 470 million years ago. (That one might even have left Earth with a ring of debris; *S&T:* Feb. 2025, p. 10.) The more ancient event might have supplied almost all of the meteorites at that time and still provides some 20% of falls.



▲ This image, 3 mm wide, shows transmitted polarized light from an ordinary H chondrite, called San Juan 029.

"The models are very elegant and manage to explain several key observables with a single model," says Mikael Granvik (University of Helsinki, Finland), who was not involved in the research. "I think that is a great feat, and one that will push the field forward by a great leap." The details still need to be worked out, though, he adds. "It will be very interesting to see how tests of their hypotheses will play out in the years to come."

■ JEFF HECHT

BLACK HOLES

Newfound Stellar Companion May Explain Black Hole System

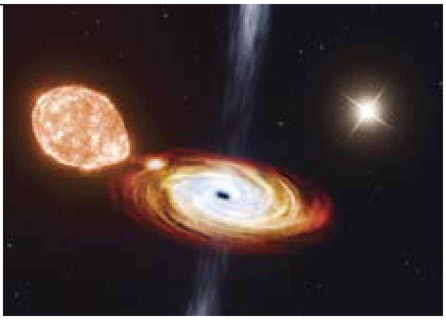
THE SYSTEM V404 CYGNI is an old favorite: Its 9-solar-mass black hole is slurping gas from a nearby star slightly less massive than the Sun. The hot, swirling gas creates an X-ray beacon, making this system a canonical *low-mass X-ray binary* (here, "low mass" refers to the companion star).

But it turns out the binary at the heart of V404 Cygni isn't alone. Even back in the early 1990s, astronomers noticed another star almost on top of the binary as seen from our perspective, though they generally assumed it to be an interloper. But as Kevin Burdge (MIT) and colleagues report in the November 14th *Nature*, this star is part of the V404 Cygni system after all.

The team determined from a suite of observations that the star moves through space with the binary and has probably been part of the system from the get-go. The tertiary star is a shirt-tail relation, however: It lies more than 3,500 astronomical units from the inner binary, or roughly 90 times farther out than Pluto lies from the Sun. Its current distance may help astronomers clinch how a black hole can form while still somehow retaining a small stellar companion in a tight orbit.

In 2016, Smadar Naoz (University of California, Los Angeles) and her colleagues suggested that a third, distant companion star could play a role in these systems' formation. The distant star's gravitational interactions with the inner binary — as well as the evolution of the star that will soon become a black hole — would create a complex interplay of changes that would ultimately lead the inner binary's orbit to shrink dramatically.

The tertiary's orbit in V404 Cygni matches what Naoz's team predicted.



▲ An artist's concept of V404 Cygni depicts a black hole stealing gas from a nearby star (center left), while another star orbits much farther away (upper right).

"I'm very excited by this discovery," she says. She's now collaborating with Burdge to investigate the system's history in more detail.

Curiously, the black hole seems to have had a quiet death. For V404 Cygni's tertiary to hang on to the inner binary, the black hole must have formed without the messy violence expected to send it reeling. The star might even have imploded without fanfare.

■ CAMILLE M. CARLISLE

METEORITE: JÉRÔME GATTACCECA / CNRS / CEREGE; V404 CYGNI: JORGE LUGO

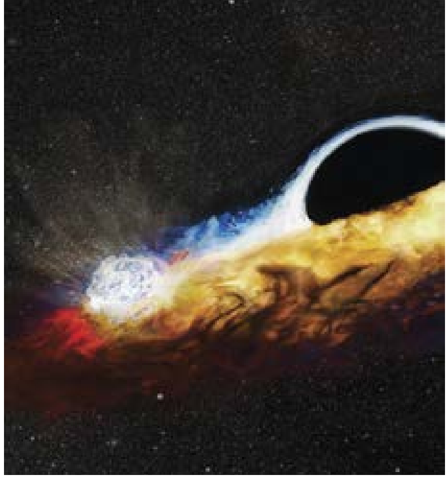
BLACK HOLES

Black Hole Eats One Star; Remains Pummel a Second

IN 2019 A SUPERMASSIVE black hole began to eat a star. Although the resulting flare of light occurred some 210 million light-years away, it was bright enough that the Zwicky Transient Facility in California caught the event, dubbing it AT2019qiz. But this wasn't an ordinary stellar feast.

Although the black hole had already spaghettified the star in 2019, it took time for that noodle of gas to slip into the maw — it wasn't until 2023 that astronomers turned the Chandra X-ray Observatory to witness the high-energy emissions from the long-term meal. That's when they found an unexpected spike in X-rays.

Follow-up observations with other space observatories found nine X-ray bursts, recurring roughly every two days. Matt Nicholl (Queen's University Belfast, UK) and colleagues published the results in the October 24th *Nature*.



▲ In this artist's illustration, material from a shredded star that envelopes a supermassive black hole (at right) also interacts with another orbiting star (at left).

Such *quasi-periodic emissions* have been observed elsewhere, but astronomers don't know why they happen. Nicholl's team thinks the bursts come from something crossing the gaseous disk that now surrounds the black hole: another star.

"We don't expect many stars orbiting this close to a black hole," admits Nicholl. "We think that most of the stars are sitting much farther away, but every now and again they can deflect each other towards the black hole."

If a single star fell toward a black hole, the strong gravitational field would shred the star to pieces. But if a stellar pair falls in, three-body gravitational interactions could enable the black hole to capture one of the stars in a stable orbit

"These captures are rare," Nicholl notes. But once bound to the black hole, the star's orbit decays only slowly. "At any given time, a black hole at the center of an average galaxy will have about one star in a tight orbit like this." Then, if another star by chance falls into the black hole, its material spreads out into a disk and begins to interact with the captured star.

"However, this is just our simple picture," Nicholl cautions. "Now that we think we know what to look for, we can observe what fraction of tidal disruption events have quasi-periodic oscillations, and this will let us actually measure how common these close orbiting stars really are, to test this theory."

■ MONICA YOUNG

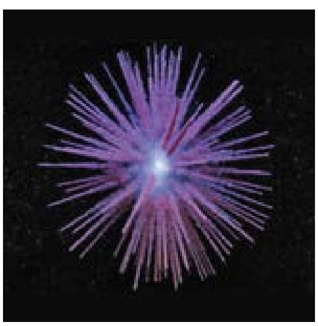
STARS

Astronomers Map Dandelion Supernova

ASTRONOMERS HAVE mapped the 3D structure of a famous dandelion-shaped supernova remnant. The map shows the explosion's debris is still speeding outward at more than 1,000 kilometers per second (2 million mph), almost a millennium after the star at the center of it all detonated.

In AD 1181, Chinese and Japanese astronomers recorded the arrival of a "guest star" in the constellation Cassiopeia. But it wasn't until 2013 that amateur astronomer Dana Patchick found the explosion's remnant in archived images from NASA's Wide-field Infrared Survey Explorer. Now we know that the object, named Pa 30, is the remnant of a Type Iax supernova, triggered by the explosion of a white dwarf star. (The "x" denotes the fact that some of the star survived the ordeal.)

After a group of astronomers discovered filaments within Pa 30 in 2023 (*S&T:* May 2023, p. 10), a team led by Tim Cunningham (Center for Astrophysics, Harvard & Smithsonian) and Ilaria Caiazzo (Institute of Science and Technology Austria) mapped the structures in 3D using the Keck Cosmic Web Imager at the W. M. Keck Observatory in Hawai'i.



◀ An artist's concept shows the spindles of the supernova remnant Pa 30.

Within the image of Pa 30, every individual pixel carries its own spectrum, from which the team could calculate the motions of the gas at that spot. The analysis is published in the November 1st *Astrophysical Journal Letters.*

"We find the material in the filaments is expanding ballistically; this means that the material has not been slowed down nor sped up since the explosion," says Cunningham. "From the measured velocities, looking back in time, you can pinpoint the explosion to almost exactly the year 1181."

The analysis reveals an unexpected asymmetry to the explosion that hints at an unusal origin. The data also reveal a large cavity inside the spindles. A *reverse shock wave*, traveling more slowly than the initial blast, may have cleared out the central space.

Georgios Dimitriadis (Lancaster University, UK), who was not involved in the research, says the detailed mapping of the most extreme supernovae, such as Pa 30, might shed light on more typical Type Ia supernovae.

■ COLIN STUART

To see a 3D view of the supernova, visit https://is.gd/DandelionSN.

TIDAL DISRUPTION EVENT: NASA / CXC / SAO AND SOHEB MANDHAI / THE ASTRO PHOENIX; DANDELION SUPERNOVA: W. M. KECK OBSERVATORY / ADAM MAKARENKO

SOLAR SYSTEM

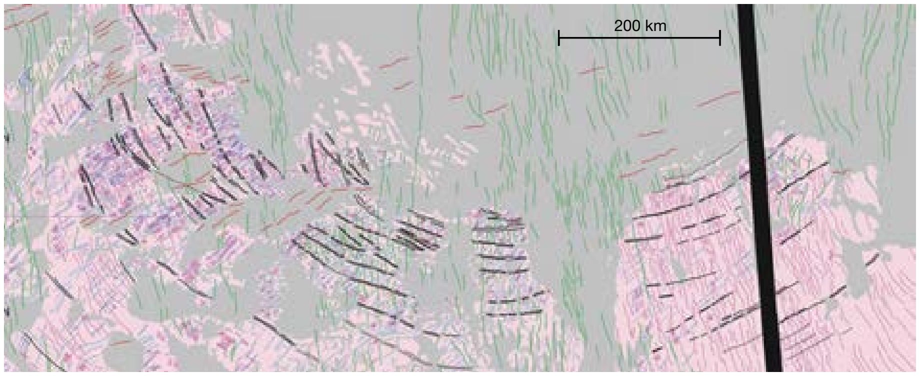
Oldest and Largest Impact Crater Found on Venus

SCIENTISTS HAVE FOUND what might be the oldest and largest crater on Venus — and it's like none ever seen on our sister planet.

Radar has previously enabled scientists to identify some 1,000 impact craters on Venus's surface. Dating only as far back as 1 billion years, and with sizes of at most 300 kilometers (190 miles) across, they're far younger and smaller than craters found on the Moon, Mercury, and Mars. Those worlds still have records of impacts from the solar system's first 2.5 billion years, when large chunks of planet-forming material still roamed around.

Now, a new discovery published in the October *Journal of Geophysical Research: Planets* might record an earlier impact on Venus. Vicki Hansen (University of Minnesota, Duluth) found the possible crater while mapping the oldest and most highly disrupted type of terrain on Venus: *tesserae*.

The team was surprised that one of these regions, the Haasttse-baad Tessera, contains a circular, multi-ringed structure 1,500 km wide. "The beautiful concentric structures were very different from the rest of the tesserae," Hansen says.



▲ On a geologic map of Haasttse-baad Tessera, black lines depict the concentric rings of an ancient impact crater.

When Hansen and fellow mapper Ivan López (Rey Juan Carlos University, Spain) went looking for solar system analogs to help explain the rings' origins, they had to go as far afield as the icy moons of Jupiter. Callisto's Valhalla Crater and Europa's Tyre Crater both sport multiple rings, probably formed after something big punched through an icy shell floating on liquid water.

While Venus wouldn't have had water, it did have lava. Team member Evan Bjonnes (Lawrence Livermore National Laboratory) used computer simulations to show that a single, large object hitting a crust a few kilometers thick could have melted the underlying layer, leaving a thin crust over a hot lava pond. A second impact hitting the same spot could then have splattered ejecta in multi-ringed fashion. (The lava pond likely remained hot for millions of years, making a double-impact scenario less unlikely.)

Venus researcher Anna Gülcher (Caltech) says she is "quite excited" about the new insight the impact scenario offers for tesserae. Understanding this odd terrain type, unique to Venus, has become one of the highest priorities for future missions to this planet, and studies like this one lay the groundwork for explaining its origin.

■ JEFF HECHT

LOPEZ ET AL. / *JOURNAL OF GEOPHYSICAL RESEARCH: PLANETS* 2024

IN BRIEF

Radio Burst from a "Dead" Galaxy

For the first time ever, astronomers have detected a *fast radio burst (FRB)* in a large elliptical galaxy. The discovery, announced by Tarraneh Eftekhari (Northwestern University) at a conference in Khao Lak, Thailand, supports earlier indications that there are various ways to form the extreme objects that produce these ultra-brief flashes of radio waves. Most FRBs for which accurate sky positions are known can be traced to galaxies with a high rate of star formation. That's one of the reasons why scientists think that the bursts occur on *magnetars* — young and strongly magnetized neutron stars left behind when massive stars end their short lives in supernova explosions. However, FRB 20240209A doesn't fit this picture. Between February and July, the Canadian Hydrogen Intensity Mapping Experiment (CHIME) radio observatory detected 22 bursts. Thanks to the repeated bursts and the recent addition of a smaller outrigger telescope, CHIME pinpointed the burst's origins to the outskirts of an old, massive, and luminous elliptical galaxy almost 2 billion light-years away that doesn't show any signs of recent star formation. If FRB 20240209A occurred on a magnetar, the object may have resulted from some other process than a core-collapse supernova.

■ GOVERT SCHILLING

Read more at https://is.gd/FRB0209.

New Views of Vega's Dusty Disk

Astronomers have used the Hubble and James Webb space telescopes to gain an unprecedented view of the vast disk of gas and dust surrounding the star Vega — and it's exceedingly smooth. Schuyler Wolff (University of Arizona) led an effort using Hubble to peer at the outer, cooler part of the disk, where small, smoke-size particles glint in Vega's light. Meanwhile, team member Kate Su (also at University of Arizona) led an accompanying analysis of Webb data, revealing sand-size particles in the hotter, inner part of the disk. The disk's smooth gradient is marred only by a subtle gap located about twice as far from Vega as Neptune circles the Sun. The results will appear in the *Astrophysical Journal*. While other stars' disks exhibit distinct gaps that might have been cleared out by giant planets, the absence of such planets around Vega could explain its disk's smoothness. According to René Oudmaijer (Royal Observatory of Belgium), who wasn't involved in these studies, "it is becoming more established that more massive stars are less likely to be accompanied by planets than lower mass stars such as our Sun." Or, if Vega *does* have planets, they might be smaller than these new observations can pick up; the data can only rule out planets bigger than Neptune in large orbits.

■ COLIN STUART

 by Javier Barbuzano

Astronomy in a Changing Cli

Professional and amateur astronomers are seeing the impact that a warming world is having on doing astronomy.

DEBRA CERAVOLO

In their quest for the best observing conditions, astronomers have long established their observatories on remote mountaintops. These sites not only offered escape from light pollution but also the benefit of thin, stable, and dry atmospheres — ideal for peering at the wonders of the universe.

However, even these pristine environments are now facing challenges. While light pollution and satellite constellations often top the list of astronomers' woes, another insidious threat looms as greenhouse gases build up in Earth's atmosphere. Climate change can diminish our views of the universe in several ways. Wildfires, disrupted weather patterns, and extreme weather events from hurricanes to heat waves have become more frequent, creating hazards to observatories and support facilities, for professional and amateur astronomers alike.

These changes introduce subtler challenges as well. Sometimes these are indirect, as the resulting damage to roads, power grids, and communication lines can interfere with observatory operations and maintenance. Other changes are incremental. Shifting atmospheric conditions drive up wind and humidity that can force dome closures. A warming atmosphere can also exacerbate atmospheric turbulence at both ground and high-altitude levels, further

mate

degrading the quality of astronomical images. Observatory sites meticulously chosen for their unique atmospheric conditions could lose their suitability as climate patterns shift — compromising the future of the next generation of instruments currently under construction.

While directly attributing specific weather events to climate change is fraught with uncertainty, a growing body of evidence suggests a clear correlation between the increase in average global temperature and the observed upward trend in extreme weather patterns. Such phenomena should become increasingly common in a warming climate. Technological advances may mitigate some of the consequences but ultimately might not be enough, since the disruptions will likely exceed our current capabilities.

The full scope of what climate change has in store for astronomy remains uncertain. Some scientists are taking the lead and trying to answer the most pressing questions. Their efforts are already yielding surprising insights about how shifting climate patterns will affect observing sites, providing the foundation for how astronomers will adapt to a changing world.

▲ **SEEING RED** Wildfire smoke shrouds the setting Sun over the mountains of southern British Columbia, Canada, in August 2018. The star-party site Mount Kobau sits just off the right edge of the photo.

Looking Up as the World Burns

The first thing that should worry both amateur and professional astronomers is whether a sudden onslaught from nature will demolish their observatories or favorite skywatching spots. Storms, wildfires, and floods are becoming more frequent and severe, putting people and facilities at risk.

Severe weather has damaged numerous observatories. The Arecibo Observatory in Puerto Rico is a dramatic example, repeatedly struck by storms and hurricanes. A recent report concluded that the damage from Hurricane Maria in 2017 exacerbated then-unknown problems with the cables suspending the instrument platform over the radio dish. Left largely unaddressed, the cable sockets failed and the platform collapsed, destroying the dish (see page 8).

Strong winds can also damage observatories. Telescopes are designed with stringent requirements to withstand the extreme weather normally expected at their locations, but in a changing climate, those requirements could become obsolete within the observatories' lifetimes.

For example, planners designed the prototype Large-Sized Telescope (LST) of the future Cherenkov Telescope Array Observatory on the Spanish island of La Palma (*S&T:* Aug. 2024, p. 12) to resist winds up to 200 km/h (120 mph). The telescope passed a stress test in 2020 when a storm with 170 km/h winds only tore off a few mirror panels.

However, recent years have seen a change in the tropical cyclones that form near the African coast south of La Palma: An increasing number of these storms are deviating from their usual path westward and drifting more northward. In 2022, Tropical Storm Hermine took an unprecedented track due north and came within 300 kilometers (less than 200 miles) of La Palma, bringing heavy rain and winds to the island. Wind speeds fell far short of the LST's design limit, but if north-directed storms become the norm, the LST could end up experiencing stronger winds in its 30-year lifespan than it was planned to handle.

Wildfires present another critical threat. In the U.S., the number of fires tripled in the 2000s compared with the previous two decades. In 2020, California alone suffered more than 8,000 fires, fueled by extreme drought. That year, Lick Observatory on Mount Hamilton narrowly escaped destruction, the encroaching flames requiring personnel and nearby residents to evacuate. In Arizona, firefighters saved telescopes on Mount Graham from destruction in 2017, while the 2022 Contreras Fire on Kitt Peak razed several support buildings.

KITT PEAK Views from the 4-meter Mayall Telescope on Kitt Peak show the 2022 Contreras Fire threatening the observatory.

KPNO / NOIRLAB / NSF / AURA (2)

Worldwide, the number of extreme wildfires more than doubled between 2003 and 2023. Observatories faced threats at both the start and end of that time span. In Australia, for instance, the extreme bushfire season of 2003 completely destroyed the Mount Stromlo Observatory near Canberra, wiping out all its research telescopes. In 2023, the worst fire in 40 years reached the observatory on the slopes of Mount Teide on Tenerife in the Canary Islands, forcing firefighters to battle the flames right under the telescope domes.

Even after the blaze is quenched, wildfires can still disrupt observations for long periods. Domes are kept shut to prevent ash from blowing inside and damaging instruments. Smoke and haze can significantly reduce nighttime sky clarity for weeks. The largest wildfires are powerful enough to inject smoke directly into the stratosphere, where it can travel vast distances and persist for long periods of time. That was the case in June 2023, when the smoke from fires in Canada reached New York.

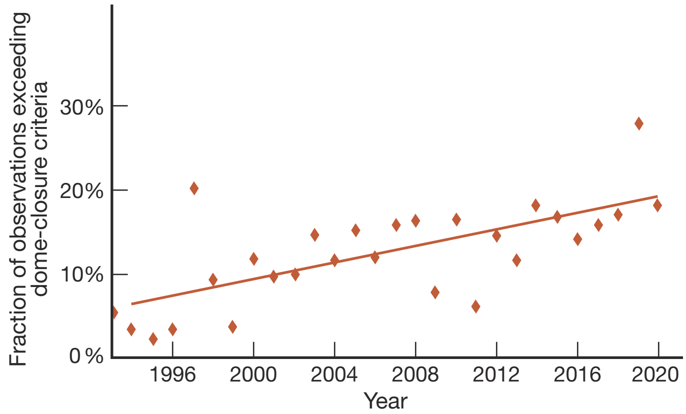
Two main causes lie behind this increase in the frequency of intense fires. One is climate change. The fire season is becoming longer, meaning there are more days when meteorological factors are conducive to wildfires. There are long droughts and record-breaking temperatures. The atmosphere is also changing, as higher temperatures lead to more unstable conditions. An unstable atmosphere acts like a chimney, enabling hot, smoky air to rise more easily, pulling in fresh, oxygen-rich air from the surroundings and fueling flames. As a result, a fire's spread accelerates.

An unstable atmosphere also forms more storms, which may produce lightning. A recent study shows that the number of lightning strikes could increase by 40% by the end of the century, leading to even more wildfires.

A second factor, however, is the way society has managed fires in recent decades. Fires are part of the natural cycle of the forest, removing undergrowth and older trees. Sometimes, the focus has been put on suppressing all fires; other times, neglect or negligence has left vegetation uncontrolled. Both approaches leave forests chockful of flammable material, making them more susceptible to large, destructive blazes — regardless of whether the spark is natural or humanmade.

"It's not why a fire starts that is worrying, but why it cannot be stopped," says Andrea Duane (University of California, Davis) who studies the interaction between wildfires, landscape, and climate. "Things have always burned, but recently we found that our most advanced extinction methods are not enough to control these fires." The solutions are different for each region, Duane says, but at this point adapting management practices to the new reality looks like the best strategy.

Amateur astronomers, dispersed in remote, forested areas, are arguably more exposed than their professional counterparts. In recent years, "the forests are burning, observatories are being threatened, and amateur star parties are getting badly smoked or canceled outright," says *S&T* Contributing Editor Ken Hewitt-White, an amateur based in southern British Columbia, Canada.



▲ **SUMMIT WEATHER** Over the last few decades on Mauna Kea, the percent of nighttime observations during which meteorological conditions exceeded the Keck Observatory's dome-closure criteria has risen. Individual conditions have not necessarily changed significantly; rather, the *combination* of conditions is worsening.

BEATRIZ INGLESSIS / *S&T*, SOURCE: M. A. M. VAN KOOTEN AND J. G. IZETT / *PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC 2022*

As a regular attendee of the Mount Kobau Star Party in British Columbia, Hewitt-White has witnessed an increase in the number of wildfires since the turn of the century. Smoke and fire risk have become increasingly common threats. In the last five years, the Mount Kobau party has been canceled or delayed three times due to fire risks that threatened the site or its access roads. Other events have suffered similar cancellations, such as the Oregon Star Party.

Hewitt-White recalls a harrowing experience in 2015, when a wildfire erupted near Mount Kobau and raced up the slopes in the late afternoon. About 80 attendees had to hastily pack their optical and camping equipment and flee down a bumpy, winding gravel road. All escaped, "but it was terrifying," he says.

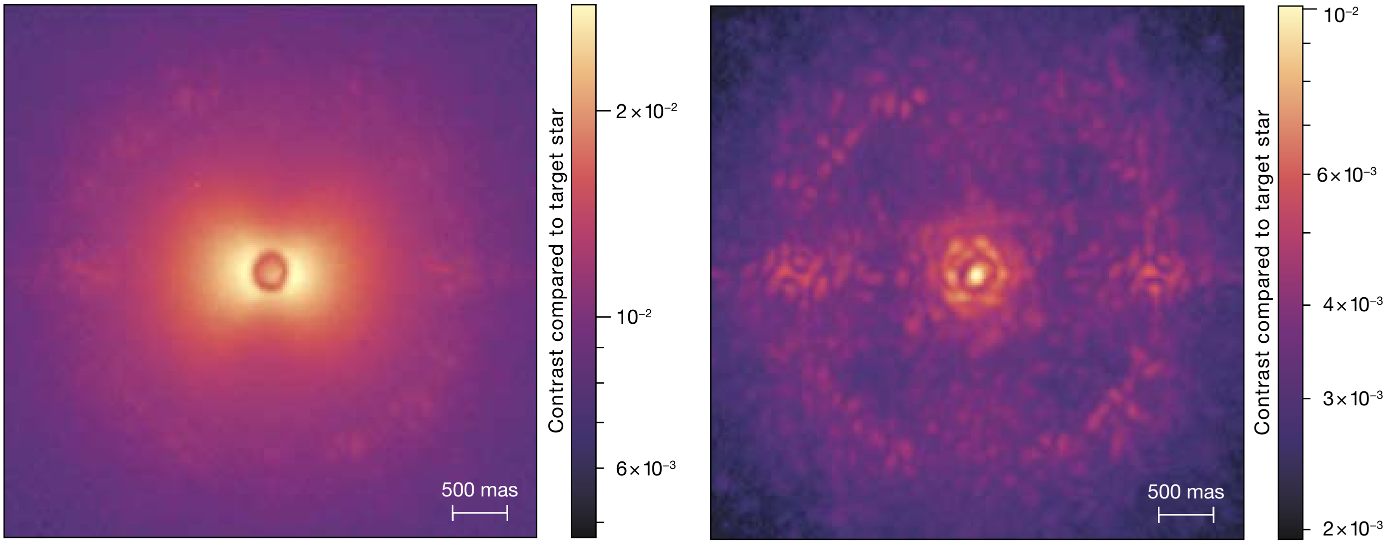
A Fogged Up Window to the Universe

Climate change also subtly deprives us of the sharpest views of the cosmos. Astronomical observations rely on specific atmospheric conditions — minimal light pollution, low humidity, and a stable atmosphere — which climate change may alter in complex ways. Professional telescopes are feeling the pinch first.

Observatories hoard decades' worth of detailed weather data, collected routinely during daily operations and site surveys. Most of these data, however, remain largely unexplored for climatic trends.

In 2020, exoplanet researchers Faustine Cantalloube and Julien Milli (both now at the Institute for Planetary Sciences and Astrophysics, Grenoble, France) tapped into this resource for the first time. The astronomers were working at the European Southern Observatory's Very Large Telescope (VLT), located at the Paranal Observatory in Chile's Atacama Desert. To detect the faint signals of distant exoplanets, they require exceptionally sharp images.

However, they noticed that under certain atmospheric conditions, the sharpness of the VLT images suffered. This



▲ **WIND-DRIVEN HALO** Two infrared images taken with the Very Large Telescope's SPHERE-IRDIS instrument show the difference winds can make: Both images are of the young star HR 4796A, which is surrounded by a debris disk. The edge-on disk is invisible around the star in the image with the wind-driven halo *(left, 96-second exposure)* but visible in the other *(right, 32-second exposure)*. The larger ring around the edge of each image is due to adaptive-optics corrections.

FAUSTINE CANTALLOUBE

prompted them to investigate potential climate impacts on their own work by analyzing the observatory's weather data.

But first, they had to wrestle with those data. Despite having weather stations for daily operations, observatories often lack data readily usable for research. The data may not be recorded or stored properly, or they're in a format incompatible with later analysis. Sometimes, weather stations suffer disruptions, such as relocation or construction of new facilities nearby, creating misleading trends.

Nevertheless, after piecing together available information, the researchers revealed some concerning patterns at Paranal. Temperatures there have risen 1.5°C (2.7°F) in the past 40 years, outpacing the global average of 0.2°C per decade. They are projected to climb another 4°C by the end of the century.

This increase is already impacting observations. Large telescopes like the VLT must maintain the same temperature inside the domes as will be outside at sunset, to prevent turbulence from forming above the mirrors during operations. However, the VLT's cooling system can only handle temperatures below 16°C (61°F). As nights become warmer, there are increasingly more nights where the outside air is hotter than the inside of the domes.

"Turbulence is the number one enemy of optical and near-infrared astronomy," says atmosphere scientist Angel Otárola (European Southern Observatory). Turbulence can decrease observations' quality, especially for high-precision endeavors such as imaging and detecting exoplanets.

Problems also arise because the instruments themselves operate best when cold. "We have cooling capacity," Otárola says. "The problem is letting things warm up [inside], because the electronics inside the telescopes need to be relatively cool."

Other trends are less obvious. One of the reasons Cantalloube and Milli began exploring weather data was because they'd seen a significant decrease in image sharpness during strong El Niño events. El Niño is a natural but irregular weather pattern that is produced by warmer-than-average sea surface temperatures in the eastern Pacific Ocean. El Niño events intensify the *southern subtropical jet stream*, an air current that forms at an altitude of about 12 km with wind speeds up to 60 m/s (130 mph). These winds can overwhelm the adaptive optics system of the VLT by creating turbulent patterns that change faster than the deformable mirrors can compensate for. A noticeable smear in the direction the winds are blowing appears up to 40% of the time above the VLT, decreasing contrast by a factor of 10.

Based on computer simulations that combine real weather data with physics-based models, Cantalloube and Milli found that the speed of the subtropical jet stream has increased by 3 to 4 m/s in the last 40 years.

But such simulations rely on data with low spatial and temporal resolution, often from satellite observations, Otárola cautions. If he had a large enough budget, he says, he would have real measurements at different altitudes, maybe using recently developed drone technology for atmospheric monitoring. "If we could monitor that for the next 10 or 20 years, my successors would have a good database to determine what is happening."

Cantalloube's work inspired Otárola and his colleagues to look at long-term trends in the weather data from all three European observatories in the Atacama Desert, paying extra attention to the variability caused by El Niño and its cooler counterpart, La Niña. They found that during El Niño periods, roughly one-quarter of the year saw temperatures above 16°C at sunset. During La Niña, there are fewer hot days, but many with relative humidity higher than 50%. High humidity complicates some observations, particularly those in the mid- and near-infrared, because water absorbs light at these wavelengths.

Their study, however, did not confirm the overall deterioration in *seeing* — turbulence's blurring effect — that Cantalloube and Milli's work had found.

Closed Domes and Lost Photons

Other observatories face different challenges. In 2022, astronomer Maaike van Kooten (now at the Herzberg Astronomy and Astrophysics Research Centre, Canada) collaborated with atmospheric scientist Jonathan Izett (University of California, Santa Cruz) to investigate the impact of climate on Mauna Kea, another landmark for ground-based astronomy.

While overall conditions at the observatory have remained relatively stable, the study revealed that maximum wind speeds have increased over the decades. The team also found that the frequency of weather conditions that would require dome closures — including freezing temperatures, high winds, and excessive humidity — has more than doubled in the last two decades.

The domes aren't necessarily closed every time these conditions occur; the local operators have the final call. Also, for telescopes like Keck's two 10-meter instruments, domes are already closed about 40 nights per year for non-meteorological reasons, such as planned maintenance. Still, the increase in bad weather conditions means more nights when no observations are done.

As in the Chilean studies, Van Kooten and Izett found that 40 years are not enough to see clear trends, due to the variable nature of weather data. They also had problems with data quality, for instance when instruments were replaced. No record of these changes was made to guide future researchers accessing the data.

Apart from weather, the atmosphere itself is also becoming less transparent to photons coming from space, as it heats up and its water vapor and aerosol content increase. In a 2022 study, Eric Steinbring (Herzberg Astronomy and Astrophysics Research Centre, Canada) showed that there's been a nearly 0.2% decrease per decade in the amount of light that reaches the ground. He compared 17 years of data collected by the 8-meter Gemini North and South telescopes in Hawai'i and Chile, respectively, with observations from the Gaia spacecraft, which isn't affected by Earth's atmosphere. This decrease is in line with what would be expected from the global rise in air temperature.

The drop is the equivalent of poking a 12-centimeter hole in the primary mirror of an 8-meter telescope every year, Steinbring said in a presentation. While it might not seem like a lot, "it's adding up."

Extreme Locations, Difficult Predictions

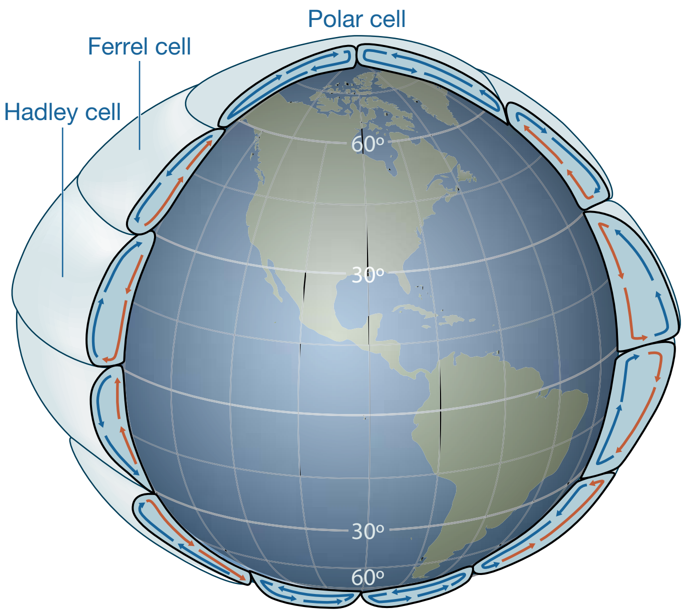
Anticipating climate change's effects on astronomical sites is challenging. The best available simulations generally forecast deteriorating conditions, but their resolution is too coarse to accurately represent small geographical features like islands and mountaintops, where most observatories are located.

A comprehensive study published in 2022 by Caroline Haslebacher (University of Bern, Switzerland) and others analyzed climate projections for eight major observing sites located on four different continents and in Oceania: Mauna Kea, Cerro Paranal, La Silla, Cerro Tololo, La Palma, Sutherland, Siding Spring, and San Pedro Mártir. The only common trends the researchers could find for all the sites were an increase both in average temperatures and in the total water vapor content in the atmosphere.

However, while these projections account for the observatories' elevations, they neglect crucial topographical factors that significantly influence local weather patterns, and they aren't good at simulating interactions between land and

JIM FAILES

▶ **SMOKY SKIES** Lightning-sparked fires and their smoke compete with the starry vista above the Mount Kobau Star Party in August 2018. Mars sits above the trees at left.



▲ **ATMOSPHERIC CIRCULATION** Due to the complex interplay of Earth's rotation and heat transport, the lower atmosphere in each hemisphere divides into three distinct wind cells. Each cell is essentially a closed circuit of circulating winds that redistributes heat. Several of the world's professional observatories lie near where cool air in the Hadley cells sinks toward the surface (see map on facing page).

ocean. They also do a poor job at dealing with variables like cloud cover and changes in astronomical seeing.

"Clouds are very hard to model," Haslebacher said. Maybe the next generation of climate models could help with that, she adds. "You would need higher-resolution climate models to really be able to simulate clouds."

More importantly, climate projections rely on historical data, limiting their ability to predict unprecedented extreme events or novel climate scenarios. "Climate as we measured it is no longer a guide to what we might expect in the future — we're in a no man's land," says Edward Graham (University of the Highlands and Islands, United Kingdom). Computer simulations, especially those based on artificial intelligence and machine learning "cannot foresee extreme events that have not occurred before."

Graham has conducted a thorough analysis of the plausible evolution of the *Hadley cells*, the giant overturning circulation patterns powered by hot air that rises at the equator. That air cools as it travels poleward and sinks at roughly 30° latitude. Not by chance, some of the most prominent observatories of the world are in the sinking branches of the Hadley cells: The sinking air moves very slowly and has lost almost all its humidity during the trip from the equator, creating stable, dry atmospheres optimal for astronomers.

Graham found that the Hadley cells, powered by extra heat in the atmosphere, are expanding. The Pacific Hadley cell is growing fastest, moving at a rate of between half a degree to two degrees in latitude per decade. That's a shift of hundreds of kilometers over 50 years.

"That's enough to move an observatory away from a preferable zone to a less preferable zone," Graham says. Also, these cells now have more energy in them, and their air currents are moving faster. "What goes up more quickly should go down more quickly, too, and that has the potential to affect stability in the atmosphere," Graham adds.

It's not like Mauna Kea or Paranal are going to turn into a place like Scotland, he says, "but the precision required in astronomy today could easily be affected by the relatively minor perturbations that we expect from climate change."

More than Clear Skies

Astronomical observatories in remote locations require a careful balance of scientific and logistical factors. Practical considerations such as energy, water, food, safety, and healthcare for staff are as important as scientific requirements. The human element, however, is often overlooked. "It's not only an observatory running by itself, there are people there," Cantalloube says. As demonstrated by events like the Chilean protests of 2019 and the COVID-19 pandemic, political and social stability are as essential as clear skies. Otherwise, "we could go to North Korea, it's a good site," Cantalloube says. "But we don't go to North Korea, right?"

Climate change exacerbates these challenges. Extreme weather events not only disrupt operations but put people in harm's way. The 2023 Lahaina fire in Hawai'i, for example, destroyed more than 2,200 homes and killed nearly 100 people — a far graver outcome than losing observing time.

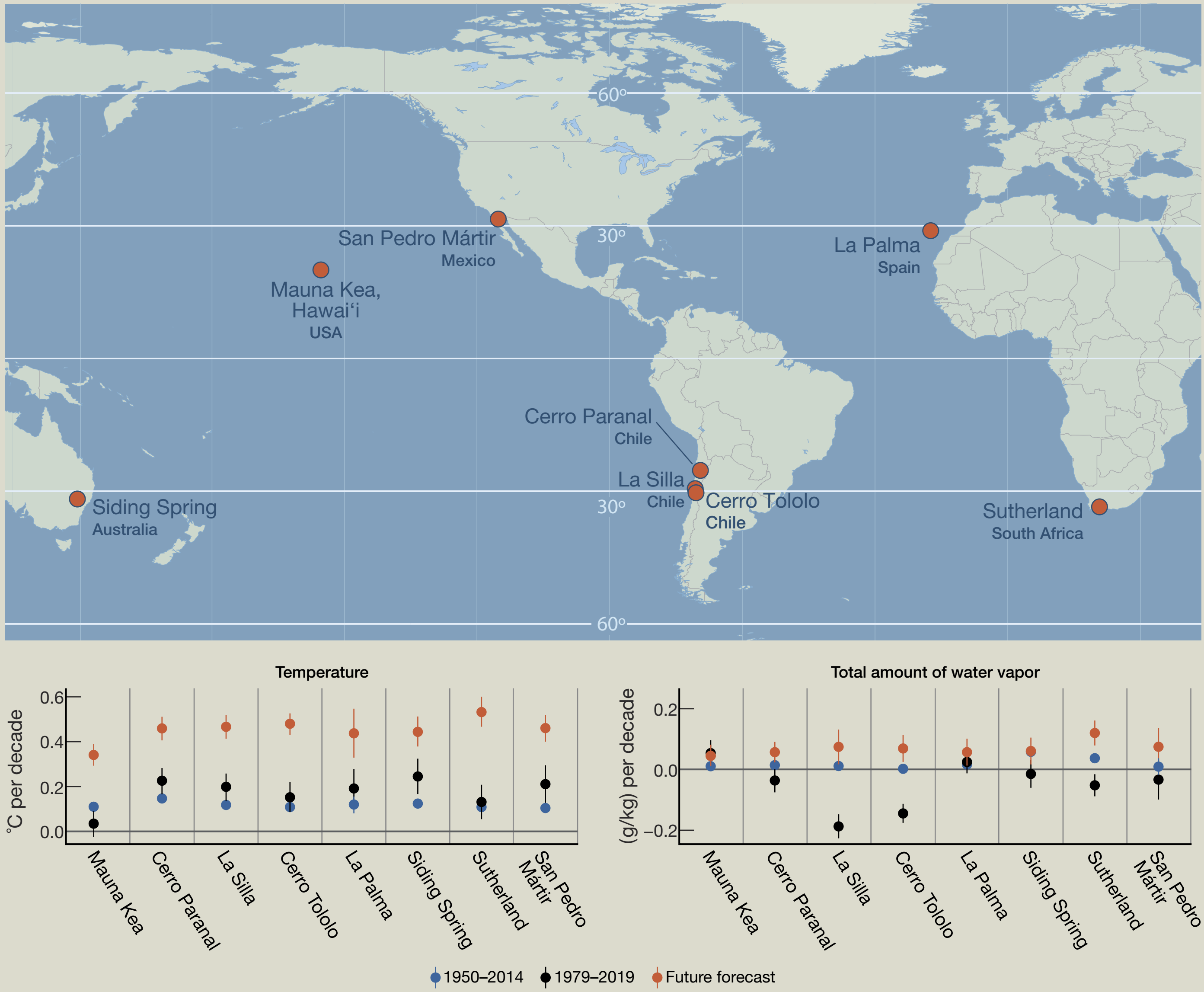
The broader societal impacts of climate change, including economic instability and resource scarcity, can also indirectly affect astronomical research through funding cuts and reduced public support. "I would say those are the things that astronomers might feel first," Graham says.

Some are already noticing. Van Kooten says that since the pandemic, fewer astronomers are traveling to observatories to observe, relying even more on local telescope operators instead. This trend may be reinforced as individuals avoid airplane travel due to concerns about its environmental impact. Institutions and governments might eventually discourage travel. This push to stay home could lead to the loss of hands-on experience for astronomers, particularly younger generations, hindering their understanding of telescope systems and overall development. "I've just met people who have chosen not to fly to observe, and that's already [one way] climate change is affecting astronomers right now," van Kooten says.

Skywatchers worldwide are also losing opportunities to enjoy their hobby. "Smoke makes it impossible to get good deep-sky images," says *S&T* Contributing Editor Alan Dyer, an astrophotographer based in southern Alberta, Canada. He has canceled several observing trips due to smoke and fire risks.

Astronomical organizations and institutions need to proactively address the evolving climate to narrow the uncertainty, mitigate risks, and ensure the future of their operations, Graham says. "Not nearly enough work has been done in this particular area."

HADLEY CELLS: BEATRIZ INGLESSIS / *S&T*



▲ **ON THE RISE** Astronomers looked at the change in temperature, water vapor, and other variables for eight observatories, using multiple simulations based on historical weather data. These simulations cover the periods 1950–2014 (blue data points) and 1979–2019 (black points). Then, using high-resolution global climate models, the researchers predicted what might happen in the future (orange points). Of the variables studied, only temperature and the total amount of water vapor in the air were reliable when compared with real data. Those results indicate that temperatures have risen about 0.1°C per decade in the last few decades and will rise by 0.3°C to 0.6°C per decade between now and 2050. The atmosphere's water vapor content will likely rise slightly, too.

CHARTS: ADAPTED FROM C. HASLEBACHER ET AL. / *ASTRONOMY & ASTROPHYSICS* 2022; MAP: BEATRIZ INGLESSIS / S&T, SOURCE: C. HASLEBACHER ET AL. / *ASTRONOMY & ASTROPHYSICS* 2022

Enhancing weather-monitoring infrastructure is a crucial first step, followed by continuous monitoring of key parameters and the impact of atmospheric conditions on instrument performance. Analyzing the weather data from Mauna Kea "showed me that while I thought there was lots of good-quality data available, it wasn't as great as I thought," van Kooten says.

Otárola says that astronomers should be vigilant when it comes to improving site characterization and developing better technology to overcome turbulence, since this is one of the factors that could limit the effectiveness of many large projects already under way, such as the European Extremely Large Telescope or the Vera Rubin Observatory.

Cantalloube, however, warns that while technology is certainly improving, it's the activity itself — the act of doing astronomy — that could be at risk. "The window to the sky might be slowly closing, that's my feeling."

According to Graham, the main risk is the unknown. The climate will continue to change as global warming worsens. What we know and understand is giving way to a new reality. "It's happening now," Graham says. "It started yesterday."

■ Contributing Editor **JAVIER BARBUZANO** is a freelance journalist specializing in astronomy and geoscience — and, sometimes, the way the two fields overlap.

NEBULA DEEP-DIVE by Howard Banich

Launch a detailed exploration of one of the best-known emission nebulae.

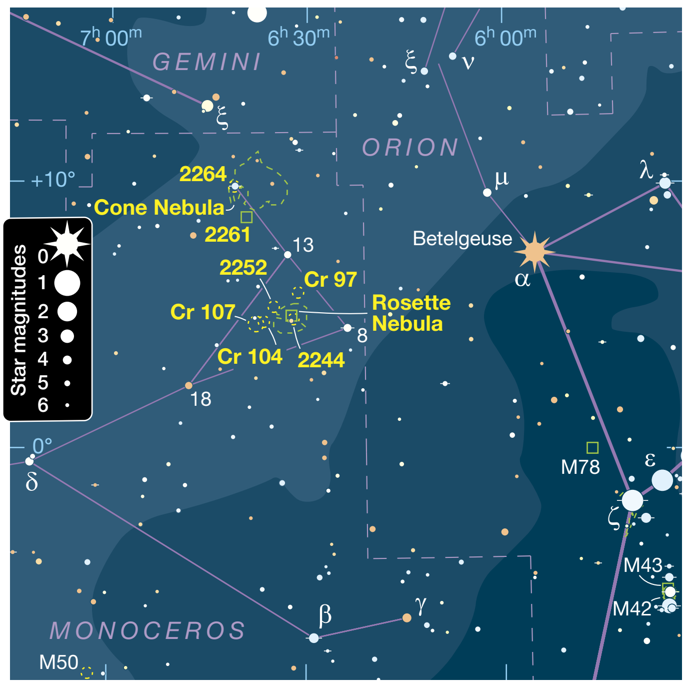
The autumn and winter of 2023–24 had been cold, cloudy, and wet, and the long-range forecast called for more of the same. Ugh. When a sparkling two-night clearing came along in March, I jumped at the chance to drive to one of the best observing sites in southeastern Oregon, Chickahominy Reservoir. I'd been waiting for an opportunity to observe and sketch the **Rosette Nebula** all winter, and this was it.

I packed up my 8-inch f/3.3 and 30-inch f/2.73 Dobsonians even though this clear stretch was just two days before the first-quarter Moon. Experience suggested the skies would be dark enough, so I went for it. Good thing I did, because in the season's final observing window in April I was washed out.

Like many who observe deep-sky objects, I sometimes treat the Moon like kryptonite. But from an otherwise dark site, sky conditions can still be quite favorable so long as the Moon is less than full — and that proved to be true on this trip. The first night I got Sky Quality Meter (SQM) readings around 21.35, which is pretty good! The second night the SQM readings started at 20.95 and the sky gradually became darker as the not-quite-first-quarter Moon sunk closer to the horizon.

Right after moonset on the second night — an absolutely stunning sight over the reservoir — the SQM readings improved to 21.68. The effect was like turning off a light,

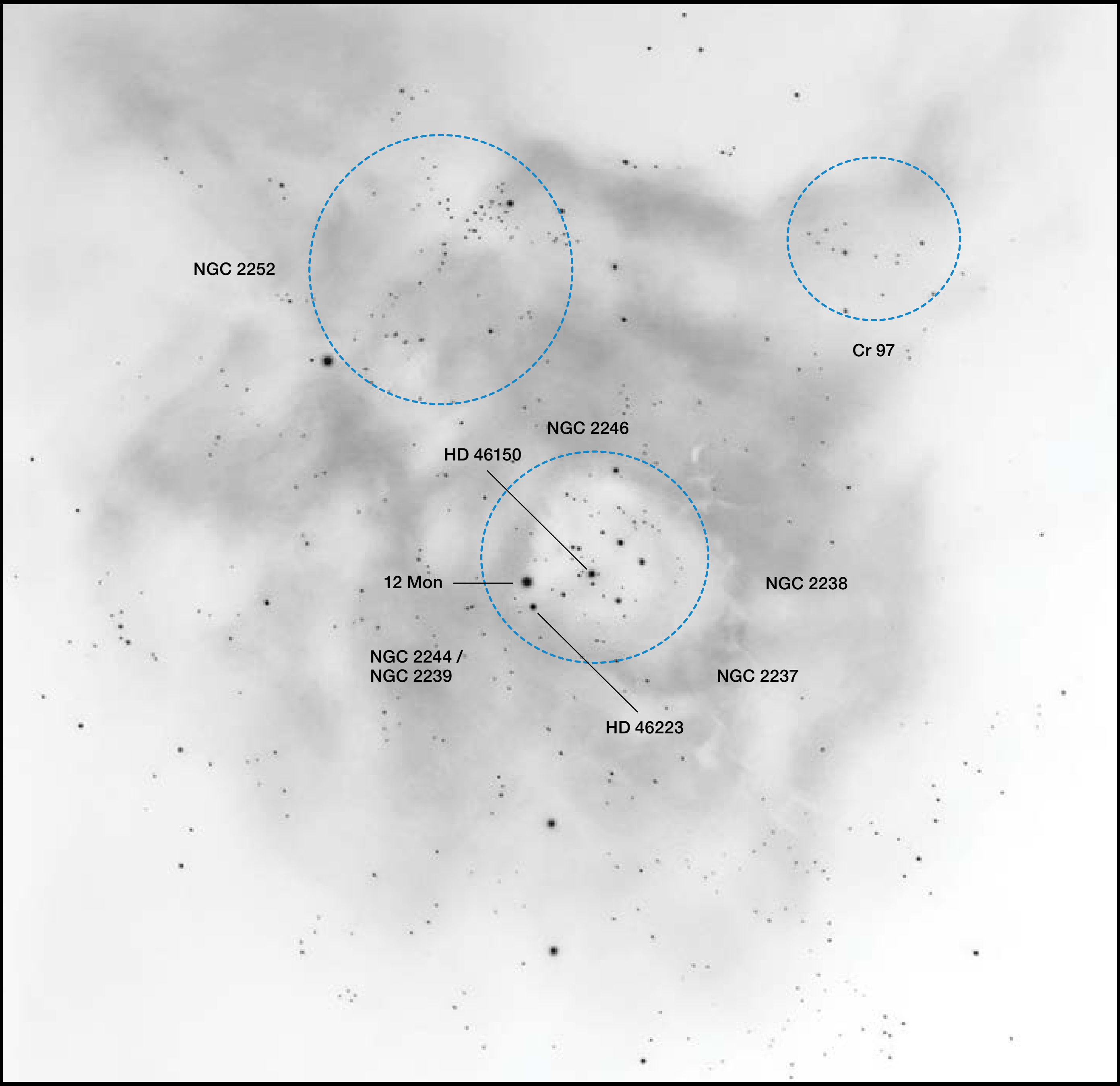
▼ **IN MONOCEROS** The Rosette Nebula is in the celestial Unicorn just east of Orion. It's particularly easy to find by star-hopping in a dark sky as it's located nearly dead-center of the triangle formed by the 4th-magnitude stars 8, 13, and 18 Monocerotis. Under brighter conditions, you may need to resort to other methods, such as Go To.



CELESTIAL ROSE The Rosette Nebula and its central star cluster, NGC 2244, show the beginnings of a surprise, explained in the text. North is upper left, as is the surprise.

ANTOINE AND DALIA GRELIN

A Rosette By Any Other Name



SKETCH AS FINDER My finished pencil sketch is labeled with all the objects within or near the Rosette that are mentioned in the text. I hope you find it useful as a finder chart! North is upper right.

and the sky probably continued to darken until the onset of dawn a couple of hours later, but I was too tired to find out. That moonset alone was worth the trip, and my observations of the Rosette felt like icing on the cake.

A Piecemeal Rosette

Like many of the better-known nebulae, the Rosette is a star-forming H II region. It contains a delightful 2- to 3-million-year-old open star cluster with the designation **NGC 2244**. British astronomer John Flamsteed first noted it in 1690. John Herschel observed what was later cataloged as NGC 2239 in 1830, but this is now considered a duplicate listing of NGC 2244.

Astronomers unveiled the Rosette in several phases. The prolific comet hunter Lewis Swift discovered **NGC 2237**, one of the nebula's brightest segments, in 1865 with a 4.5-inch

ALL SKETCHES BY HOWARD BANICH

refractor. John Dreyer remarked in his original *NGC* catalog (published in 1888) that this may be a rediscovery of **NGC 2238**, which German astronomer Albert Marth found a year earlier using William Lassell's 48-inch reflector on the island of Malta. In 1886, Swift reobserved the Rosette and noted another section of the nebula, which is now designated **NGC 2246**.

Curiously, neither William nor John Herschel noted any of the Rosette's nebulosity. Perhaps the small field of view of their instruments combined with the brightness of NGC 2244 washed out the subtle glow of the 1.3°-wide Rosette Nebula.

The multiple NGC numbers for the nebula's brightest segments have sometimes caused confusion about the designation of the entire object. (In fact, *Sky & Telescope*'s *Pocket Sky Atlas* lists it as NGC 2237-8/46.) As it doesn't have an overall NGC number, some astronomers simplify by referring to it using its Sharpless designation, Sh 2-275.

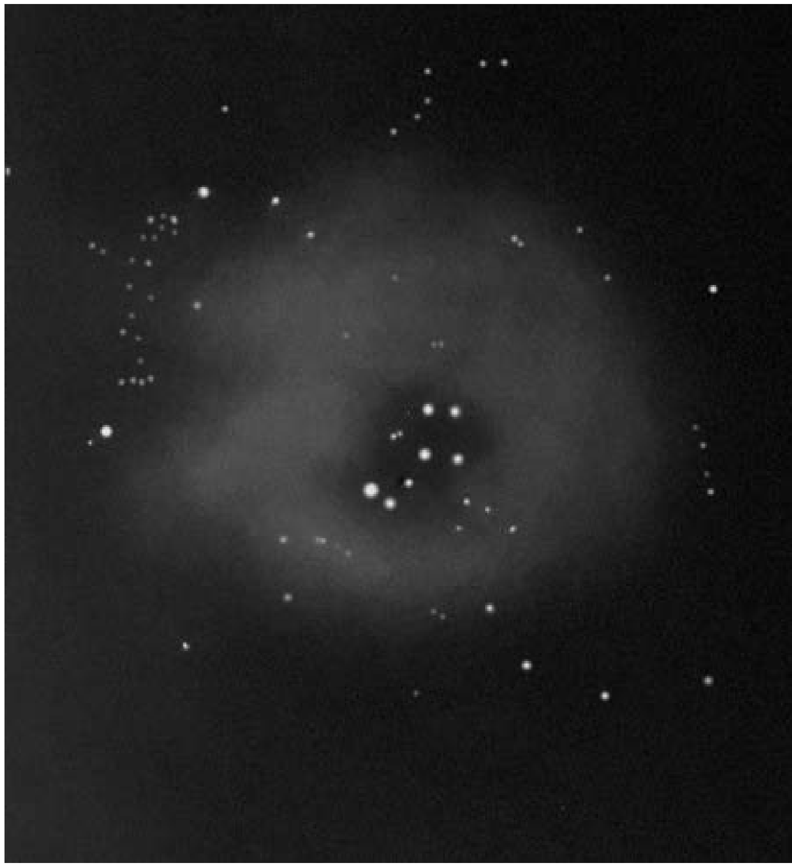
There are four open clusters near the nebula: **Collinder 97**, **Cr 104**, **Cr 107**, and **NGC 2252**. To my eye only NGC 2252 — and possibly Cr 97 — stand out well enough to resemble clusters, with the others blending into the starry field of view.

Different methods for measuring the distance to the Rosette place it anywhere from 4,200 to 5,100 light-years away, which means its apparent diameter translates to 95–115 light-years. It's superimposed on the southern edge of the Monoceros Loop supernova remnant, G205.5+0.5, and recent measurements disagree as to whether G205.5+0.5 and the Rosette are at the same distance. Depending on which study you find more plausible, the two objects may or may not be interacting.

Nevertheless, the European Space Agency's Gaia mission's parallax measurements of the NGC 2244 cluster stars place them at 5,053 light-years, which greatly supports a distance of 5,100 light-years for the nebula. The powerful nature of the O-type stars in NGC 2244 (as the illuminating source) argues even more strongly for the cluster and nebula to be at the same distance. Even so, an article published in the *Monthly Notices of the Royal Astronomical Society* in 2022 discussed the possible distance discrepancy as real, putting the cluster hundreds of light-years behind the nebula! (If nothing else, this corroborates how notoriously difficult it is to pin down astronomical distances — see, e.g., *S&T:* Oct. 2022, p. 12.)

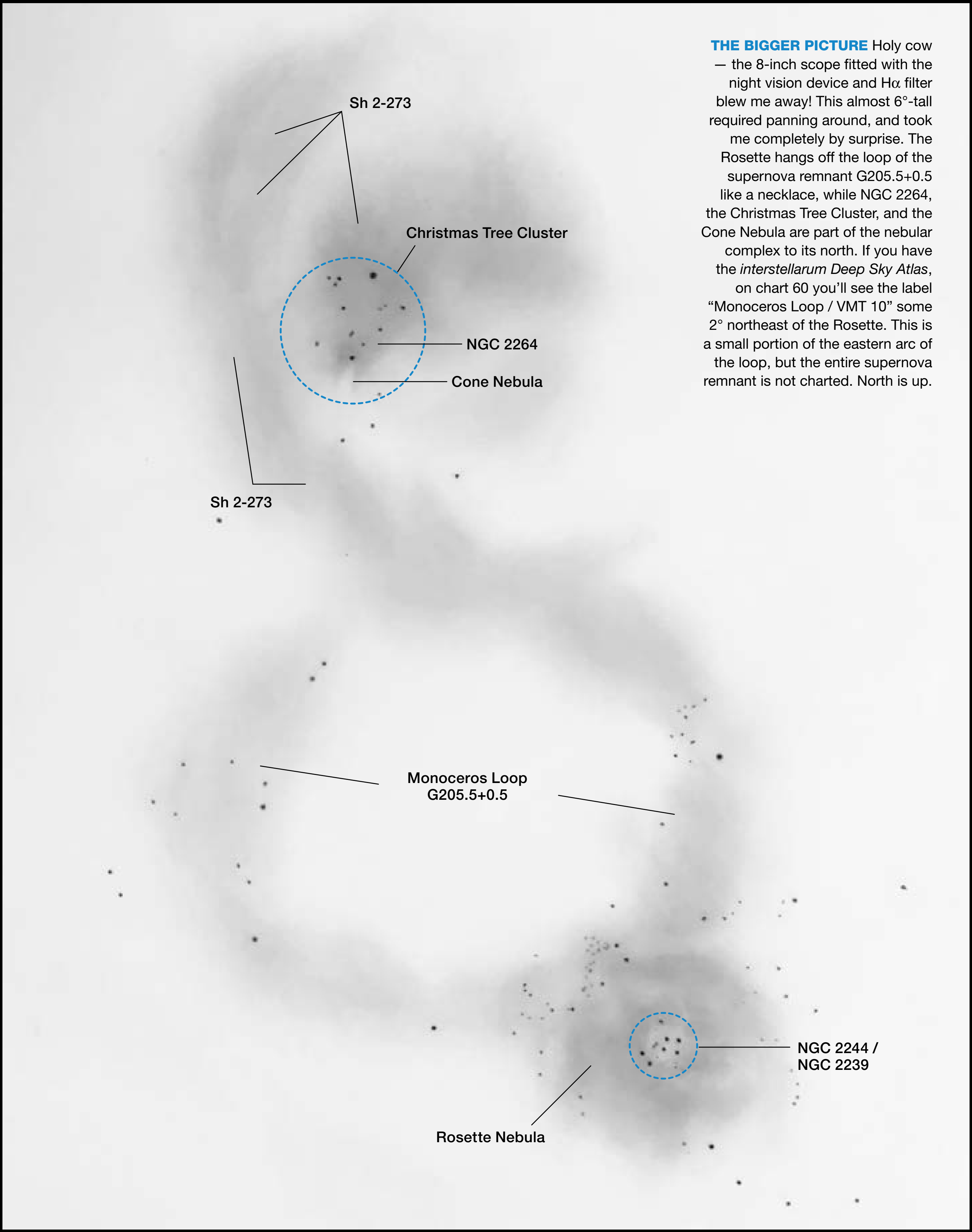
Night One: O III Observations

I used filters for all my observations of the Rosette — namely, an O III and a hydrogen-alpha (Hα) filter (more on the latter



▶ **FIRST DIP** *Top:* I started the night's observing by pointing my 8-inch scope fitted with an O III filter at the Rosette Nebula and NGC 2244. I saw the open cluster NGC 2252 as more subtle than I've drawn here. Also note the dipper shape of NGC 2244 — it even has a hook at the end of its short handle. North is up.

▶ **GOING DEEPER** *Bottom:* This sketch shows what the Rosette looked like through my 30-inch with an O III filter. Notice the increased detail within the nebula and additional stars, especially NGC 2252 at upper left — overall, a memorable view!



THE BIGGER PICTURE Holy cow — the 8-inch scope fitted with the night vision device and Hα filter blew me away! This almost 6°-tall required panning around, and took me completely by surprise. The Rosette hangs off the loop of the supernova remnant G205.5+0.5 like a necklace, while NGC 2264, the Christmas Tree Cluster, and the Cone Nebula are part of the nebular complex to its north. If you have the *interstellarum Deep Sky Atlas*, on chart 60 you'll see the label "Monoceros Loop / VMT 10" some 2° northeast of the Rosette. This is a small portion of the eastern arc of the loop, but the entire supernova remnant is not charted. North is up.

later). Without them, the nebula was too faint to be more than a subtle stain in the eyepiece. It would take an exceptionally transparent night to see much beyond the Rosette's overall shape and the bright cluster at its center.

The O III filter greatly improved the visual contrast of the nebulosity in both my 8-inch and 30-inch scopes. The filter helped more than I expected, especially in the 8-inch.

I sketched the nebula and star cluster with the 30-inch and then the 8-inch in quick succession. Because this was mid-March, I only had about four hours before the Rosette sank too low in the west to view. Nonetheless, I was able to see some impressive detail and take the time to admire the beauty of this striking object.

Checking the star chart on page 20, you'll see that the Rosette is only about 5° south of **NGC 2261** (Hubble's Variable Nebula) and **NGC 2264** that comprises the Christmas Tree Cluster and the elusive Cone Nebula. This is a busy and beautiful part of the sky.

NGC 2244 is a distinctive open star cluster, which I easily saw with my 80-mm finderscope. The apparently brightest star of the cluster is 5.8-magnitude **12 Monocerotis**, but it's a foreground star at only 1/10 the distance of the cluster. Two O-type stars, which *are* part of the cluster — 6.7-magnitude **HD 46150** and 7.3-magnitude **HD 46223** — are up to 50 to 60 times more massive than our Sun. Overall, there are seven O stars in NGC 2244, ranging from magnitude 6.7 to 8.2. They're the perfect kind of stars to energize the hydrogen gas of the nebula to glow, and which is why it makes sense that they'd be at the physical center of Rosette. The nebula's fluffy, circular shape with its central hole is quite beautiful, especially if you can get the whole object into the field of view of your telescope.

The NGC parts of the Rosette did not stand out in my 8-inch with the O III filter — instead, I saw a fairly even glow of its entire wreathlike shape. Not surprisingly, the view was significantly more detailed in the 30-inch. But wait! In addition to the targets I already mentioned, just off the northeastern edge of the Rosette is the final NGC object in the area, the open cluster NGC 2252. It's elongated, and subtly follows the curve of the Rosette. Easy to overlook in the 8-inch, it stood out quite well in the big scope.

To me, one of the wonderful aspects of observing the Rosette was enjoying the beautiful balance of nebulosity and stars. They had a similar visual weight, which I appreciated more the longer I observed. As I sketched, I saw more stars and more detail within the Rosette. After just a few hours though, I had to stop because I was pooped from the five-hour drive to the observing site. So, I hit the sack in my van.

Encouragingly, the sky looked even more transparent the next day, and I was ready for some Rosette Hα action.

Night Two: Hydrogen-alpha Observations

At this point, you might be asking yourself: "Hydrogen alpha? For a faint nebula like the Rosette?" Aren't Hα filters used for observing the Sun or by astrophotographers acquiring multi-hour exposures? Yes, but not exclusively. Coupled with a night-vision device, such a filter opens up the sky at this very interesting wavelength. I think of it as using an electronically assisted filter, so even though this is *not* visual observing in the conventional sense, the intensified image is presented in real time.

The way a night-vision device works is to attach it to the top of an eyepiece afocally with an adaptor, with the filter on the other end of the eyepiece. The night vision device has a small viewing screen that looks like a built-in eyepiece, and this is where you see the image.

I have a TNV/PVS-14, which is currently one of the more popular night vision devices (for a review see *S&T:* June 2018, p. 58). The PVS-14 has a spectral range of approximately 580 to 900 nanometers, which spans the spectrum from yellow to the near-infrared. Given that Hα's wavelength is 656 nm, it's well within the PVS-14's range, making it a great match with an Hα filter.

As for the Rosette, the PVS-14 + Hα filter combination completely transformed what I could see — the view was like looking at a detailed, grayscale photo. The enhancement was similarly strong in both scopes, and I devoted most of my second night to observing the Rosette in Hα.

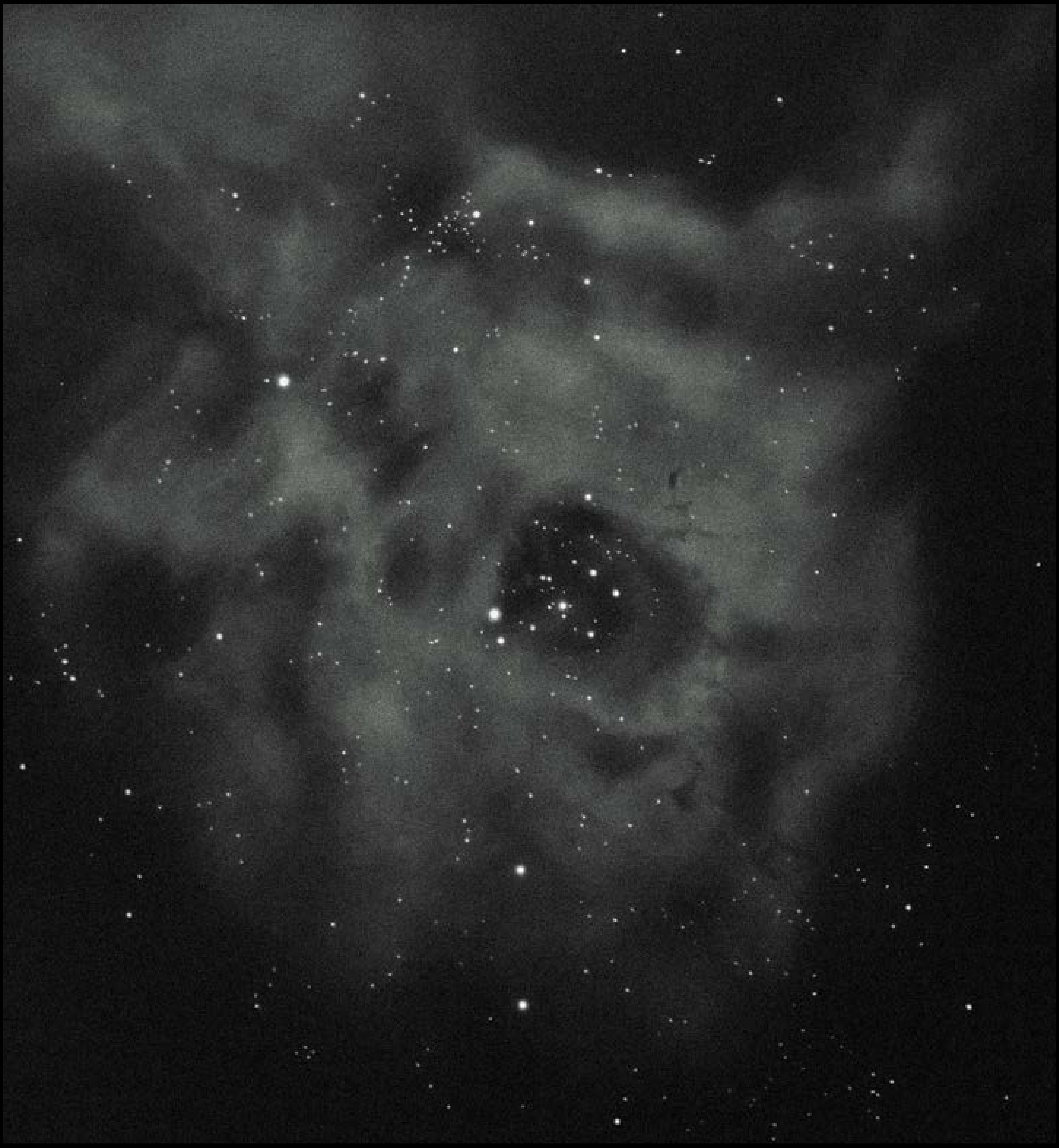
How Image Intensification Works

You might be wondering how the image-intensifier technology inside night-vision devices improves the view. As photons enters the instrument they're turned into electrons, undergo amplification ("electron avalanche"), accelerated through an electrical field, and then the electrons hit a phosphor screen, where they're converted into visible-light photons. Depending on the device, the amplification may be on the order of 30,000 to 60,000 times!

Generally, night vision devices produce a bright green image. However, you can purchase the PVS-14 with a "filmless white phosphor tube," which renders a nearly color-free grayscale image. It's still very slightly green though, which shows up much more in images taken through the units afocally than what is seen in the device's viewscreen.

Also, night vision devices have a "gain" adjustment to fine-tune the image to produce the most pleasing result with the least amount of electronic noise.

Their main drawback is cost — and availability (this technology cannot be exported from the U.S.). Night-vision devices will typically set you back several thousand U.S. dollars, plus a few hundred for an hydrogen-alpha filter, which limits their wider use. However, resistance to opening your wallet probably depends on how you're introduced to night vision astronomy. In my case, it practically made my head explode.



GLORIOUS VISION I sketched the Rosette Nebula in all its Hα glory as I saw it through my 30-inch scope. I wasn't exaggerating that the amount of detail is phenomenal and is way beyond what's possible to see with an O III filter. Because of limited observing time, I sketched the main nebulous areas at the "eyepiece" of the night vision device, and then referred to a photo taken with a 12-inch scope equipped with a PVS-14 + Hα filter to add the details — all of which I'd detected in my 30-inch. Among many other things, you can see the southern part of the G205.5+0.5 loop at the top (north and northeast) of the Rosette. For me, the best part is the fine detail of the dark nebulae zig-zagging along the western side of the central opening — wow! North is upper right.

A Splendid Surprise

I started with the 8-inch, which produced a view that was brighter overall and showed more detail than the 30-inch did the night before with just the O III filter. Before I started sketching this marvelous sight, I slowly panned around to see if there were any outer wisps I could see. And sure enough, there were some off the northern quadrant of the Rosette Nebula.

It quickly became apparent that these wisps were part of an arc of nebulosity curving northward, and I soon found myself admiring NGC 2264, and I could plainly see the Cone Nebula at its southern tip. Wow! On the other hand, I could not make out Hubble's Variable Nebula, probably because it doesn't produce enough Hα emission. I also saw the **Christmas Tree Cluster** well, and there was a less defined field of nebulosity west of NGC 2264.

When I returned home, I wondered if I'd missed anything in my eagerness to start sketching the Rosette in Hα with the 30-inch. I searched online for Hα images to see what else may have been in the area, and I found that I'd overlooked a fainter arc of nebulosity that flows from the northeastern edge of the Rosette, forming a huge circular feature with the first arc I'd seen. The second arc doesn't quite make it to NGC 2264, and, to my amazement, both arcs form the Monoceros Loop supernova remnant I mentioned earlier. I just had to try and see this second arc, but cloudy weather at all my favorite observing sites in central and eastern Oregon conspired to keep me home in April.

Fortunately, much like in Hα astrophotography, Hα observing works nearly as well under light-polluted conditions as it does under a dark sky. Two weeks after returning home the clouds parted for a few hours, and I set up my 8-inch in the backyard. I now saw the nearly full circle of the Monoceros Loop supernova remnant, with the Rosette hanging off the southwestern end, and NGC 2264 and the other clusters perched above the northern end! Wow, wow, wow! I added this arc to my earlier sketch.

The Hα sketch I made of the Rosette with my 30-inch became a challenge because of the incredible density of detail I saw in the "eyepiece" of the night vision device and my now-limited time to draw it. I would have needed many more hours to do the Hα Rosette justice with my 30-inch instead of the two hours I had left. (See the caption for the 30-inch hydrogen-alpha sketch on page 26 for my workaround.)

I've found a similar abundance of detail in the Hα structure in many of the nebulae I've observed, and the amazing ability of a night vision device to so clearly show previously invisible structure is something I'll never get tired of. Technology that works this well, and with so little fuss, is a rare and wonderful thing.

■ As powerful as night vision devices and Hα filters are together, Contributing Editor **HOWARD BANICH** is still a visual observer 95% of the time. That seems to be gradually changing, though.

RECOMMENDED To get an idea of what the Hα sky looks like without buying anything, visit the MDW Hydrogen-Alpha Sky Survey website at **mdwskysurvey.org**. This all-sky survey is the brainchild of the late David Mittleman, along with *Sky & Telescope* Associate Editor Sean Walker and Senior Contributing Editor Dennis di Cicco.

In and Around the Rosette Nebula

Object	Type	Mag(v)	Size	RA	Dec.
NGC 2244	Open cluster	4.8	24′	$06^h 32.3^m$	+04° 51′
NGC 2237	Emission nebula	—	80′ × 50′	$06^h 30.9^m$	+05° 03′
NGC 2238	Emission nebula	—	80′ × 60′	$06^h 30.7^m$	+05° 01′
NGC 2246	Emission nebula	—	—	$06^h 32.6^m$	+05° 08′
Collinder 97	Open cluster	5.4	25′	$06^h 31.0^m$	+05° 50′
Collinder 104	Open cluster	9.6	20′	$06^h 36.5^m$	+04° 50′
Collinder 107	Open cluster	5.1	30′	$06^h 37.7^m$	+04° 45′
NGC 2252	Open cluster	—	—	$06^h 34.3^m$	+05° 19′
NGC 2261	Emission nebula	—	3′	$06^h 39.2^m$	+08° 45′
NGC 2264	Emission nebula	4.1	40′	$06^h 41.0^m$	+09° 54′
12 Monocerotis	Variable star	5.8	—	$06^h 32.3^m$	+04° 51′
HD 46150	Young stellar object	6.7	—	$06^h 31.9^m$	+04° 57′
HD 46223	Young stellar object	7.3	—	$06^h 32.2^m$	+04° 49′

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

Bart and Priscilla Bok: *A Galactic Love Story*

Two astronomers shared a connection with the stars that was both personal and professional.

Late last summer, while getting ready for a night of observing from my backyard patio in Flagstaff, Arizona, I heard a voice asking, "Is that a telescope?" I had caught the attention of two ladies on an evening stroll. "Yes," I replied, "do you have one too?" "No," the elder lady said, "but my father was a famous astronomer." To my surprise and delight, one of my visitors was Joyce Bok Ambruster, the daughter of Bart Bok and Priscilla Bok! It turns out that she, along with the Boks' granddaughter, Jeanne Bok Ambruster, and their great-granddaughter, Jane Fairfield Becher, also live in town. The stars must have been favorably aligned that warm summer night, as it marked the 40th anniversary of Bart's passing on August 5, 1983. Clearly my encounter with his family was predestined. I arranged to interview them so that I could write this article about their famed relatives.

At Home in the Milky Way

Most readers of this magazine are familiar with the Boks. Few 20th-century astronomers contributed as much to unraveling the mysteries of the Milky Way than Bartholomeus Jan "Bart" Bok and Priscilla Bok. The couple focused on the Milky Way's origin, evolution, and composition. In doing so they followed in the footsteps of William Herschel, who first attempted to map and model the galaxy visually in 1785, and E. E. Barnard and Max Wolf, who pioneered wide-field Milky Way photography at the turn of the 20th century. As the couple wrote in the opening pages of their immensely popular book, *The Milky Way*, ". . . we invite you to join us on a brief tour along the road to the heaven of the Greeks. Modern science has provided the transportation facilities and, without its being necessary for you to leave your comfortable chair, we would like to show you the sights."

Little did they realize when their book first appeared in 1941 that the tour they described was only the beginning of a remarkable journey that would change our understanding not just of our home galaxy but of the realm of galaxies beyond. Exactly 40 years later, Bart Bok, now a widower, poignantly dedicated the fifth and final edition of *The Milky Way* this way: "To Priscilla with my love. This is the first time I have revised the book without her. . . ."

Bart Bok, along with Gerard Kuiper, Jan Oort, and Pieter Oosterhoff, were among a cohort of distinguished Dutch-born scientists who contributed to virtually every aspect of observational astronomy in the early 20th century. Bok globules, the Kuiper Belt, and the Oort Cloud are testaments to the recognition these astronomers eventually attained. Bok and Kuiper later became U.S. citizens and joined the University of Arizona, where Kuiper headed the newly established Lunar and Planetary Laboratory, and Bok led the university's Department of Astronomy and became director of its Steward Observatory.

▲ **MAGNIFICENT GALAXY** This view of our home galaxy conveys some of the grandeur that inspired Bart and Priscilla Bok to write *The Milky Way*, one of the most popular books on astronomy in the 1940s and '50s.

▶ **DYNAMIC DUO** Bart and Priscilla Bok are portrayed in this undated family photo. When the two met in 1928, Priscilla was already an established astronomer while Bart was still a graduate student at the University of Groningen in the Netherlands.

MILKY WAY: ALAN DYER; BART AND PRISCILLA BOK: BEATRIZ INGLESSIS BASED ON A PHOTO BY JEANNE BOK AMBRUSTER

SOUTHERN SPLENDOR The magnificent Eta Carinae Nebula (NGC 3372) in all its complexity as imaged by the author. The object is located in the Carina-Sagittarius Arm of the Milky Way and had a special significance for Bart and Priscilla Bok.

KLAUS BRASCH

Bart Bok's love affair with the Milky Way began when he was a 12-year-old Boy Scout in the Netherlands, standing guard at night over his troop of sleeping campers. Even as a child the majestic sight overhead left a lasting impression. In 1928 he was smitten a second time while attending the International Astronomical Union (IAU) General Assembly in Leiden, the Netherlands, where he met American astronomer Priscilla Fairfield. Although 10 years Priscilla's junior (and having known her for just a week), Bart proposed marriage in a romantic setting — a bench in the Saint Germain-en-Laye Gardens, near Paris, France. She accepted but insisted on a year's wait. After surviving their long-distance relationship, the couple were married in 1929 when Bok moved to Cambridge, Massachusetts, to work with Harlow Shapley at Harvard College Observatory, the nation's preeminent center of astrophysics at the time and a vanguard training institution for many prominent women astronomers. The newlyweds quickly became close collaborators.

In 1932, Bart completed his doctoral dissertation on the Eta Carinae Nebula, one of the largest and most active star-forming regions in the Milky Way. Lying some 7,500 light-years from us in the southern constellation of Carina, French astronomer Nicolas-Louis de Lacaille first observed the nebula in 1752 during a star-mapping expedition to the Cape of Good Hope in South Africa. The huge gaseous cloud of mostly ionized hydrogen (H II) with traces of carbon oxides, helium, and silicate dust, houses many massive young suns, including Eta Carinae — a star with 50 to 100 solar masses. Intense ultraviolet radiation from these newborn stars ionizes the surrounding gas, causing it to glow, while stellar winds disperse the material, creating the dust nodules from which new star systems form. These dark nodules were first observed in the 1940s by Bart Bok, which he and colleague Edith F. Reilly in 1947 likened to insect cocoons. Modern observations in near-infrared and millimeter wavelengths have confirmed that these "Bok globules" are undergoing gravitational collapse and accreting into protostars.

Eta Carinae was a favorite object of study for both Boks in their efforts to find evidence of spiral structure in the Milky Way. Indeed, Bart and Priscilla were so taken with the sheer splendor of the nebula that after Priscilla's death he quipped that when he "popped off" he would join her there so they could spend eternity together in their favorite nebula. In the words of daughter Joyce and granddaughter Jeanne, Bart and Priscilla's love for each other, their family, and astronomy were inseparable.

Stars Down Under

After a nearly 30-year stint at Harvard, the Boks relocated to Australia from 1957 to 1966, where Bart served as director of Mount Stromlo Observatory near Canberra, the sole major astronomical facility in the country at the time. Priscilla continued stellar research there, and, with Bart, taught at the Australian National University where they helped recruit new, young astronomers, who were sorely lacking in the country at the time.

▲ **BOK RELATIVITY** Bart and Priscilla Bok's granddaughter Jeanne (left) and daughter Joyce, in a recent photo taken at their home in Flagstaff, Arizona. A chance encounter with the author in 2023 led to a friendship and, ultimately, this article.

It soon became clear to the Boks that by the 1960s Mount Stromlo was an antiquated facility increasingly hobbled by light pollution. Something better was needed to stay on the frontlines of astronomical research.

Fortunately, Bart and Priscilla were also extraordinary and persuasive advocates for the science of astronomy. It was through their talents that they were able to convince the Aus-

STROMLO FIELD STATION Stars trail behind the dome of the Anglo-Australian Telescope at Siding Spring Observatory. (A passerby carrying a red flashlight made the trail in the foreground.) While serving as director of Mount Stromlo Observatory, Bart Bok was instrumental in selecting the site and persuading the Australian government to fund the construction of this facility, which officially opened in 1964.

KLAUS BRASCH (2)

WINTER ROSE As one of the most prominent and closest star-forming regions to us, the Rosette Nebula, located in the winter constellation Monoceros (see page 20), displays prominent tracks of extended Bok globules: dark, opaque regions within which star formation begins.

KLAUS BRASCH

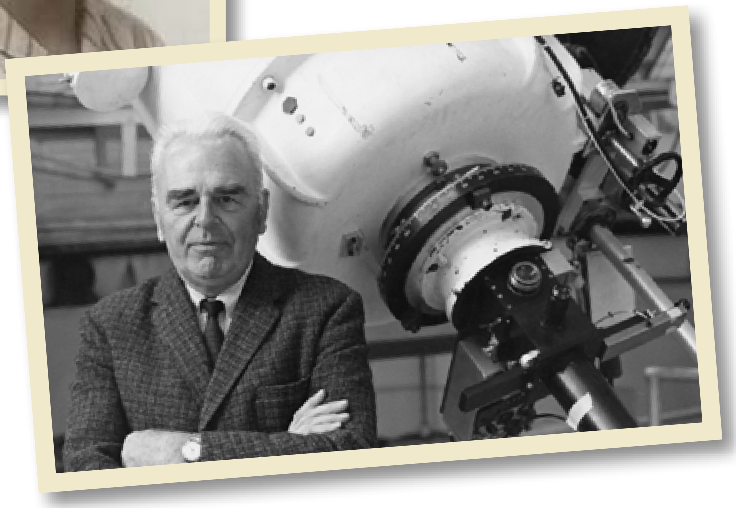
tralian government and Prime Minister Robert Menzies to fund a new state-of-the-art observatory at a superb location on Siding Spring Mountain in New South Wales. As Priscilla knew all too well, it was hard to say no to Bart! Indeed, she often said that his effervescent personality was best summarized by the phrase, "once met, never forgotten." In fact, it was Bart's enthusiasm for astronomy that led David H. Levy to good-naturedly title his 1993 Bok biography *The Man Who Sold the Milky Way.*

As a result of the Boks' efforts, Australia became a leading center for optical astronomy with the 3.9-meter Anglo-Australian Telescope (AAT) and the 48-inch (1.2-meter) United Kingdom Schmidt Telescope (UKST). The AAT is comparable to the 4-meter Nicholas U. Mayall Telescope at Kitt Peak

National Observatory near Tucson, Arizona, and the UKST to the 48-inch Schmidt at Palomar Mountain, California — all among the most important telescopes of their era.

In addition to optical astronomy, the Boks recognized radio astronomy's increasing importance, eventually securing funding from the American and Australian governments for construction of the Parkes Observatory radio telescope in New South Wales. Affectionately dubbed the Dish, the instrument played a major role in the Apollo 11 Moon landing. It also elevated the country to the forefront of astronomical research and served as a model for the 64-meter antennas of NASA's Deep Space Network. Today, the Dish continues to operate at the cutting edge of astronomical research as part of the Australia Telescope National Facility, a network of radio observatories.

◀ **FUTURE ASTRONOMER** This 1917 photo of a young Priscilla Fairfield shows her at age 21 while attending Boston University. Asteroid (2137) was named Priscilla in her honor following her death in 1975 at age 79.



▼ **STELLAR SALESMAN** Author David H. Levy entitled his 1993 biography of Bart Bok *The Man Who Sold the Milky Way* in recognition of Bok's effervescent personality and persuasive charms. He passed away in 1983 at age 77.

Arizona Bound

Upon their return to the United States in 1966 the Boks settled at the University of Arizona. Bart continued his drive for larger and more advanced astronomical facilities, including construction of the 2.1-meter (84-inch) telescope atop Kitt Peak, and for national organizations of professional astronomers. He also sold Arizona politicians, like his good friend Senator Barry Goldwater, on the value of investing in astronomy. His granddaughter, Jeanne, was visiting Tucson when it was announced that the University of Arizona had the top astronomy program in the country, ranked even ahead of Harvard's. Bart celebrated with a giant cannonball into his backyard pool!

Sadly, Priscilla's health declined sharply in 1972, and Bart had to curtail his work to care for her. The couple spent their final years entertaining family and friends and enjoying the oasis they had created together in the desert. As a Dutch boy and a New England girl, they never lost their love for green grass and spring flowers.

After Priscilla's passing in November 1975, "[Bart] became deeply depressed," says his daughter Joyce. Effectively retired, Bart was "at a loss as to what to do next." Priscilla had anticipated this possibility and given him permission to mope for just *one* year, after which she said she would spook him.

When the Year of Moping had passed, daughter Joyce and granddaughter Jeanne persuaded Bart to accept an invitation from a cruise line to lead a solar eclipse tour departing from Los Angeles. Unsure about the wisdom of taking on such a demanding role at the age of 70, he asked Jeanne to join him so that at least "someone could have fun." Alas, as a busy student, she had to stay behind. Soon, however, Jeanne received a photograph showing Bart having the time of his life partying with a bevy of young eclipse chasers. Clearly his winning personality had surfaced once again. Along with the photo, he included a short note: "So glad you didn't come along! You would have cramped my style."

In addition to becoming an avid eclipse chaser and popular tour guide, Bart also got involved in organizations dedicated to debunking pseudoscience and claims of the paranormal. He maintained a high level of activity to the very end. In a letter dated August 4, 1983, to the organizer of Northern Arizona University's program on "Human Strategies" to which he had been invited, Bart stated, "I would like to use my 10–15 minutes to talk about a variety of aspects of the contributions that astronomy has made and is continuing to make to our society, practical ones as well as moral and aesthetic ones. Astronomy is in a special position because we are not directly involved in preparation for war, but have great power in helping to achieve peace."

Bart Bok reached his own peace the following day, August 5, 1983, when he "popped off" with arms full of champagne and shrimp for a pool party he planned to throw that night at his Tucson home. Indeed, as his daughter Joyce noted, it was as if he had inadvertently planned his own celebration of life under the stars before making his way to Eta Carinae to be with his beloved Priscilla.

■ Retired bioscientist and lifelong amateur astronomer **KLAUS BRASCH** is co-editor (with William Sheehan) of *The Space Age Generation* (University of Arizona Press, 2024). He is greatly indebted to Joyce and Jeanne Bok Ambruster for their generous assistance in preparing this article.

PRISCILLA BOK: JEANNE BOK AMBRUSTER; BART BOK: AIP EMILIO SEGRÈ VISUAL ARCHIVES, GALLERY OF MEMBER SOCIETY PRESIDENTS

AUTUMN COMET by Sean Walker

BRILLIANT PLUNGE
Comet Tsuchinshan-ATLAS displayed a bright dust tail and a sinuous bluish ion tail on the morning of September 30, 2024.

GERALD RHEMANN / MICHAEL JÄGER

Tsuchinshan-ATLAS Shines

Comet C/2023 A3 put on a fine display for observers worldwide.

The year's most highly anticipated comet did not disappoint. That's the consensus among observers after Comet Tsuchinshan-ATLAS (C/2023 A3) blazed forth before and after perihelion this past September and October.

Tsuchinshan-ATLAS was first spotted as an 18.7-magnitude object at China's Purple Mountain Observatory (*Tsuchinshan*, according to transliteration) on January 9, 2023, and reported to the Minor Planet Center, though no follow-up observations were made by the observatory to confirm its position or identity. More than a month later, the Asteroid Terrestrial-impact Last Alert System (ATLAS) swept up an 18.1-magnitude object on February 22nd at the Sutherland Observatory in South Africa. Preliminary orbital calculations determined it was the previously reported object and therefore was named for both discovery observatories. A search of earlier images taken along the orbital path by other facilities yielded images taken with the Zwicky Transient Facility at Palomar Observatory in California, which showed the object. The deep exposures revealed its cometary nature. Orbital calculations determined it to be a non-periodic comet on its first trip to the inner solar system, resulting in the designation C/2023 A3.

Observers with large telescopes monitored the icy snowball as it crept ever closer to the Sun during 2023. Through August of 2024, the comet's brightness was trending upward, following predictions — and Tsuchinshan-ATLAS may have been even slightly brighter, according to some reports. At at the time, it sported a short dust tail and slightly longer ion tail.

▼ **MOONLIT ARCHES** The comet sported a 15° tail as seen from Arches National Park in Utah on the evening of October 14th despite the nearly full Moon brightening the early evening sky.

ALAN DYER

▲ **THREE TAILS** By early August, 2024, the comet achieved naked-eye brightness and sported a bifurcated tail and a greenish coma.

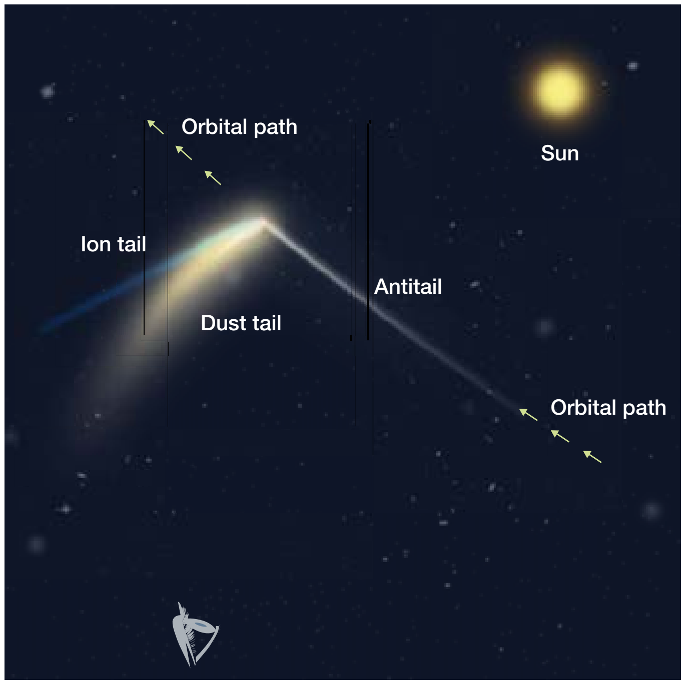
▲ **INNER HOODS** The view through large telescopes revealed dust spiraling out from the comet's pseudo-nucleus. Debra Ceravolo captured this remarkable shot using a Boller and Chivens 16-inch f/18 Cassegrain and a Canon EOS R6 mirrorless camera on October 17, 2024, from her observatory on Anarchist Mountain in British Columbia.

The Morning Display

By late September, Northern Hemisphere observers with unobstructed eastern horizons at dawn were treated to glimpses of the comet's brightening coma. The best views, however, were had by those located south of the equator, where, at perihelion on September 27th, the comet's long, thin dust tail stood straight up from the horizon spanning some 15° or so. Viewing geometry meant that the dust and ion tails overlapped, though impacts from the solar wind caused kinks in the ion tail on a few occasions (see an example on page 34). By the start of October, it was clear that the comet had survived its 58.6-million-kilometer (36-million-mile) encounter with the Sun. By this time Tsuchinshan-ATLAS had brightened to about 1st magnitude. It continued to brighten as it moved between Earth and the Sun but was briefly lost in the solar glare.

EARLY IMAGE: GERALD RHEMANN; COMET CLOSE-UP: DEBRA CERAVOLO

▲ **POINTED ANTITAIL** Following its transition from the morning to the evening sky, Comet Tsuchinshan-ATLAS exhibited a long, thin antitail appearing to point sunward. Longtime *Sky & Telescope* contributor Johnny Horne recorded this image on October 14th using a Celestron Rowe-Ackermann Schmidt Astrograph and ZWO ASI2600MC camera from Little Singletary Lake in White Oak, North Carolina.



▲ **A TRICK OF PERSPECTIVE** Comet Tsuchinshan-ATLAS sported a prominent antitail for more than a week after emerging into the evening sky. This needle-like feature appears to point toward the Sun and is made up of larger bits of dust deposited by the comet along its orbital path, as illustrated above. The antitail is typically visible around the time when Earth crosses the comet's orbital plane.

ANTITAIL: ALAN DYER; DIAGRAM: BEATRIZ INGLESSIS / S&T

On October 7th, the comet brightened further due to forward scattering, as recorded by the SOHO spacecraft's LASCO C3 coronagraph. Astronomers estimate the coma achieved an impressive magnitude −4.9, making it the brightest comet since Comet McNaught (C/2006 P1), which put on a fantastic display in early 2007. Some adventurous observers were able to image Tsuchinshan-ATLAS in broad daylight, though it was a challenge as it was so close to the Sun. As it transitioned from a morning to evening object on October 9th, its bright dust tail "flipped" as seen from Earth. The tail was so long that it took more than a week for the entire comet to pass through the SOHO spacecraft's LASCO C3 field. *Sky & Telescope* Contributing Editor Bob King noted, "The combination dust-and-anti-tail extended for at least 50°!"

The Main Event

Tsuchinshan-ATLAS made its closest approach to Earth on October 12th, when it slipped by at a distance of 70 million km. Within days, it slowly climbed higher above the horizon, displaying a bright, straight dust tail more than a dozen degrees long. The comet was easy to spot in evening twilight, with a long, thin antitail of dust trailing behind it. This feature was most pronounced on the 15th when Earth crossed the comet's orbital plane and remained visible for roughly a week despite the waxing Moon brightening the evening sky. I was easily able to spot the dust tail spanning some 6° on the night of the full Moon on the 17th.

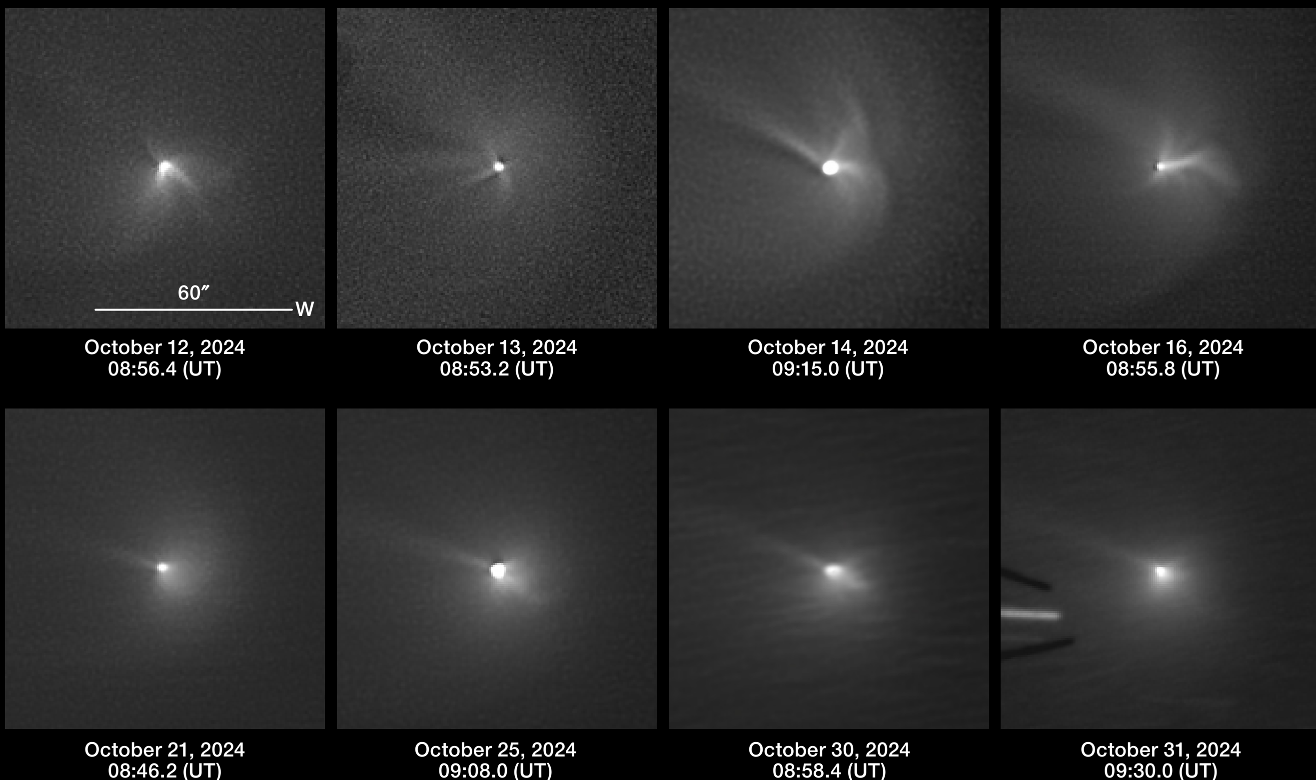
By October 20th, the Moon had departed the scene, allowing for a good look at the extended tail and slightly diminished antitail. Although the comet had dimmed to about 4th magnitude, its tail appeared about 10° long and displayed almost twice that length in photographs.

The comet faded by about a magnitude each night as it sped away and was lost to the naked eye from my moderately light-polluted backyard by October 25th, though remained an impressive object in binoculars and small telescopes.

Telescopically, the inner coma of Tsuchinshan-ATLAS displayed interesting details after perihelion. Due to its low altitude in the evening sky following closest approach, the false nucleus appeared slightly orange for several days. The view through mid-sized instruments with magnification of 100× or more revealed several "hoods" of material in the inner coma. Japanese imager Shinichi Watanabe recorded several jets in the inner coma throughout October using a Larson-Sekanina filter, which removes circular structures from an image to better highlight other details.

In early November the Moon returned to the evening sky, challenging the fading comet's visibility as it blended into the star fields of the Milky Way in Ophiuchus.

So, was Tsuchinshan-ATLAS a "great comet"? Although it



▲ **MULTIPLE JETS** Using a rotational gradient filter during processing, Japanese amateur Shinichi Watanabe captured multiple jets emanating from the comet over a nearly three-week period in October.

▲ **DUSTY SWATH** This four-panel mosaic captures the full extent of Tsuchinshan-ATLAS's tail on the evening of October 20th. Chris Schur recorded the images using a 135-mm f/2.4 lens paired with a ZWO ASI2600MC camera from Payson, Arizona.

WIOLETA M. GORECKA

AURORAL COMPETITION The aurora borealis adds a brilliant splash of color to this photograph of Tsuchinshan-ATLAS above the Black Sand Beach at Vík í Mýrdal, Iceland, on October 26th.

▶ **COMETARY TEARDROP** The long tail of Tsuchinshan-ATLAS appears above the beachfront of Soneva Fushi in the Maldives on the evening of October 20th.

▼ **HOLD STILL** Artist Deirdre Kelleghan drew this marvelous pastel of Tsuchinshan-ATLAS as it peeked above Atlantic clouds along the western coast of Ireland on October 16th.

achieved a peak magnitude about as bright as Venus, it did so when it was close to the Sun and hardest to observe. When it was well-placed for observers, it was about magnitude 1 or fainter — still impressive. That's brighter than NEOWISE (C/2020 F3) in 2020, but most comet aficionados agree Tsuchinshan-ATLAS wasn't a "great" comet (and some still debate that title being bestowed on NEOWISE). Still, it put on a wonderful display and for that we are thankful.

At press time, the Tsuchinshan-ATLAS show wasn't completely over, but by the time you receive this issue, the comet will be a fading telescopic object well on its way back to the outer solar system. Nevertheless, its brief display will be remembered for a long time.

■ Associate Editor **SEAN WALKER** has enjoyed observing comets since witnessing Halley's Comet with his mother 39 years ago.

COMET AND MILKY WAY: PETR HORÁLEK

SKY AT A GLANCE
March 2025

1 DUSK: Low in the west, the waxing crescent Moon hangs a bit more than 6° lower left of Venus. Mercury is below, closer to the horizon. Turn to page 46 for more on this and other events listed here.

5 EVENING: Look to the west to see the Moon, one day shy of first quarter, in Taurus forming a very shallow triangle with Jupiter and the Pleiades.

8 DUSK: High in the southeast, the waxing gibbous Moon is in Gemini with Mars a little more than 1° lower right, while Pollux shines 5° lower left of the pair. The sight becomes more dramatic as twilight deepens into night.

8 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:48 p.m. PST (see page 49).

9 DAYLIGHT-SAVING TIME starts at 2 a.m. for most of the U.S. and Canada.

11 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:37 p.m. EDT (8:37 p.m. PDT).

11–12 ALL NIGHT: The Moon, two days from full, and Leo's lucida, Regulus, arc across the sky in tandem. The distance between them shrinks from about 3½° when the pair is low in the east at dusk to around 1° when they set in west-northwest before dawn.

14 FULL MOON (2:55 A.M. EDT) A total lunar eclipse will be visible across the Americas, the Pacific Ocean, Oceania, western Europe, and the western half of Africa. Turn to page 48 for more details.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:26 p.m. EDT.

16 MORNING: Face south-southwest to see the waning gibbous Moon in Virgo about 4½° right of Spica.

20 SPRING BEGINS IN THE NORTHERN HEMISPHERE at the equinox, 5:01 a.m. EDT (2:01 a.m. PDT).

20 MORNING: The Moon, two days before last quarter, gleams in the south about 3° right of Antares, the red supergiant that marks the heart of the celestial Scorpion.

29 NEW MOON (6:58 A.M. EDT) A partial solar eclipse is visible across northeastern North America, Greenland, Iceland, most of Europe, and northwestern Russia. Turn to page 50 for details.

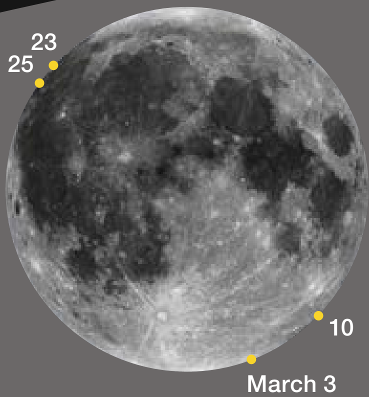
30 EVENING: In the west, Mars sits less than ½° lower right of Pollux, Gemini's brightest light.
—DIANA HANNIKAINEN

▲ The eclipsed Moon stands among the stars of Pisces on the evening of September 28, 2015. This month's lunar eclipse should look similar. SEAN WALKER

MARCH 2025 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

FIRST QUARTER
March 6
16:32 UT

FULL MOON
March 14
06:55 UT

LAST QUARTER
March 22
11:29 UT

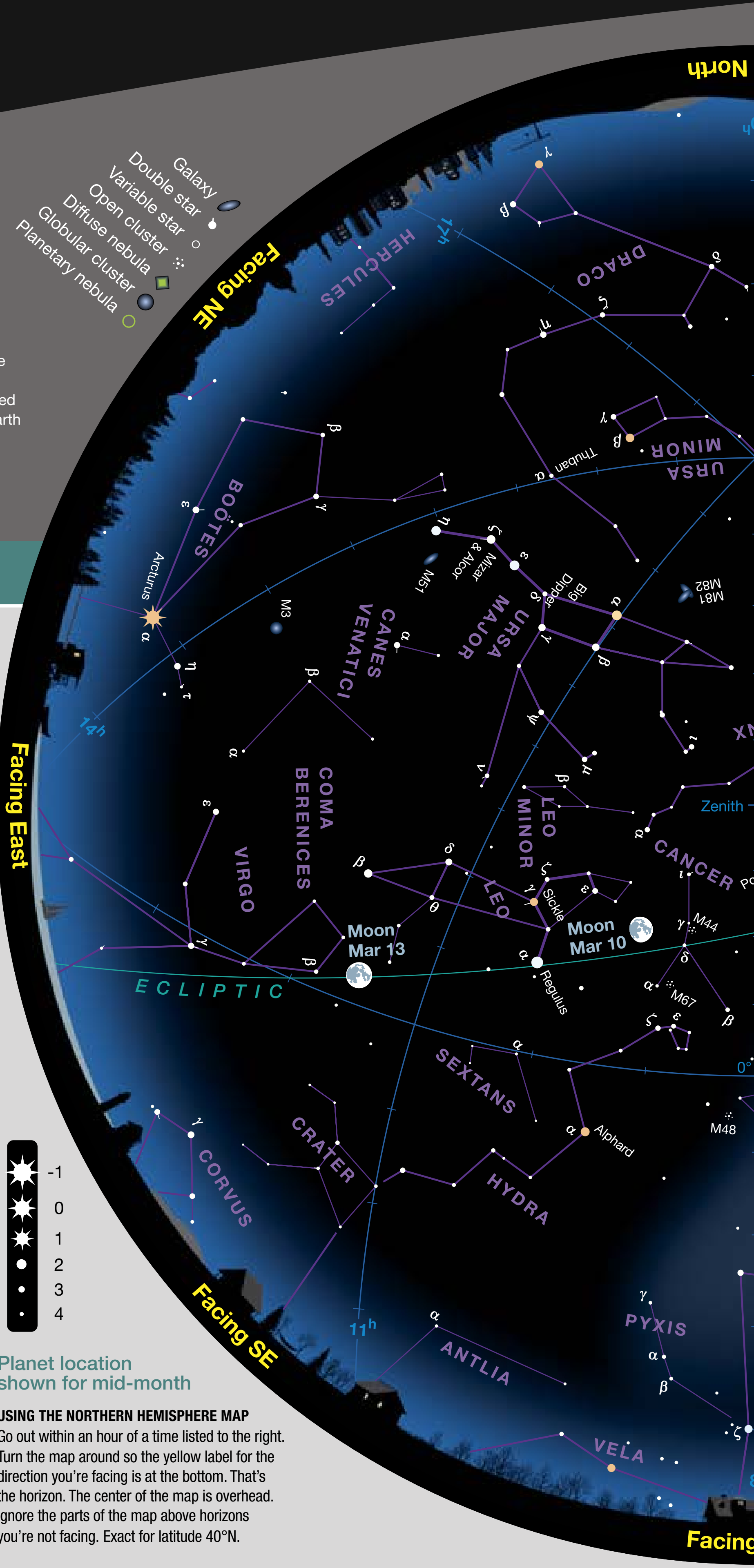
NEW MOON
March 29
10:58 UT

DISTANCES

Perigee	March 1, 21ʰ UT
361,964 km	Diameter 33′ 01″
Apogee	March 17, 17ʰ UT
405,754 km	Diameter 29′ 27″
Perigee	March 30, 5ʰ UT
358,131 km	Diameter 33′ 22″

FAVORABLE LIBRATIONS

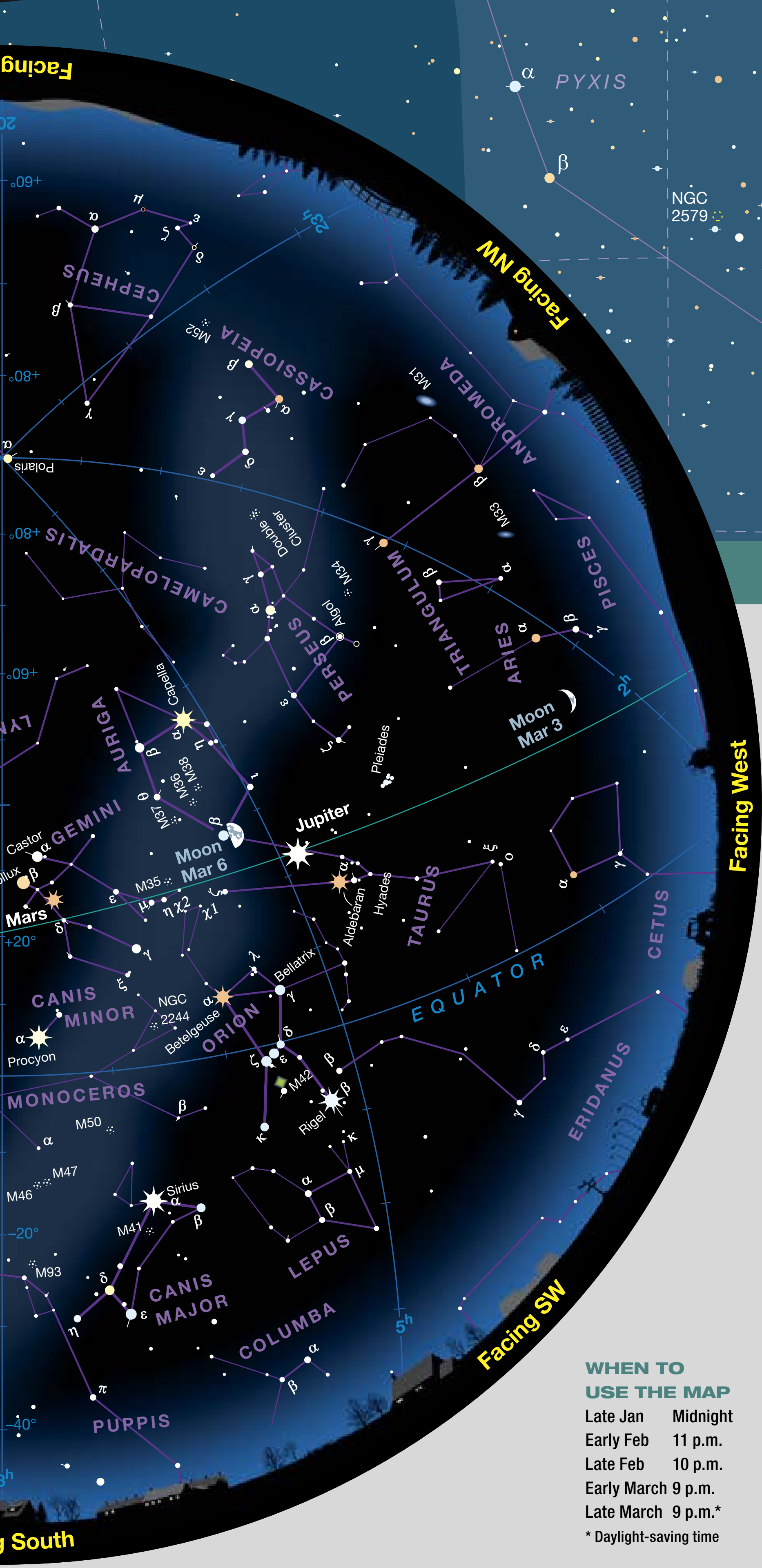
- Petrov Crater — March 3
- Hamilton Crater — March 10
- Rimae Gerard — March 23
- Lavoisier Crater — March 25

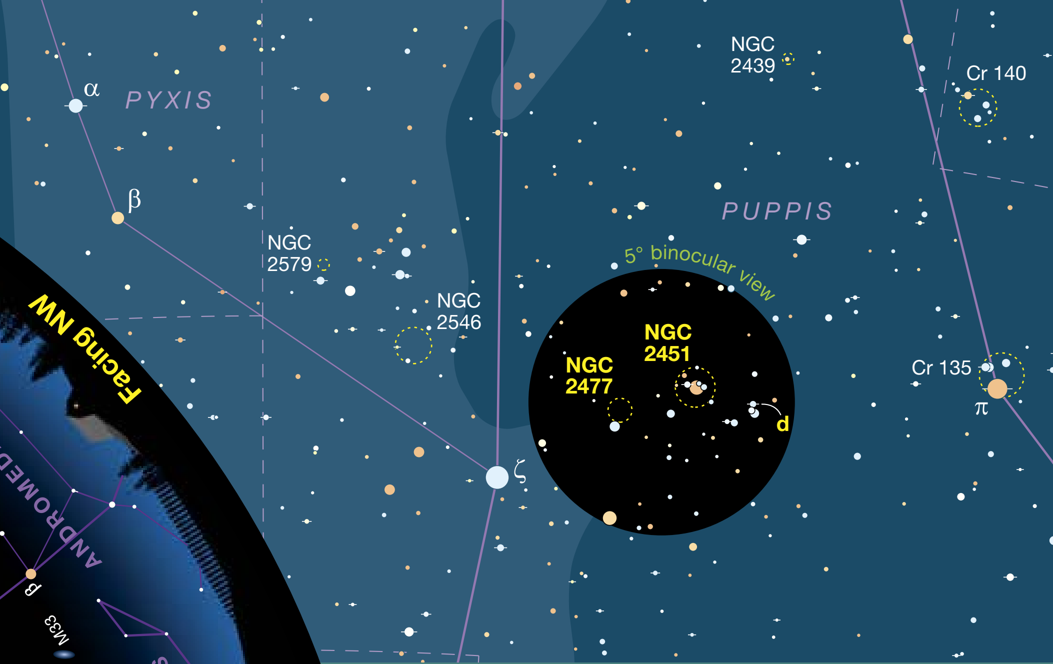


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

Full Speed Astern!

If there's one constellation I've given short shrift to — both as an observer and a writer — it's Puppis, the Stern of the mythical ship Argo. I dip into Puppis quite often to take the Messier clusters near its northern border, but I rarely explore the length and breadth of this vast, rich constellation. That's a shame, because Puppis is packed with good stuff.

A prime example is the 2.8-magnitude open cluster **NGC 2451**. Thanks to its –38° declination, you'll need an unobstructed southern horizon to take in this celestial gem, which floats 4° northwest of Zeta (ζ) Puppis, or Naos. NGC 2451 presents a scattering of stars between 6th and 9th magnitude around the 3.6-magnitude red giant c Puppis. In his book *Hidden Treasures*, Contributing Editor Stephen James O'Meara described stars "arranged into weak spiral arms centered on the core," and I find that impression almost inescapable in my 15×70s. In 7× or 10× binoculars these details are compressed into an irregular, faintly grainy glitter, but it's a very fetching cluster — or is it *two*? Photometric surveys suggest two condensations of stars here, one about 600 light-years away and another twice as far.

There's more to enjoy in the same binocular field. About 1½° east-southeast of NGC 2451 is a smaller and fainter open cluster, 5.8-magnitude **NGC 2477**. And just 1° west-southwest of NGC 2451 you'll find a charming trio of 5th- and 6th-magnitude stars collectively known as **d Puppis**. The clusters and clutch of stars all comfortably fit within a 3° circle, so they're easily framed in most conventional binoculars.

NGC 2451 makes a fine jumping-off point for exploring central Puppis. Happy hunting!

■ Will **MATT WEDEL** ever get through the observing targets to be found near his southern horizon? Keep watching this space!

WHEN TO USE THE MAP

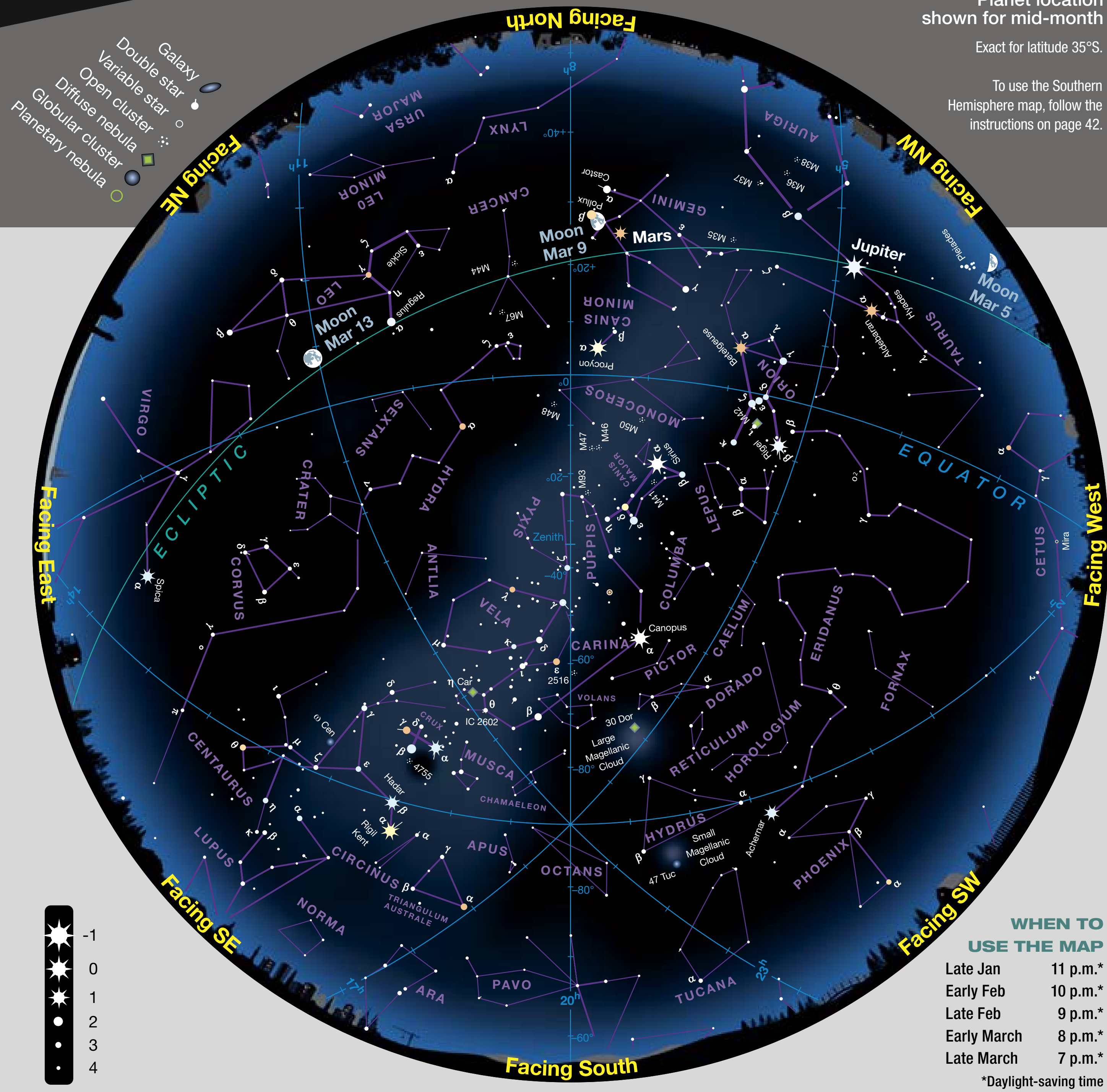
Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early March	9 p.m.
Late March	9 p.m.*

* Daylight-saving time

MARCH 2025 OBSERVING

Southern Hemisphere Sky Chart

by Jonathan Nally



WHEN TO USE THE MAP

Late Jan	11 p.m.*
Early Feb	10 p.m.*
Late Feb	9 p.m.*
Early March	8 p.m.*
Late March	7 p.m.*

*Daylight-saving time

THE SOUTHERN MILKY WAY is filled with splendid open star clusters, many of which can be spotted with the unaided eye. One example in the constellation Carina is **NGC 2516**, also known as the Southern Beehive for its resemblance to the Beehive Cluster (M44) in Cancer.

Nicolas-Louis de Lacaille first cataloged the Southern Beehive in January 1752 during his two-year observing marathon at the Cape of Good Hope in South Africa. With a total magnitude of 3.8, the cluster is visible under ideal conditions as a fuzzy patch about 3° west-southwest of 2nd-magnitude Epsilon (ε) Carinae, the star at the base of the False Cross asterism. Those with excellent eyesight and dark skies can see that the Southern Beehive spans nearly 30′ — about as large as the full Moon. ■

Foxy Canis Minor

A little canine makes a big fuss in the sky.

If you've ever owned a little dog, you know how cute and cunning they can be. It's that way, too, with the constellation Canis Minor, the Lesser Dog, at least mythologically speaking. Originally, only two stars comprised the quaint constellation: Procyon, its +0.4-magnitude Alpha (α) star, and 2.9-magnitude Gomeisa, its Beta (β) star. Ask any skywatcher what these stars represent, and sure as "kibbles is kibbles," they'll say it's one of Orion's two hunting dogs — the other one being Canis Major, the Greater Dog. But as far as myths go, the bond between Canis Minor and Orion may give us pause.

In Homer's epic poem the *Iliad,* for instance, the 8th-century BC Greek poet tells us, albeit indirectly, that the brightest star in the night sky "is also called by the name of The Dog of Orion." He's referring to Sirius. Note the singular possession: Sirius is not one of Orion's dogs, but *the* dog.

In his *Poeticon Astronomicon* of 1482, Latin author Gaius Julius Hyginus informs us that because Canis Minor "rises before the Greater Dog he is called Procyon, meaning 'He that runs before the dog.'" Again, "the dog" in this case is Sirius; it was common back then to substitute the name of a constellation with the name of its brightest star.

Hyginus identifies Procyon as Maera, the hound of Icarius — the legendary Athenian who learned winemaking from Dionysus, Greek god of the potency and fertility of nature. When Icarius offered his libations to some shepherds, they became intoxicated. Thinking Icarius had tried to poison them, they stoned him to death. But Maera escaped; the faithful dog returned home and brought Icarius's daughter Erigone to the scene of the crime. In grief, Erigone buried her father beneath a tree, then hanged herself. Maera, equally distraught, leapt into a well. Zeus honored Icarius and Erigone with a place in the heavens as Arcturus and Spica, respectively.

What about Maera? Its identity is unclear. While the Greeks preferred Procyon as Maera, Roman poets, including Ovid (43 BC – AD 17), branded the dog as Sirius, adding to the canine confusion.

There is a tale, however, in which Canis Major and Canis Minor both play a role — but not as two dogs. In it, Canis Major is Laelaps, a magical hound as swift as the wind that never fails in the hunt. And Canis Minor is the Teumessian fox, a magical beast so swift it can never be caught.

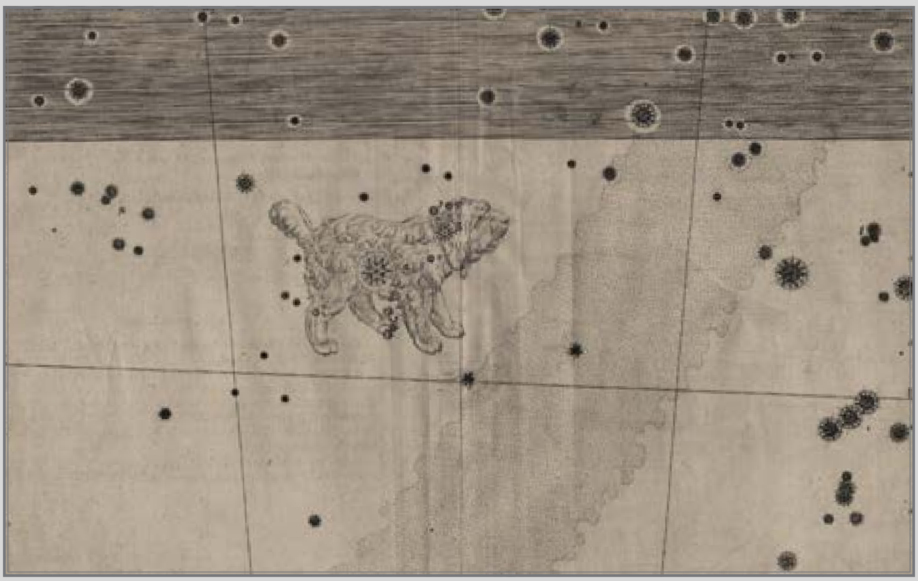
In one version of the story, told in Ovid's epic poem *Metamorphoses*, the creatures chased each other in endless circles until Zeus, Olympian god of the sky, intervened. Not wanting either animal to be defeated, he turned them both into stone. Zeus also placed their figures in the sky, as the constellations Canis Major and Canis Minor, to commemorate their never-ending chase.

The Greeks and Romans were not the first to envision Canis Minor as a fox. That interpretation dates to ancient Mesopotamia, where skywatchers knew Procyon as either *Shelebu* or *KA.A;* both words mean "the fox." That animal took part in many myths, including the Mesopotamian creation myth. In it, Enki, god of the life-giving waters of Earth, has been separated from his wife Ninhursag, goddess of fertility and birth. Without her, he is dying, and the fate of humanity depends on them getting back together.

Seeing the dilemma, Ninhursag's sacred fox strikes a bargain with the gods. He says he'll persuade Ninhursag to return and heal Enki, if, in return, he is rewarded with fame. And though the text has been lost describing how the clever fox achieved its goal, all is well in the end: Ninhursag returns to heal Enki, and humanity is saved.

The map below shows how close Procyon is to the Milky Way (the shaded area at top) — which can be imagined as the celestial counterpart of Enki's life-giving waters. Seen in this way, it certainly looks like the fox received a heavenly reward for saving Enki's life. What a sly little dog . . . oops, I mean, what a wily little fox.

■ Contributing Editor **STEPHEN JAMES O'MEARA** has been studying the stars and their lore for more than 50 years.



CALTECH ARCHIVES

▲ By 1603, when Johann Bayer published his *Uranometria* star atlas, the constellation Canis Minor was a small dog. Many centuries earlier, it was sometimes considered to be a fox instead.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

A Big Month for the Moon and Venus

A set of conjunctions and a pair of eclipses are on the lunar docket in March.

SATURDAY, MARCH 1

Conjunctions between the **Moon** and **Venus** are among the most arresting naked-eye sights in astronomy. So, what could be better than the chance to see one? How about the chance to see *two* in one month! What makes this month's twofer so remarkable is that we get one at dusk and the other at dawn (see March 27, on the facing page).

As it happens, this evening's event is the last one in the current Venus apparition, which began back in June 2024. The 5%-illuminated waxing lunar crescent sits less than 6½° lower left of the Evening Star, which gleams magnificently at magnitude –4.8. As twilight fades, keep an eye out for *earthshine* on the Moon's "unlit" side — pale light reflected onto the lunar surface by the 95%-illuminated gibbous Earth.

If you have a reasonably unobstructed western horizon, see if you can add the bonus sight of **Mercury**, positioned 10° lower right of the Moon. The innermost planet currently shines at magnitude –1.0, which should make it reasonably easy to pick out even through thin, horizon-hugging haze.

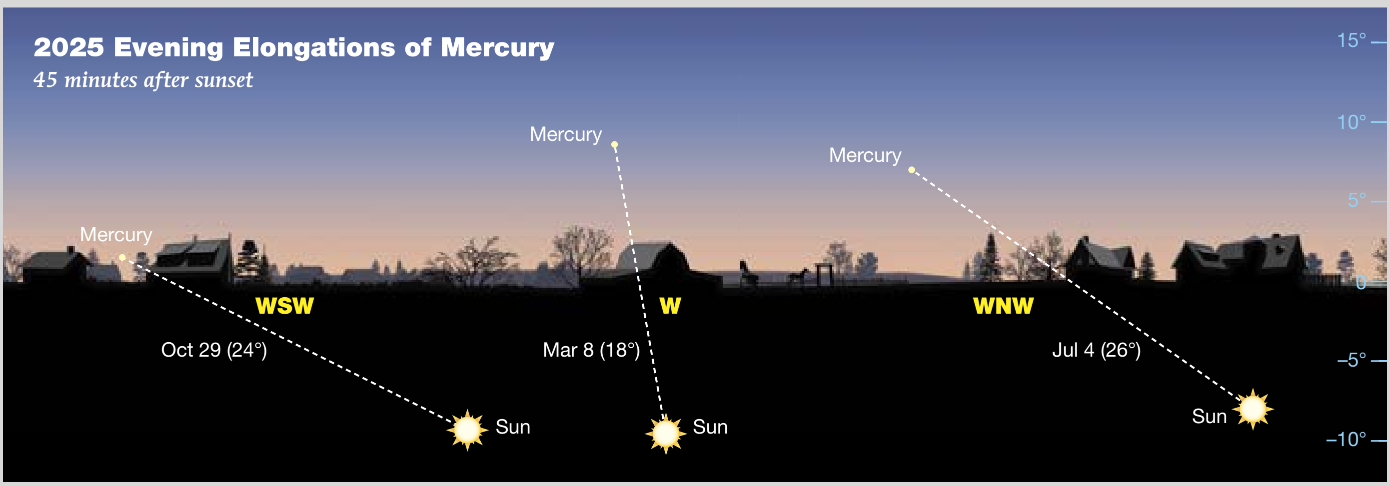
SATURDAY, MARCH 8

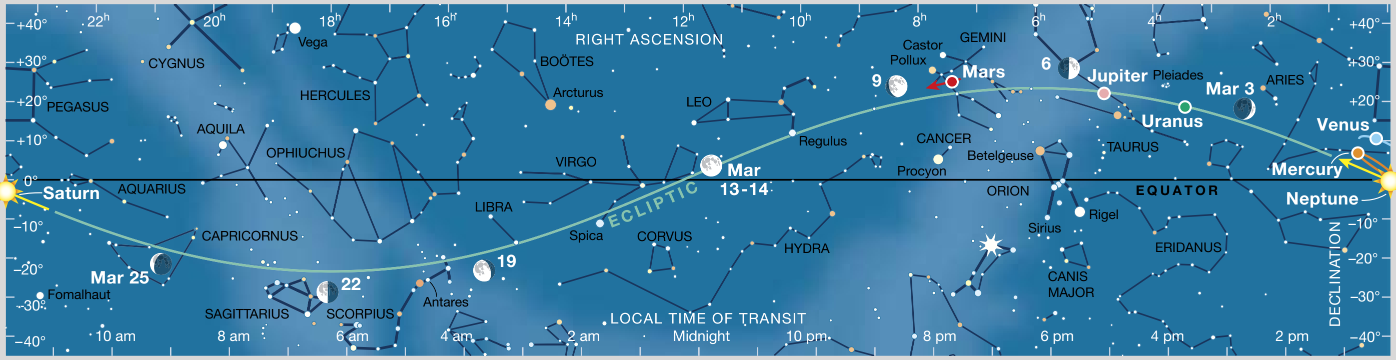
One week after **Mercury** was part of a dusk triangle with the Moon and Venus, the little planet reaches its greatest elongation for this brief evening apparition. Mercury is 18° east of the Sun — a separation great enough that it lingers above the western horizon for 1½ hours after sundown. This is the first of three dusk apparitions for Mercury in 2025. As the horizon diagram below shows, the current one is the most favorable. This evening, Mercury shines at magnitude –0.3 and has an altitude of 8° about 45 minutes after sunset.

Even as Mercury reaches its highest point, Venus is swiftly sinking lower as it plunges toward inferior conjunction with the Sun on March 23rd (UT). Venus passes Mercury on the 12th, when the two planets are about 5½° apart. By then, however, Mercury has dimmed significantly to magnitude +0.6, making it a much tougher find. Binoculars are your friend here — locate Venus first, then look for Mercury to its left.

A little later on the evening of the 8th, a second lovely sight awaits. Nearly overhead, the 75%-illuminated gibbous **Moon** hangs less than 1½° above **Mars**. The Red Planet is nearly two months past opposition and has dimmed from its peak brightness of magnitude –1.4 down to –0.1. Still, it's plenty prominent even next to a bright Moon. What makes this night's scene even more impressive is that both objects lie near Castor and Pollux in Gemini; the Moon is about 5° from Pollux, the brighter of the two stars. Taking in an even wider view, you can create a wonder-

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.





▲ The Sun and planets are positioned for mid-March; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

fully symmetrical hexagon by connecting the Moon-Mars pair with Procyon (in Canis Minor), then down to Sirius (Canis Major), over to Rigel (Orion), up to Jupiter, on to Capella (Auriga), and back to the Moon and Mars.

WEDNESDAY, MARCH 12

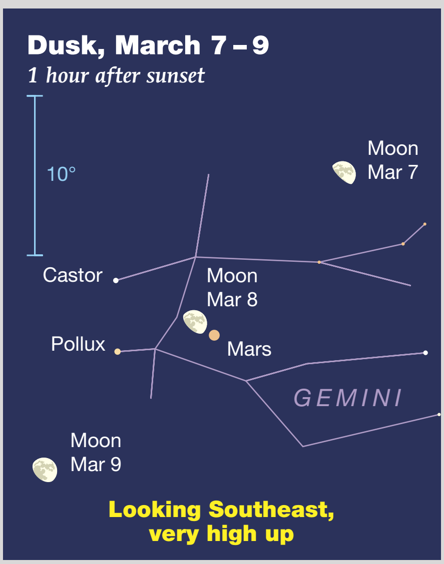
Since the 8th, the **Moon** has traveled eastward from Gemini, through Cancer, into Leo. There it has its closest encounter with a bright star this month when it stands about 1° upper right of **Regulus** in the predawn hours. Of all the 1st-magnitude stars strung out along the *ecliptic* — the path the Sun, Moon, and planets tread across the celestial sphere — Regulus is the faintest. Shining at magnitude 1.4, it's a half magnitude fainter than the brightest ecliptic star, Aldebaran, in Taurus. The Moon is nearly full (96% illuminated) when it's closest to the star, at around 5:30 a.m. EDT. Here again, binoculars are a big help.

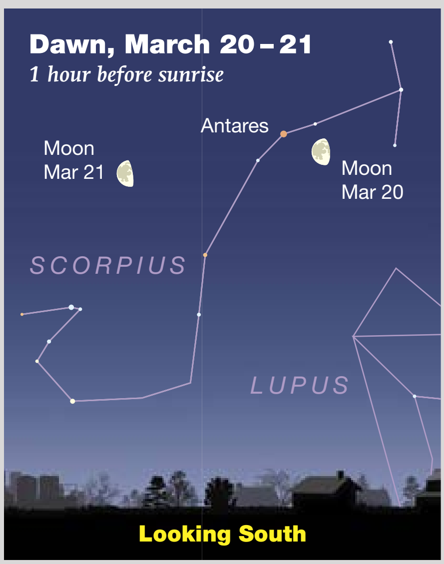
FRIDAY, MARCH 14

This morning all of the U.S., Canada, Central America, and much of South America get to enjoy the first total eclipse of the **Moon** since 2022. Totality begins at 2:26 a.m. EDT and lasts a bit more than an hour, concluding at 3:32 a.m. The event is described in full starting on page 48.

SATURDAY, MARCH 22

If you get up before dawn today, cast your gaze to the south-southeast to see something quite unusual: the last-quarter **Moon** sitting just above the spout of the Sagittarius Teapot. With a declination of –29½°, this is very nearly as far south as the Moon can get. It's all down to something called the "major lunar standstill." We'll discuss this phenomenon in more detail next month, but for now, suffice it to say that extreme southern and northern positions for the Moon are the result of a couple of factors working together: the Moon's 5° orbital inclination and its arrival at the southern (or northern) extreme of the ecliptic. In the meantime, enjoy this unusual sight.





THURSDAY, MARCH 27

This morning you have the rare opportunity to catch a second conjunction involving the **Moon** and **Venus**. While two such meetings in a month are not especially uncommon, it *is* unusual to have one at dusk (see March 1, on the facing page) and another at dawn. That said, this morning's conjunction isn't especially close — the 6%-illuminated waning lunar crescent sits 22° right of the Morning (formerly, Evening) Star. Venus itself gleams gamely at magnitude –4.1. With earthshine adorning the lunar disk, the pairing is undeniably a pretty sight, but in truth it's the novel circumstance that makes this conjunction worth rising early to see.

■ Given a choice, Consulting Editor **GARY SERONIK** will always opt for an evening conjunction over one that takes place at dawn.

A Long-Awaited Lunar Eclipse

This month Earth's umbral shadow covers the Moon for the first time since 2022.

Like hands and feet, eclipses come in pairs. During the month of March we'll experience a total lunar eclipse followed by a partial solar eclipse. Both are visible in North America although the latter will be limited to a few locations along the East Coast.

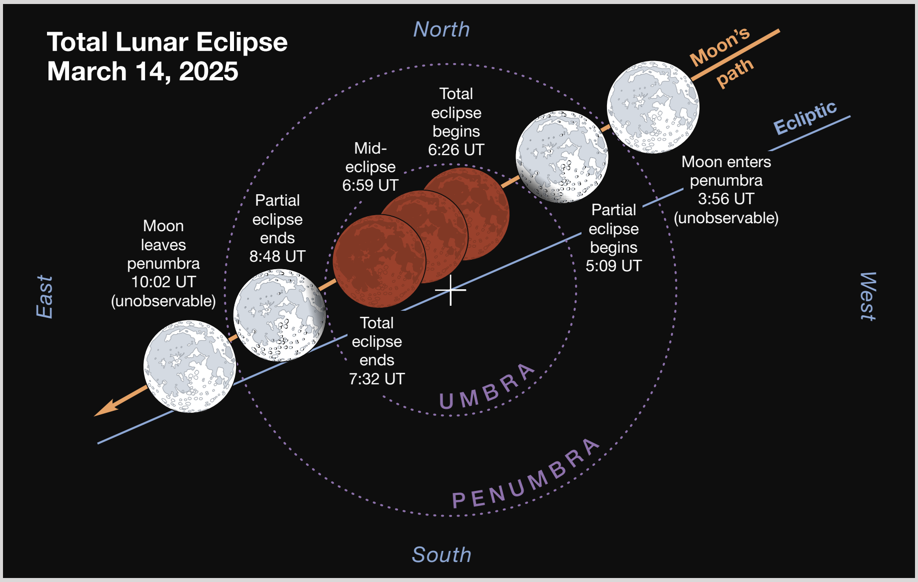
The Moon's orbit is tilted by about 5° to the *ecliptic*, the plane of Earth's orbit around the Sun. As the Moon revolves around our planet it alternately dips above and below that plane, intersecting it at two points called *nodes*. For a lunar eclipse to occur, the Moon must be full at the same time it crosses a node. When these circumstances are met the Sun, Earth, and Moon neatly line up in that order, and the Moon passes through our planet's shadow as it does on the night of March 13–14. At new Moon, two weeks later, it cuts through that plane again, but this time it passes between the Earth and Sun, generating a solar eclipse.

Observers across the Americas have the best seats in the house for the lunar eclipse. All 50 U.S. states will see the entire event, though western Alaska and Hawai'i miss the start of the penumbral phase. The partial eclipse begins at 1:09 a.m. EDT on March 14th, with totality lasting from 2:26 a.m. to 3:32 a.m. EDT. Mid-eclipse occurs at 2:59 a.m. EDT. From the West Coast, the partial phase begins at 10:09 p.m. PDT on the 13th, with mid-eclipse occurring almost exactly at midnight, at 11:59 p.m. PDT. Western European observers will see the totally eclipsed Moon setting in morning twilight, while on the other side of the world, New Zealanders get to watch the Moon rise totally eclipsed.

This won't be a particularly deep eclipse because the entire lunar disk misses the center of Earth's umbral shadow. During totality we should expect to see the northern portion of the Moon glow brighter than the southern due to the former's proximity to the umbral shadow's northern edge.

▲ This set of photos from the most recent total lunar eclipse on November 8, 2022, show the Moon shortly before totality (right), during totality (center), and shortly after (left).

En route to the umbra, the Moon passes through Earth's outer shadow, called the *penumbra*. Here, sunlight and shadow mix to produce a filmy, gray shading across the lunar disk. Watch for the penumbral shadow to become noticeable along the southeastern (sky direction) portion of the lunar disk starting around 4:30 UT. During the September 2024 partial lunar eclipse,



LUNAR ECLIPSE IMAGES: BOB KING; LUNAR ECLIPSE DIAGRAM: LEAH TISCIONE / S&T; SOURCE: FRED ESPENAK the penumbra was much more obvious on my camera's live-view screen compared to what my eyes saw. I recommend this approach as a good way to monitor the Moon's progress during the event's early phases.

The umbra takes its first nibble of the Moon at 5:09 UT — the start of partial eclipse. Well before totality, attentive observers will notice the shadowed portion of the lunar disk glowing smoky-red from sunlight refracted by Earth's atmosphere. Excitement mounts as totality approaches. When the last sunlit sliver of Moon is swallowed by the umbra at 6:26 UT, you can almost imagine a chorus of "wows!" rising skyward from eclipse watchers.

During the eclipse, the Moon is relatively far from Earth and just a few days shy of apogee, which occurs on March 17th. As a result, the smallish lunar disk spends a generous 66 minutes crossing the northern portion of the umbra. Absent direct sunlight, the eclipsed orb always looks small and subdued to my eye compared to the boisterous brilliance of the full Moon. The eerie darkness that descends over the landscape during totality further adds to the contemplative mood of this leisurely paced show.

Dedicated observers use the five-point Danjon scale (in which 0 is darkest, 4 is lightest) to estimate the brightness and color of the eclipsed Moon — qualities linked to the clarity of Earth's atmosphere. Major volcanic eruptions can pollute the air with aerosols that strongly darken the Moon (see page 58).

Photographing a lunar eclipse is straightforward. Indeed, with the capabilities of modern DSLR and mirrorless cameras, you hardly need a tripod for the partial phases. But a sturdy support is essential when the Moon dwindles to a crescent and especially during totality when exposures are longer. A tracking mount ensures good photos during all phases, particularly with longer lenses. While a smartphone works for handheld shots, most devices render the lunar disk disappointingly small. Instead, set up a telescope and either hold your phone's lens up to the eyepiece, or purchase an adapter to attach it directly. This *afocal* method yields screen-filling images you'll be eager to share on social media.

You can also use a telescope on a tracking mount to shoot a close-up video of the eclipse to see if you can capture flashes from meteoroids striking the lunar surface. If you own a smart telescope, put it to work creating a time-lapse or video while you sit back and watch the event unfold with binoculars or a second scope.

Sky & Telescope Senior Contributing Editor Roger Sinnott encourages observers to record the times when specific craters enter and exit the umbral shadow. The umbra is larger than pure geometry predicts because of atmospheric effects, which vary from eclipse to eclipse. For instructions, check out Roger's article at **https://is.gd/lunartiming.**

On eclipse night, you'll want to bundle up warmly. Even in early spring, temperatures in some regions may drop below freezing late at night. But imagine what it's like on the Moon's surface as Earth blocks the light and heat from the Sun. During the May 2022 total lunar eclipse, the Thermal Infrared Sensor instruments on the Landsat 8 and 9 satellites recorded rapidly plummeting temperatures on the Moon as it slid into Earth's shadow. The temperature dropped from a toasty 97°C (207°F) down to −93°C. The data also revealed that different features cooled at different rates. Craters tended to hold onto their heat longer than their surroundings.

After mid-eclipse at 6:59 UT, the Moon slowly drifts out of the umbra and back into sunlight starting at 7:32 UT. The event concludes when the Moon exits Earth's penumbral shadow at 10:02 UT. From beginning to end, the eclipse lasts 366 minutes. The next one occurs on September 7th when the Moon puts on a similar show but for the opposite side of the planet.

◀ Landsat recorded this infrared image sequence during the total lunar eclipse of May 16, 2022, revealing how different regions of the Moon retain heat as sunlight is extinguished during the event. Impact craters retain higher temperatures (brighter appearance) compared to the loosely textured lunar regolith. The warmest and most prominent crater is Tycho, glowing brightly in the lunar south.

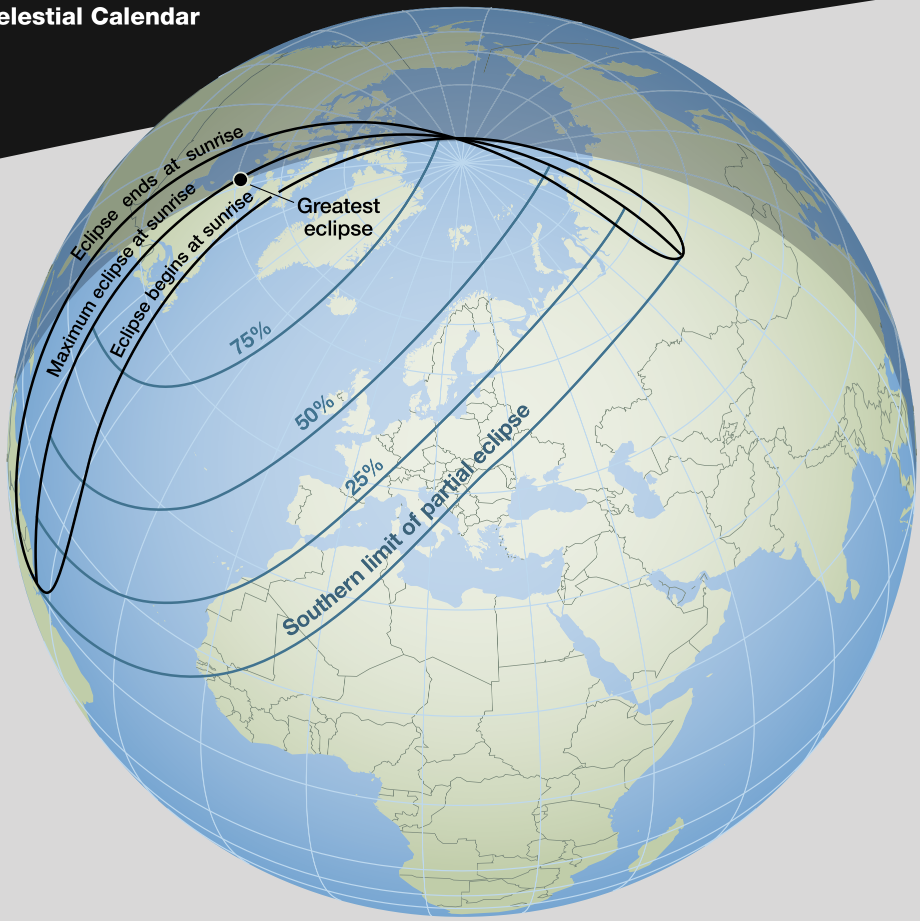
NASA EARTH OBSERVATORY IMAGES BY JOSHUA STEVENS, USING LANDSAT DATA FROM THE U.S. GEOLOGICAL SURVEY AND MATTHEW MONTANARO / GSFC / RIT

Minima of Algol

Feb.	UT	Mar.	UT
2	20:55	3	13:09
5	17:45	6	9:58
8	14:34	9	6:48
11	11:24	12	3:37
14	8:13	15	0:26
17	5:02	17	21:16
20	1:52	20	18:05
22	22:41	23	14:54
25	19:30	26	11:44
28	16:20	29	8:33

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus is conveniently high in the northwest during evening hours in March. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).



S&T ILLUSTRATION, SOURCE: FRED ESPENAK

A Solar Treat for the Northeast

THE MOON IS at bat again on March 29th as it partially eclipses the Sun for observers in the northeastern U.S., eastern Canada, Greenland, Iceland, Europe, Northwest Africa, and northwestern Russia. At maximum, 93.1% of the solar disk will be hidden, with greatest eclipse occurring over northern Quebec. In the U.S., the eclipse is underway before sunup. Residents of northern Maine see 86% of the Sun covered — the maximum possible from the U.S. Weather permitting, observers there can watch the Sun rise as a thin crescent distorted by atmospheric refraction. Maximum obscuration occurs just a few minutes after sunrise.

Moving south along the New England coast and inland as far as western New York, central Pennsylvania, Washington D.C., and eastern Virginia, less and less of the Sun is eclipsed as it rises. From Boston, Massachusetts, the Moon covers a little more than half the Sun at 6:32 a.m. EDT. The percentage drops to 11% for Philadelphia, Pennsylvania, 8% in Rochester, New York, and down to just 1% in Washington D.C. Observers in the eclipse zone need to stake out a location with an unobstructed eastern horizon for the most dramatic views. There should be incredible photo opportunities when the Sun's horns first breach the horizon at sunrise. Just remember to never view or photograph the partially eclipsed Sun without using a safe solar filter.

In easternmost Canada, Iceland, and Europe, the eclipse begins after sunup. In Saint John's, Newfoundland, the Moon blots out 83% of the solar disk. Dubliners (Ireland) will see 41% covered at maximum, while in Vienna, Austria, the Moon nibbles away just 6%. To get detailed information for any location in the eclipse zone, consult Xavier Jubier's interactive eclipse map at **https://is.gd/2025partial**.

Action at Jupiter

THERE'S NO DENYING that March represents the final, best observing window in Jupiter's current apparition. As the month opens, the planet arrives at the meridian only minutes after sunset and becomes a tricky telescopic target around local midnight when its altitude drops to only 30°. By the end of March, it reaches that point two hours earlier. More than most planets, however, Jupiter is a fine sight even in bright twilight — the contrast between its Great Red Spot and a deep-blue background sky is especially striking.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

February 1: 2:32, 12:28, 22:23; **2:** 8:19, 18:15; **3:** 4:11, 14:06; **4:** 0:02, 9:58, 19:53; **5:** 5:49, 15:45; **6:** 1:41, 11:36, 21:32; **7:** 7:28, 17:24; **8:** 3:19, 13:15, 23:11; **9:** 9:06, 19:02; **10:** 4:58, 14:54; **11:** 0:49, 10:45, 20:41; **12:** 6:37, 16:32; **13:** 2:28, 12:24, 22:20; **14:** 8:15, 18:11; **15:** 4:07, 14:03, 23:58; **16:** 9:54, 19:50; **17:** 5:46, 15:42; **18:** 1:37, 11:33, 21:29; **19:** 7:25, 17:20; **20:** 3:16, 13:12, 23:08; **21:** 9:03, 18:59; **22:** 4:55, 14:51; **23:** 0:46, 10:42, 20:38; **24:** 6:34, 16:30; **25:** 2:25, 12:21, 22:17; **26:** 8:13, 18:08; **27:** 4:04, 14:00, 23:56; **28:** 9:52, 19:47

March 1: 5:46, 15:42; **2:** 1:38, 11:34, 21:29; **3:** 7:25, 17:21; **4:** 3:17, 13:13, 23:08; **5:** 9:04, 19:00; **6:** 4:56, 14:52; **7:** 0:47, 10:43, 20:39; **8:** 6:35, 16:31; **9:** 2:26, 12:22, 22:18; **10**: 8:14, 18:10; **11**: 4:05, 14:01, 23:57; **12**: 9:53, 19:49; **13**: 5:44, 15:40; **14**: 1:36, 11:32, 21:28; **15**: 7:23, 17:19; **16**: 3:15, 13:11, 23:07; **17**: 9:03, 18:58; **18**: 4:54, 14:50; **19**: 0:46, 10:42, 20:37; **20**: 6:33, 16:29; **21**: 2:25, 12:21, 22:17; **22**: 8:12, 18:08; **23**: 4:04, 14:00, 23:56; **24**: 9:51, 19:47; **25**: 5:43, 15:39; **26**: 1:35, 11:31, 21:26; **27**: 7:22, 17:18; **28**: 3:14, 13:10, 23:06; **29**: 9:01, 18:57; **30**: 4:53, 14:49; **31**: 0:45, 10:41, 20:36

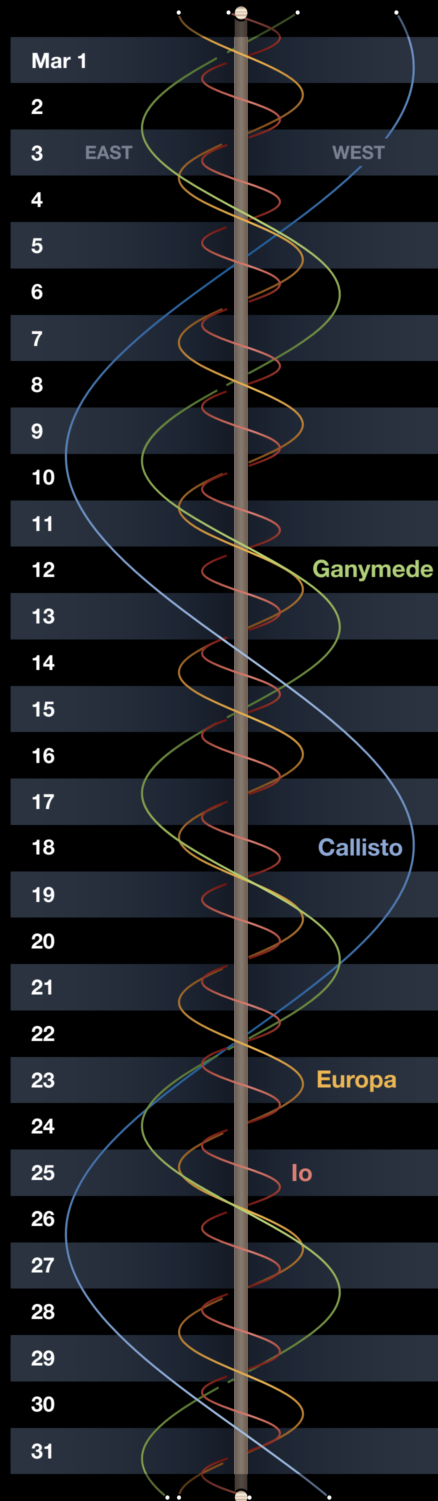
These times assume that the spot will be centered at System II longitude 71° on March 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 71° and 1⅔ minutes later for each degree more than 71°.

Phenomena of Jupiter's Moons, March 2025

Mar. 1	3:11	III.Oc.D
	5:34	III.Oc.R
	7:46	II.Tr.I
	8:29	III.Ec.D
	10:02	I.Oc.D
	10:19	II.Sh.I
	10:19	II.Tr.E
	10:57	III.Ec.R
	12:55	II.Sh.E
	13:33	I.Ec.R
Mar. 2	7:15	I.Tr.I
	8:33	I.Sh.I
	9:27	I.Tr.E
	10:45	I.Sh.E
Mar. 3	2:12	II.Oc.D
	4:30	I.Oc.D
	4:49	II.Oc.R
	4:53	II.Ec.D
	7:33	II.Ec.R
	8:01	I.Ec.R
Mar. 4	1:44	I.Tr.I
	3:02	I.Sh.I
	3:56	I.Tr.E
	5:15	I.Sh.E
	17:24	III.Tr.I
	19:45	III.Tr.E
	21:03	II.Tr.I
	22:41	III.Sh.I
	22:59	I.Oc.D
	23:37	II.Sh.I
	23:37	II.Tr.E
Mar. 5	1:08	III.Sh.E
	2:13	II.Sh.E
	2:30	I.Ec.R
	20:13	I.Tr.I
	21:31	I.Sh.I
	22:25	I.Tr.E
	23:43	I.Sh.E
Mar. 6	15:32	II.Oc.D
	17:28	I.Oc.D
	18:10	II.Oc.R
	18:13	II.Ec.D
	20:53	II.Ec.R
	20:59	I.Ec.R
Mar. 7	14:42	I.Tr.I
	16:00	I.Sh.I
	16:54	I.Tr.E
	18:12	I.Sh.E
Mar. 8	7:12	III.Oc.D
	9:36	III.Oc.R
	10:21	II.Tr.I
	11:57	I.Oc.D
	12:30	III.Ec.D
	12:55	II.Sh.I
	12:55	II.Tr.E
	14:59	III.Ec.R
	15:28	I.Ec.R
	15:31	II.Sh.E
Mar. 9	9:11	I.Tr.I
	10:29	I.Sh.I
	11:23	I.Tr.E
	12:41	I.Sh.E
Mar. 10	4:52	II.Oc.D
	6:26	I.Oc.D
	7:29	II.Oc.R
	7:32	II.Ec.D
	9:57	I.Ec.R
	10:12	II.Ec.R
Mar. 11	3:40	I.Tr.I
	4:58	I.Sh.I
	5:52	I.Tr.E
	7:10	I.Sh.E
	21:27	III.Tr.I
	23:40	II.Tr.I
	23:50	III.Tr.E
Mar. 12	0:55	I.Oc.D
	2:13	II.Sh.I
	2:14	II.Tr.E
	2:42	III.Sh.I
	4:25	I.Ec.R
	4:48	II.Sh.E
	5:10	III.Sh.E
	22:09	I.Tr.I
	23:27	I.Sh.I
Mar. 13	0:21	I.Tr.E
	1:39	I.Sh.E
	18:12	II.Oc.D
	19:24	I.Oc.D
	20:50	II.Oc.R
	20:51	II.Ec.D
	22:54	I.Ec.R
	23:32	II.Ec.R
Mar. 14	16:39	I.Tr.I
	17:56	I.Sh.I
	18:51	I.Tr.E
	20:08	I.Sh.E
Mar. 15	11:17	III.Oc.D
	12:59	II.Tr.I
	13:43	III.Oc.R
	13:53	I.Oc.D
	15:30	II.Sh.I
	15:33	II.Tr.E
	16:30	III.Ec.D
	17:23	I.Ec.R
	18:06	II.Sh.E
	19:00	III.Ec.R
Mar. 16	11:08	I.Tr.I
	12:25	I.Sh.I
	13:20	I.Tr.E
	14:37	I.Sh.E
Mar. 17	7:33	II.Oc.D
	8:22	I.Oc.D
	11:52	I.Ec.R
	12:51	II.Ec.R
Mar. 18	5:37	I.Tr.I
	6:54	I.Sh.I
	7:50	I.Tr.E
	9:06	I.Sh.E
Mar. 19	1:34	III.Tr.I
	2:19	II.Tr.I
	2:52	I.Oc.D
	3:59	III.Tr.E
	4:48	II.Sh.I
	4:53	II.Tr.E
	6:21	I.Ec.R
	6:43	III.Sh.I
	7:24	II.Sh.E
	9:12	III.Sh.E
Mar. 20	0:07	I.Tr.I
	1:23	I.Sh.I
	2:19	I.Tr.E
	3:35	I.Sh.E
	20:55	II.Oc.D
	21:21	I.Oc.D
Mar. 21	0:49	I.Ec.R
	2:10	II.Ec.R
	18:36	I.Tr.I
	19:52	I.Sh.I
	20:49	I.Tr.E
	22:04	I.Sh.E
Mar. 22	15:25	III.Oc.D
	15:38	II.Tr.I
	15:50	I.Oc.D
	17:53	III.Oc.R
	18:06	II.Sh.I
	18:13	II.Tr.E
	19:18	I.Ec.R
	20:30	III.Ec.D
	20:42	II.Sh.E
	23:02	III.Ec.R
Mar. 23	13:06	I.Tr.I
	14:21	I.Sh.I
	15:18	I.Tr.E
	16:33	I.Sh.E
Mar. 24	10:16	II.Oc.D
	10:20	I.Oc.D
	13:47	I.Ec.R
	15:29	II.Ec.R
Mar. 25	7:36	I.Tr.I
	8:50	I.Sh.I
	9:48	I.Tr.E
	11:02	I.Sh.E
Mar. 26	4:49	I.Oc.D
	4:59	II.Tr.I
	5:46	III.Tr.I
	7:23	II.Sh.I
	7:34	II.Tr.E
	8:12	III.Tr.E
	8:16	I.Ec.R
	10:00	II.Sh.E
	10:45	III.Sh.I
	13:15	III.Sh.E
Mar. 27	2:05	I.Tr.I
	3:19	I.Sh.I
	4:17	I.Tr.E
	5:31	I.Sh.E
	23:19	I.Oc.D
	23:38	II.Oc.D
Mar. 28	2:45	I.Ec.R
	4:49	II.Ec.R
	20:35	I.Tr.I
	21:48	I.Sh.I
	22:47	I.Tr.E
Mar. 29	0:00	I.Sh.E
	17:48	I.Oc.D
	18:19	II.Tr.I
	19:36	III.Oc.D
	20:41	II.Sh.I
	20:54	II.Tr.E
	21:13	I.Ec.R
	22:06	III.Oc.R
	23:18	II.Sh.E
Mar. 30	0:30	III.Ec.D
	3:03	III.Ec.R
	15:04	I.Tr.I
	16:17	I.Sh.I
	17:17	I.Tr.E
	18:29	I.Sh.E
Mar. 31	12:18	I.Oc.D
	13:00	II.Oc.D
	15:42	I.Ec.R
	18:08	II.Ec.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

A Martian Polar Expedition

Watch spring unfold in the Red Planet's arctic.

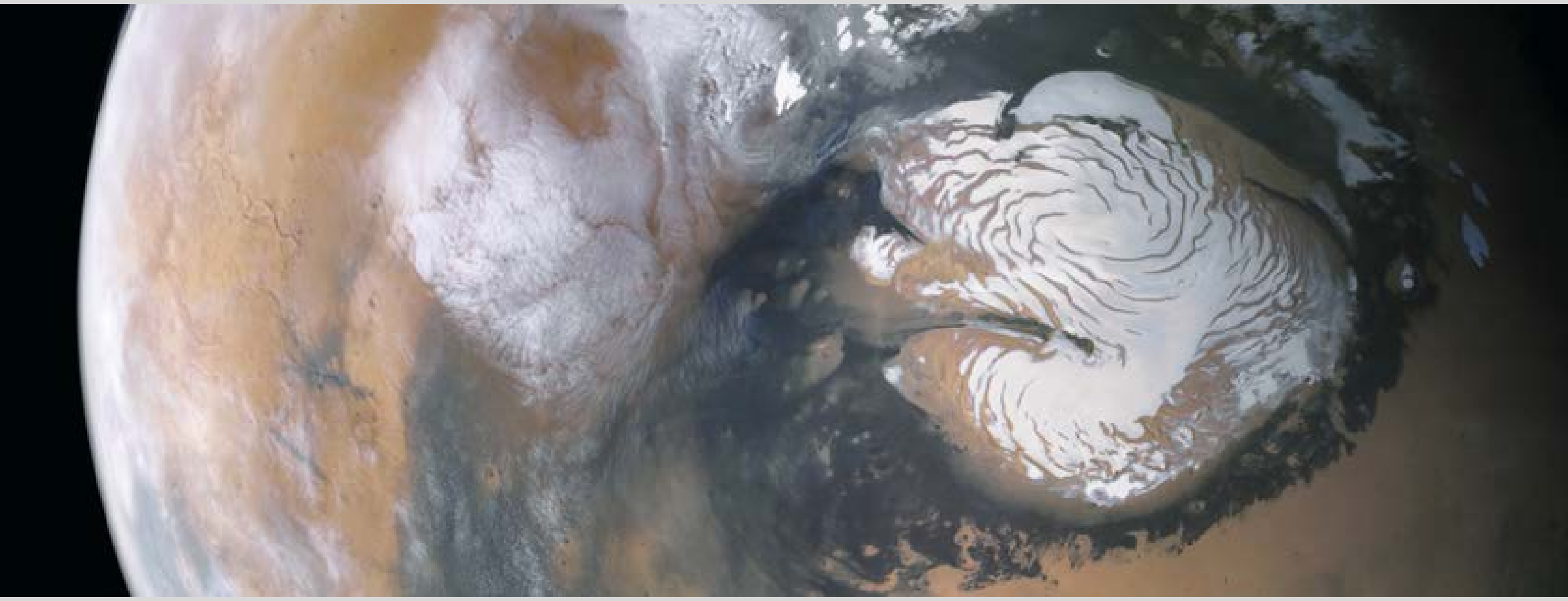
The north pole of Mars is tilted earthward during the current apparition, providing observers with an excellent vantage point to watch the retreat of the North Polar Cap as spring unfolds in the Red Planet's northern hemisphere. Although the apparent size of the Martian disk won't exceed 14.6″ in 2025, the planet achieves a high altitude above the horizon that will compensate to some degree for its small size.

With an axial tilt only slightly greater than Earth's, Mars experiences similar seasons to our home world. However, Martian seasons are nearly twice as long as Earth's because the length of a year on Mars is 687 terrestrial days. To mark the passage of the seasons during a Martian year, planetary scientists use solar longitude, often abbreviated as Ls. At vernal equinox (the beginning of northern spring) Ls is 0°, it's 90° at summer solstice, 180° at autumnal equinox, and 270° at winter solstice.

Vernal equinox in the northern hemisphere of Mars occurred on November 12, 2024, so spring was well underway at closest approach to Earth in January. Summer solstice occurs on May 29th this year, when the receding planet's apparent diameter shrinks to a paltry 5.6″.

Axial tilt accounts for nearly all the seasonal changes we experience because Earth's orbit is nearly circular. But Mars has the highest orbital eccentricity of any planet except Mercury. During one Martian year the planet's distance from the Sun varies from 249 million kilometers (150 million miles) at aphelion to 206 million kilometers at perihelion. These distance extremes correspond to a difference of almost 30% in the intensity of solar heating, giving rise to seasonal changes that are far more pronounced than Earth's.

There's a considerable disparity in the size of the north and south polar caps of Mars caused by the eccentricity of its orbit. The climate in the planet's northern hemisphere is less extreme than in its southern hemisphere, with a smaller annual temperature range. The larger southern cap grows during the 382-terrestrial-day-long southern hemisphere autumn and winter when Mars is near aphelion, and typically extends down to 50° latitude by late winter. Conversely, the northern cap grows during the shorter, warmer 305 terrestrial days of northern autumn and



▼ In May 2014, the European Space Agency's Mars Express spacecraft imaged the summer remnant of the water-ice cap, revealing the distinctive collar of dark dune fields. The spiral troughs that pinwheel around the pole are sculpted by strong, Coriolis force winds.

winter when Mars is near perihelion, so it seldom extends below 60° latitude at its maximum extent.

The north polar cap's permanent core persists into late summer and consists primarily of water ice. This remnant contains an estimated 1.6 million cubic kilometers of water ice (equivalent to about 30% of the Greenland ice sheet) and extends from the pole to about 80° latitude.

During winter, carbon dioxide, the principal constituent of the Martian atmosphere, freezes into a layer of frost and snow less than a meter thick atop the permanent cap of water ice. This seasonal veneer of frozen carbon dioxide contains more than ⅛ of the mass of the tenuous Martian atmosphere. The "dry ice" snow component also contains water-ice crystals and particles of dust that act as condensation nuclei.

As the carbon dioxide snow sublimates, it entrains considerable amounts of water vapor. The volatiles released by the retreating polar cap cause clouds and haze to form more frequently at low latitudes. Extensive haze on the morning and evening limbs of Mars should have begun to appear in February, as well as discrete white clouds over topographic elevations like the Tharsis shield volcanoes and Libya Montes. The visibility of these features is greatly enhanced through blue (Wratten 38A) and violet (Wratten 47) eyepiece filters.

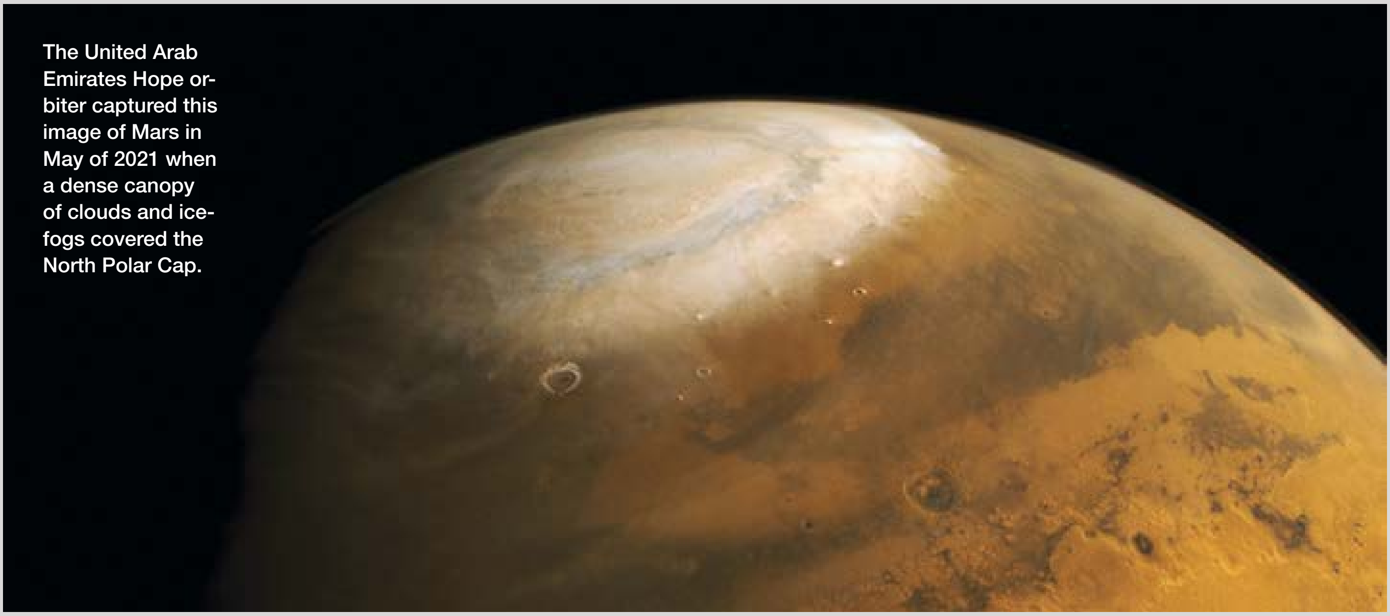
▲ This 1918 pastel drawing by the British observer T. E. R. Phillips depicts the shrunken summer polar cap surrounded by Lowell's Band. The dark, shark-fin-shaped albedo feature, Syrtis Major, had just emerged from under haze on the morning limb at right. Orographic clouds above the elevated volcanic province Elysium appear as the bright enclosed area just to the left of center.

As northern hemisphere spring arrives, longer hours of sunlight rapidly warm the arctic regions and the dense winter canopy of clouds and ice-fogs known as the "polar hood" begins to dissipate. But this year the orbital motion of Mars is also causing the planet's distance from the Sun to increase throughout early spring. (Mars will reach aphelion on April 21st, when Ls = 70°.) As a result, for several weeks the polar hood may reform and the polar cap's retreat may slow or even reverse. Best remembered for his discovery of Pluto, Clyde Tombaugh was also an avid Mars observer. He coined the term "aphelic chill" for this recurring phenomenon.

The retreating polar cap is often bordered by a narrow, dark collar known as Lowell's Band. Best seen through orange (Wratten 21) and red (Wratten 23A or 25) filters, this feature was first recorded by Wilhelm Beer and Johann Heinrich Mädler during the 1830s. In the closing years of the 19th century, Percival Lowell imagined that it was a temporary sea of meltwater from the thawing polar cap that fed a global network of irrigation canals. Spacecraft images have revealed this transient collar as dusky fields of dunes swept clean of frost and snow by winds blowing off the pole.

The Mars we know today isn't as captivating as Lowell's romantic vision of the home of a struggling race of canal builders, but changes on the Red Planet remain enticing targets for backyard telescopes.

■ Contributing Editor **TOM DOBBINS** is co-author of *Epic Moon: A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.



The United Arab Emirates Hope orbiter captured this image of Mars in May of 2021 when a dense canopy of clouds and ice-fogs covered the North Polar Cap.

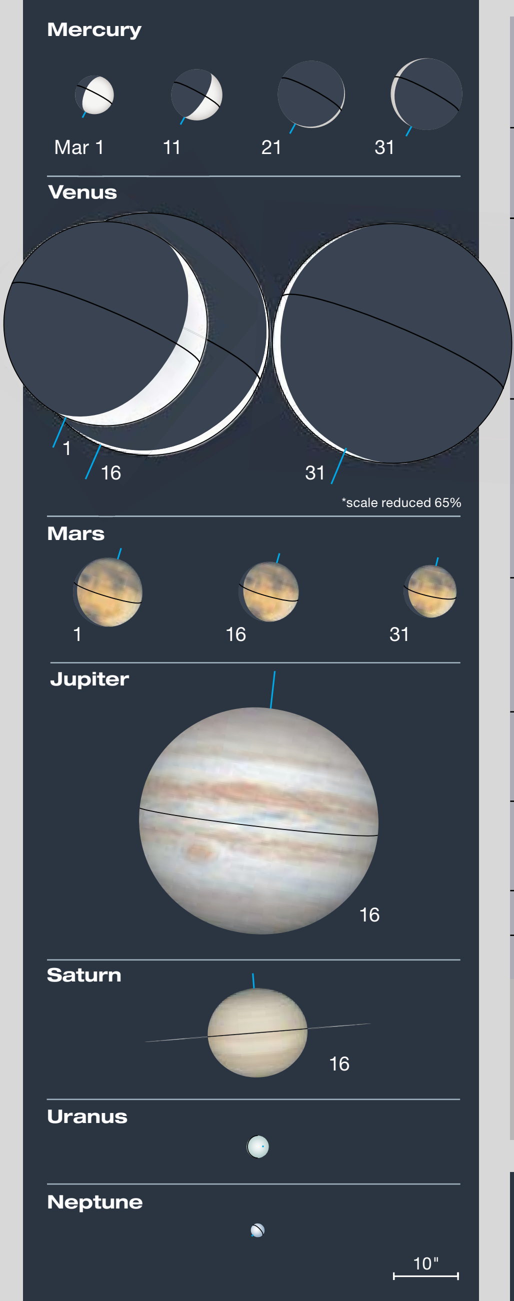
POLAR CAP: EMIRATES MARS MISSION / EXI / J. MAJOR

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk to the 15th • **Venus** visible at dusk to the 20th and then at dawn starting on the 21st • **Mars** visible at dusk and sets before morning twilight • **Jupiter** visible at dusk and sets in predawn • **Saturn** lost in the Sun's glare all month.

March Sun & Planets

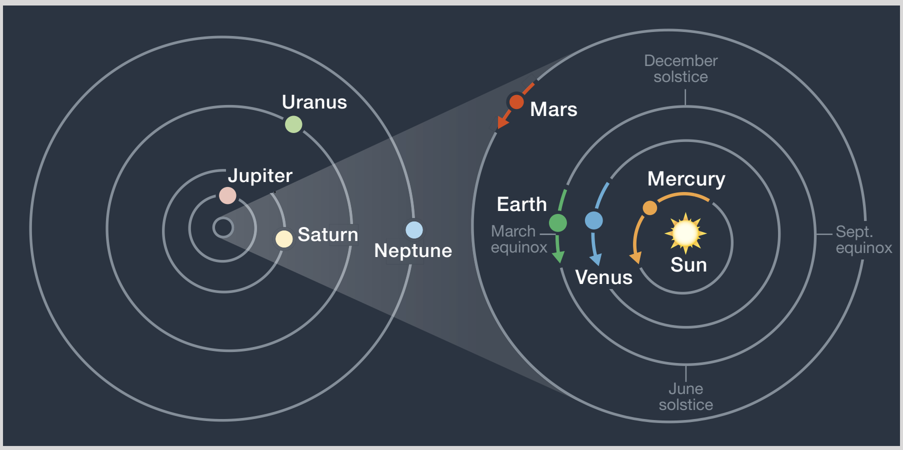
	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 47.3^m$	–7° 42′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 37.4^m$	+4° 02′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$23^h\ 44.7^m$	–1° 24′	16° Ev	–1.0	6.0″	76%	1.114
	11	$0^h\ 25.2^m$	+5° 25′	18° Ev	+0.1	8.0″	34%	0.843
	21	$0^h\ 20.6^m$	+6° 04′	8° Ev	+4.0	10.5″	3%	0.640
	31	$23^h\ 53.4^m$	+1° 20′	11° Mo	+3.4	11.2″	6%	0.602
Venus	1	$0^h\ 27.8^m$	+10° 18′	31° Ev	–4.8	48.7″	15%	0.342
	11	$0^h\ 19.4^m$	+10° 58′	20° Ev	–4.5	55.6″	6%	0.300
	21	$23^h\ 59.5^m$	+9° 14′	9° Mo	–4.2	59.4″	1%	0.281
	31	$23^h\ 39.6^m$	+5° 52′	15° Mo	–4.2	57.4″	3%	0.291
Mars	1	$7^h\ 14.8^m$	+25° 54′	126° Ev	–0.3	10.9″	94%	0.862
	16	$7^h\ 23.7^m$	+25° 10′	114° Ev	+0.1	9.4″	92%	0.991
	31	$7^h\ 40.9^m$	+24° 08′	103° Ev	+0.4	8.3″	91%	1.130
Jupiter	1	$4^h\ 41.9^m$	+21° 49′	92° Ev	–2.3	39.6″	99%	4.977
	31	$4^h\ 57.1^m$	+22° 20′	65° Ev	–2.1	36.2″	99%	5.449
Saturn	1	$23^h\ 27.5^m$	–5° 35′	10° Ev	+1.1	15.7″	100%	10.586
	31	$23^h\ 41.1^m$	–4° 09′	16° Mo	+1.2	15.7″	100%	10.558
Uranus	16	$3^h\ 25.7^m$	+18° 29′	58° Ev	+5.8	3.5″	100%	20.043
Neptune	16	$23^h\ 58.7^m$	–1° 31′	4° Ev	+8.0	2.2″	100%	30.884

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during March. The outer planets don't change position enough in a month to notice at this scale.

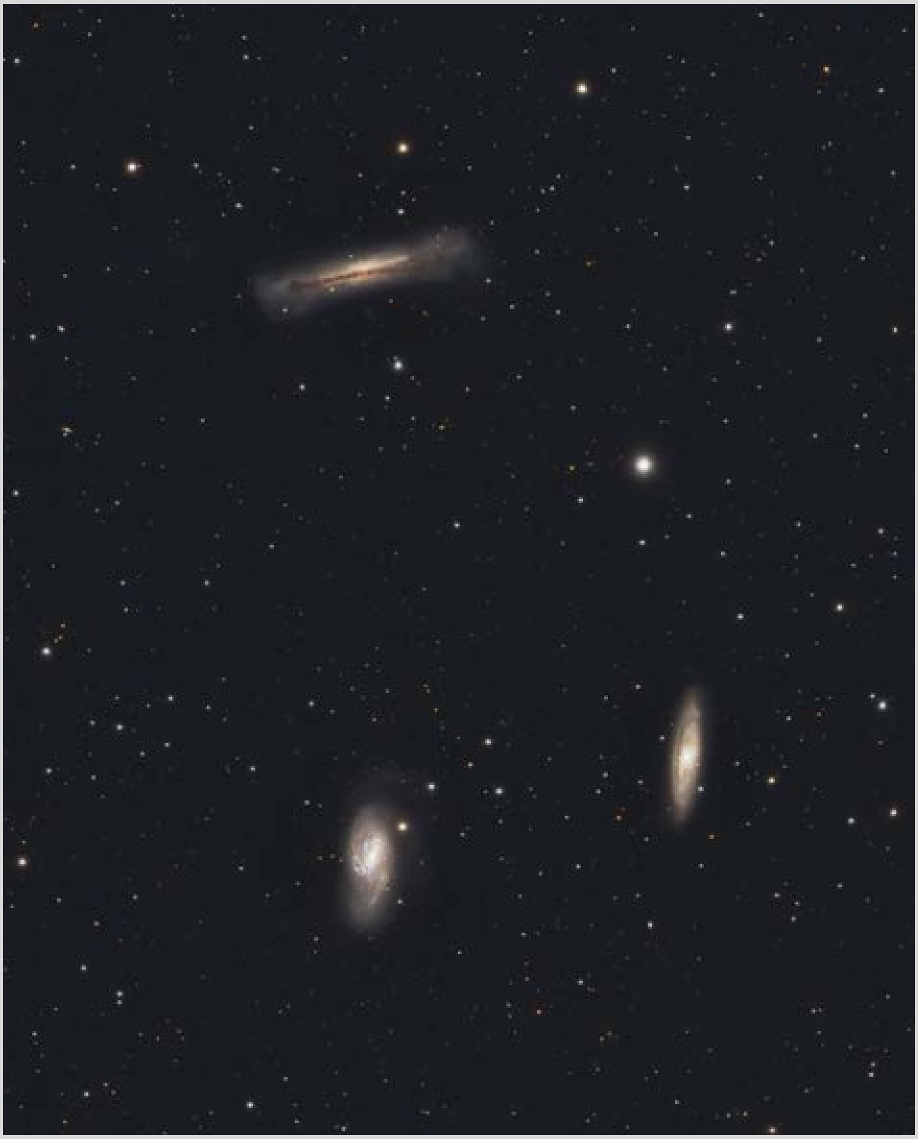


The Legs of the Lion

Southeastern Leo contains treasures both charming and challenging.

Leo's large, distinctive outline is recognizable even to suburban stargazers. The Lion's head and mane are symbolized by the Sickle, an impressive six-point asterism punctuated at its base by 1.4-magnitude Regulus. Some 20° east of the Sickle, the Lion's — ahem! — substantial rear end is established by a broad right-angle triangle formed by 2nd- and 3rd-magnitude stars. He's a big guy, front 'n back.

Although Leo is often depicted in a sitting position, some old charts picture his hind legs extended downward. The dim stars suggesting those lanky limbs aren't readily visible to city dwellers; however, they span an area of sky that contains several decent double stars plus two major galaxies. Last spring, I set up my scopes for a look-see.



▲ **LEO GALAXY TRIO** Standing just 20′ apart, M65 and M66 (lower right and left, respectively) are telescopic prizes for amateur astronomers. M65 is 40 light-years from Earth, while slightly brighter M66 is a bit closer. At the top of the image is NGC 3628. It lies some 32 million light-years away and is a fine example of an edge-on galaxy. Its proximity to M65 and M66 results in three galaxies potentially being visible in a single low-power field of view. Although NGC 3628 eludes most backyard observers who must contend with city lights, the entire Leo Trio is an easy catch for telescopes under dark country skies.

BERNHARD HUBL

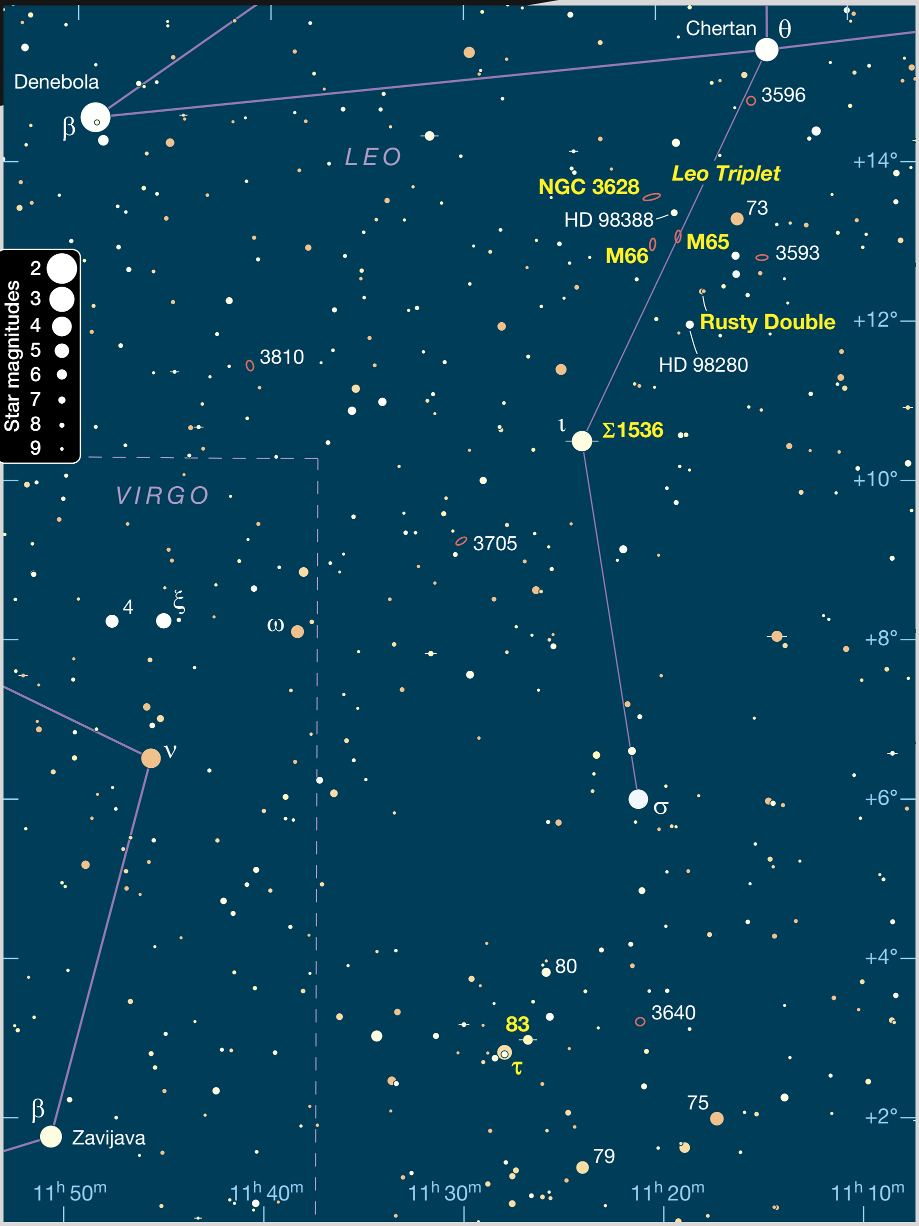
Delightful But Difficult

The galaxies in question, **M65** and **M66**, are usually referenced together because their hubs are just 20′ apart — they're a two-for-one deep-sky deal. Better yet, the side-by-side spirals are relatively prominent. M65 glows at magnitude 9.3; M66 is magnitude 8.9. Size-wise, the former is 9.8′ by 2.9′ in extent, while the latter measures 9.1′ by 4.1′. Canted attractively on similar angles, the sibling galaxies are a telescopic treat.

Or maybe not.

The party-pooper is light pollution. Not many galaxies are muscular enough to punch through the metro murk that frustrates most 21st-century observers. I chase faint fuzzies only during the clearest weather conditions — my suburban sky is awful enough without any haze or moonlight in the way. The observations of southeastern Leo described below were conducted in my backyard on a night of almost tolerable clarity, using two basic reflecting telescopes. I can declare with considerable pride (and a smidgen of stubbornness) that I didn't Go To; I star-hopped.

My staging point was 3.3-magnitude Theta (θ) Leonis, the vertex of the triangle outlining Leo's hind end. From Theta (also known as Chertan), I aimed my 10-inch f/6 Dobsonian a bit more than 2° southward and a tad eastward to 5th-magnitude 73 Leonis, which the scope's 8×50 finder picked up easily. After centering 73 Leonis in a low-power eyepiece, I shifted the Dob ¾° eastward to a solitary, 7th-magnitude star, HD 98388. A gentle nudge 18′ south of that marker netted M65. Slightly brighter M66 materialized 20′ east-southeast of M65. The two galaxies were framed in a single field of view.



▲**LEO'S LEGS** The Lion's hind legs are outlined by 4th- and 5th-magnitude stars. Those dim markers can be used to locate two well-known spiral galaxies and several double stars. While the visibility of the galaxies is compromised by city light pollution, the doubles are plainly visible in backyard telescopes.

Well, sort of. They weakly surmounted the soupy sky, appearing as whitish nebulosities at 64×.

M66 did outshine M65, but in every other respect the objects looked alike. Each galaxy exhibited a condensed hub surrounded by an extremely diffuse, elliptical halo aligned roughly north-south. Increasing the magnification didn't help matters — the lame lumps of light simply dissolved into the soup. Bravely, I tried to snare the galaxies using my 4¼-inch f/6 Newtonian reflector. Applying 54×, I centered the scope on HD 98388 and — hallelujah! — two pale puffs emerged out of the ether. Again, however, additional magnification produced no improvement.

Pushing my luck, I attempted the edge-on galaxy situated 36′ north of M66. Oriented east-southeast by west-northwest, **NGC 3628** turns our tandem into a trio. Problem: Although NGC 3628 is listed at magnitude 9.5, its light is spread over an area measuring 13.1′ by 3.1′. The galaxy's overall surface brightness works out to magnitude 13.4, which is more than half a magnitude dimmer than the same metric for M65 and M66. Worse for us urbanites, a photon-blocking dust lane runs the length of NGC 3628. I glimpsed the elusive edge-on in my trusty 10-inch but not the 4¼-inch.

Bonus Treats

Sometimes during our explorations of the deep sky, we encounter small yet pleasing star patterns we've never come across before. The element of surprise is one of the many reasons I enjoy star-hopping so much.

Astro-serendipity was on my side many years ago when my hop from Theta Leonis toward M65 and M66 accidentally (or sloppily) jumped right past 73 Leonis. In doing so, I noticed that 73 shines at the top of a 1.5°-long chain of half a dozen 7th- and 8th-magnitude stars meandering south-southeastward down one of Leo's hind legs. My attention was drawn to the second-last link in the chain, where two stars flicker at magnitudes 7.6 and 8.7, separated by 84″. The rusty-hued combo was obvious at low power. Oddly, my Rusty Double doesn't appear to be cataloged as an official double.

A proper binary system is located not far below the chain of stars mentioned above. The prize is 4.1-magnitude Iota (ι) Leonis, which hangs 2° southeast of 6.7-magnitude HD 98280, the last link in the chain. Identified in double star catalogs as **Struve 1536** (Σ1536), Iota harbors a 6.7-magnitude sun 2.3″ eastward. It's a tightly spaced, strongly uneven binary. I could detect the secondary sun in my 4¼-inch scope at 186×, provided the atmospheric seeing was steady. The 10-inch could split Σ1536 at 169×, and the result was truly satisfying at 218×.

There was more scenery farther south. Getting to the exact spot meant a couple of biggish hops, but thankfully they involved stars easy to see in my 8×50 finders (and binoculars, too). From Iota, I dropped southward 4½°

WIDER VIEW This 2.8°-wide field not only shows the Leo Galaxy Trio, but also the attractive arc of stars situated to the south and west of the galaxies. The warm-hued pair of stars at the southern end of the arc is an uncataloged binary the author has dubbed the Rusty Double. The small galaxy just right of the arc is 10.9-magnitude NGC 3593. It shows easily in photos but was beyond the range of the author's backyard scopes.

ALAN DYER

to 4.0-magnitude Sigma (σ) Leonis, then veered southeastward about 3½° to 5.1-magnitude **Tau (τ) Leonis**. A yellow-orange star, Tau is accompanied by a 7.5-magnitude dot 89.2″ southward. Shifting 20′ west-northwest of Tau brings us to a nice set comprising 6.6-magnitude **83 Leonis** with its 7.5-magnitude attendant 28.6″ southeast of it. Together with their companions, Tau and 83 Leonis make a low-power double-double in any telescope. Indeed, my tripod-mounted 10×50 binoculars resolved the Tau twosome and (barely!) 83 Leonis.

My binoculars revealed something else: Tau and 83 Leonis, plus three other 6th- and 7th-magnitude stars, are arranged in a 1¼-degree-long crescent, slanted steeply southeastward. The northernmost point of the shallow curve is established by 6.4-magnitude 80 Leonis, while the southeastern end is anchored by a 7.3-magnitude star glimmering about 8′ southeast of Tau. The quintuple crescent was conspicuous in the binocs — and my scopes, too. Discovering an asterism is always fun, the modest treasure here being the five main components of the eye-catching arc, plus the 7.5-magnitude companions of Tau and 83 Leonis.

Risin' Lion

As March opens, Leo rises in the east at nightfall. Our area of interest isn't well placed until late evening, but I hope you'll set up a scope before bedtime. Just be aware that this year the waxing Moon climbs high toward the end of the first week of the month. You'll get another chance near the end of March when Leo's rear-end region will be somewhat better placed, roughly halfway up the southeastern sky and with no moonlight to compromise your view. Evening scoping is best in the second half of April when the Lion reigns supreme, high in the south.

Doubtless you'll agree that the galactic Trio in Leo is the greatest challenge in my tour. But if your south sky is superior to mine (and I hope it is), you should be able to pick up the tough telescopic triptych. Remember to use low magnification and aim carefully. The sight of three large galaxies — each an island universe — in a single eyepiece field can be deeply satisfying.

Despite your sky, give the Trio a try!

■ Longtime Contributing Editor **KEN HEWITT-WHITE** has never seen a real lion, but he and his wife have a trio of relatively tame cats.

A Lion's Share

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M65	Galaxy	9.3	9.8′ × 2.9′	$11^h 18.9^m$	+13° 05′
M66	Galaxy	8.9	9.1′ × 4.1′	$11^h 20.3^m$	+12° 59′
NGC 3628	Galaxy	9.5	13.1′ × 3.1′	$11^h 20.3^m$	+13° 35′
Σ1536	Double star	4.1, 6.7	2.3″	$11^h 23.9^m$	+10° 32′
τ Leonis	Double star	5.1, 7.5	89.2″	$11^h 27.9^m$	+02° 51′
83 Leonis	Double star	6.6, 7.5	28.6″	$11^h 26.8^m$	+03° 01′

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

Shades of Red

Help rebuild a database logging how dark the Moon appears during lunar eclipses.

▲ A measure of how well aerosols in Earth's atmosphere block and scatter light during a lunar eclipse tells scientists how much particulate matter a volcano such as Mount Pinatubo (shown here in 1991) has belched into the atmosphere.

When a volcano blows its top — as Krakatoa did in 1883 and Mount Pinatubo did in 1991 — it spews a lot of ash and particles into the atmosphere. That particulate matter can have global consequences on Earth's climate (not to mention our view of the universe). One neat way of estimating the particles' volume is by recording how dark lunar eclipses appear following an eruption.

It's in the shadow. Graduate student Lucas Boissel (Université Paris Cité, France) discovered his passion for *paleoclimatic studies* while working on his master's thesis, which explored the impact of early 20th-century volcanic eruptions on climate and society. He specifically focused on measuring the *stratospheric aerosol optical depth*. Volcanic ash in the stratosphere, upon contact with water molecules, transforms into *sulfate aerosols*, little particles of sulfur-bearing compounds. These reflect a fraction of the incoming sunlight and absorb outgoing infrared radiation, affecting Earth's energy balance. By using reports of contrasts in shading during lunar eclipses, scientists can estimate the concentration of aerosols in the atmosphere and their climatic effects.

During a total lunar eclipse, Earth sits between the Sun and the Moon. Any sunlight that reaches the lunar surface must first pass through our atmosphere, where it's *refracted* (bent) and directed moonward. Thanks to simple geometry (and a pinch of physics), we can determine how high up in the atmosphere the rays were when they traveled through en route to the Moon. Sunlight that passes closer to the ground in the troposphere (below 10 km, or 7 miles) is refracted and absorbed the most. During an eclipse, this light is bent so strongly that it focuses on the Moon's surface in the inner *umbra*, the darkest part of Earth's shadow. The troposphere is where weather "happens," so cloud conditions along the sunrise and sunset lines largely determine the shading of the inner umbra.

Higher up in the atmosphere, in the stratosphere, refraction is less pronounced. Sunlight passing through this layer falls in the outer parts of the umbra. Under normal circumstances, that light is less diluted than the rays traversing the troposphere, and so we see lighter shading. But a particularly potent volcanic eruption will spew ash into the stratosphere, which translates into a darker-than-usual lunar eclipse. Some eclipses have even been so dark they've been referred to as "invisible."

Wanted: Lunar eclipse data. Boissel's passion for his master's subject propelled him into his current PhD research — he's done a deep dive into lunar eclipse data from the 17th and 18th centuries. But now he'd like to extend that timeline into the 19th and 20th centuries. He's already perused multiple archives, such as those of the Paris Observatory library and the National Library of France, but collecting the relevant data is challenging, he says. Some readers may be familiar with Richard Keen (University of Colorado), who had established a network of aficionados to collect data on observations of lunar eclipse shadings. But Keen passed away in 2020, leaving much of his lifetime's work unpublished.

Now, Boissel hopes to revive that network (which he's planning to name LUNAE-Volc). If you're a professional astronomer and have access to your institute's archives or are an amateur and have kept extensive notes of past lunar eclipses, Boissel would be delighted to hear from you. In addition, he's looking for your observations of upcoming eclipses — for this, he's requesting brightness estimates using the Danjon scale (ranging from 0 for very dark to 4 for very bright eclipses), as well as information on local weather conditions. You can reach him at **l.boissel@hotmail.com**. Your data may help determine the impact of volcanism on Earth's atmosphere and ultimately refine climate models.

■ Editor in Chief **DIANA HANNIKAINEN** will henceforth view differences in shading during lunar eclipses in a new way.

STOCKTREK / GETTY IMAGES

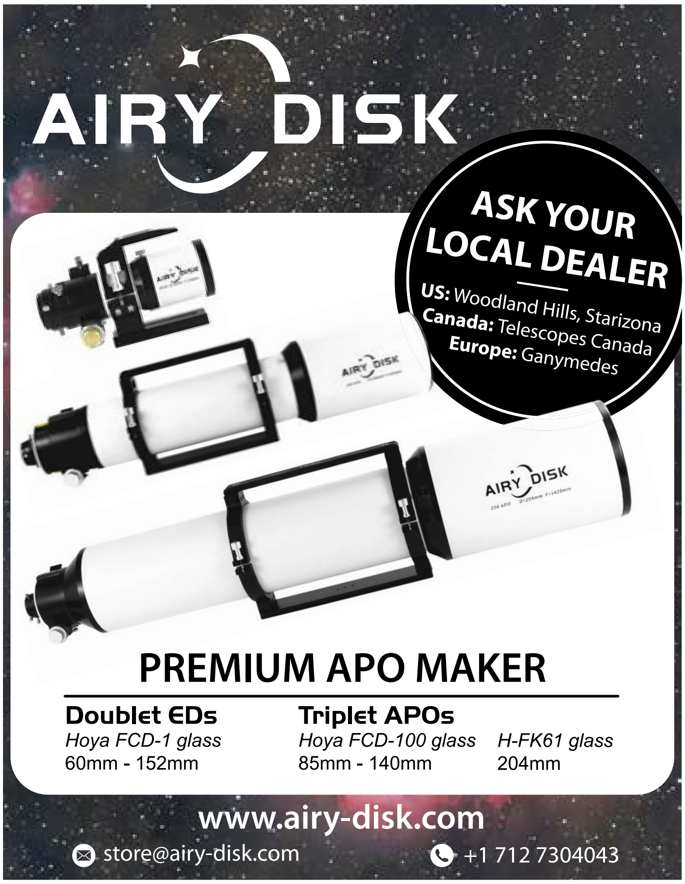

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Image: NGC 6891, a bright, asymmetrical planetary nebula in the constellation Delphinus, the Dolphin. (NASA)

The distant ice giant Neptune is a kaleidoscope of cloud activity.

Neptune is a lovely, lonely world. At the planet's vast distance past Uranus — Neptune lies 30 times farther from the Sun than Earth does and takes 165 years to complete a single orbit — high noon is as bright as our twilight. Yet that faint sunlight illuminates a planet surprisingly rich with activity.

Over the last several decades, Neptune has changed its appearance like an actor switching costumes between scenes. Festoons of white, puffy clouds come and go, strange and short-lived dark spots develop and dissipate — all potentially driven by the very Sun that lies so far away.

We've pieced together this view thanks to a variety of observations. Only one spacecraft has ever drawn near Neptune: NASA's Voyager 2, which zipped by in 1989. In the decades since, my colleagues and I have continued to explore Neptune's clouds using increasingly powerful telescopes here on Earth and in near-Earth space. We can even see the distant planet's weather change.

Yet although our knowledge has increased, Neptune keeps its secrets well due to its dimness and its small apparent size as seen from Earth (just 2.3 arcseconds in diameter). Our knowledge of Neptune's clouds therefore remains comparatively thin. However, every year we use new telescopes, new detectors, and new analysis techniques to grasp for more understanding. Here's some of what we know, and what is left to learn.

The Ice Giants

We call Neptune and its fraternal twin, Uranus, *ice giants* to differentiate them from their *gas giant* cousins, Jupiter and Saturn. We know from their shapes and gravitational fields (measured by Voyager 2) that the ice giants' atmospheres and interiors differ from those of their larger cousins (*S&T:* July 2023, p. 14).

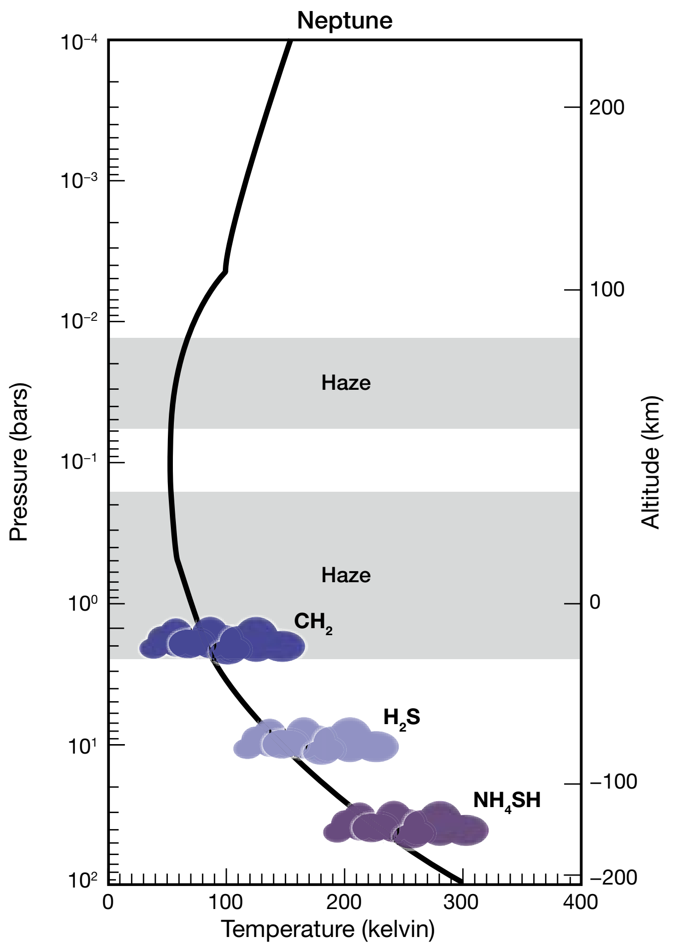
Jupiter and Saturn are primarily composed of hydrogen, with some helium and other things mixed in. Their cores are surrounded by a thick mantle of *metallic hydrogen* — a fluid phase that hydrogen adopts under very high pressure. Above this mantle lies an envelope of molecular hydrogen.

Neptune also has a small, rocky core. But we think Neptune's thick mantle is made of a briny mixture of water, methane, and perhaps other hydrocarbons. This mantle may take up some 80% of the planet's mass. Overlying the briny layer is an atmosphere consisting primarily of hydrogen and some helium (perhaps up to 10% of the total mass), along with gases that can condense to cre-

▶ **DISTANT GIANT** This near-infrared composite image from the James Webb Space Telescope shows Neptune amid a sea of stars. The bright "star" with diffraction spikes to the planet's upper left is actually its largest moon, Triton.

Seeing YOND the Blue

NASA / ESA / CSA / STSCI, IMAGE PROCESSING BY JOSEPH DEPASQUALE (STSCI) & NAOMI ROWE-GURNEY (NASA / GSFC)



▲ **NEPTUNE'S SKY** A layer of methane clouds (CH_4) floats above a deeper layer of hydrogen sulfide (H_2S). Models suggest that farther down, ammonium hydrosulfide (NH_4HS) clouds may exist. High-altitude hazes help obscure deeper regions. Discrete white clouds appear between 0.1 and 0.6 bar. The black line traces the atmosphere's conditions.

ate myriad discrete clouds and banded structure. This is the atmosphere we see at wavelengths visible to the human eye.

Whether the boundaries between the atmosphere, mantle, and core are sharp — like the boundary between oil and water — or more gradual remains unknown: We don't have enough observations to accurately model Neptune's interior structure with high confidence.

Methane Clouds and Layers of Haze

Let's instead consider the atmosphere that we see: the global layer of pale blue clouds that serves as the background to bright white storms, dark spots, and banded structure.

One of the most common misconceptions about Neptune's atmosphere is that its color is a deep azure blue. This misunderstanding resulted from the Voyager 2 images, which were processed to enhance the visibility of fainter clouds and banded structure. In fact, Neptune's true color is closer to a pale aquamarine. This color results when sunlight scatters off Neptune's atmosphere: Traces of methane gas absorb the red wavelengths of light, leaving the green and blue wavelengths to be scattered back to us observers.

Neptune is slightly bluer than Uranus. Recent cloud models explain why: To match the observations, the cloud deck at a depth of about 2 bars needs to be thicker on Uranus than on Neptune. Neptune's thinner cloud deck allows sunlight to penetrate deeper into its atmosphere before being reflected back out; this leads to more absorption by the red-absorbing gaseous methane and thus makes the planet bluer.

Even prior to the 1989 Voyager 2 flyby, we knew Neptune had an active atmosphere. Throughout the 1980s, I spent many nights studying this distant world with the University of Hawai'i 2.2-meter telescope on Mauna Kea. The Hubble Space Telescope had not yet launched, and advanced methods to remove the distortion from Earth's atmosphere in images had not yet arrived on the astronomical scene. Even with the best telescopes on the planet, I could only rarely catch clear glimpses of Neptune's tiny disk, when Earth's atmosphere was still and calm.

Nevertheless, I could see bright features traversing the planet's disk as it rotated rapidly. (Neptune takes 16 hours to make one rotation.) So, I expected a good show when Voyager 2 arrived.

Even so, both I and others were stunned by the panoply of clouds, bands, and raging winds that Voyager revealed.

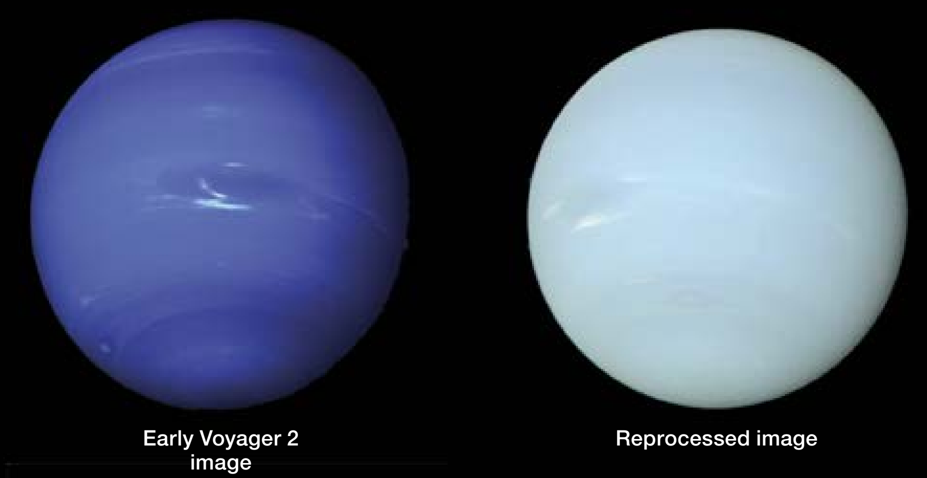
On Earth, the atmosphere is primarily molecular nitrogen, while water is the weather wonder-worker: Water's transformation through ice, liquid, and gas phases creates our myriad clouds, rain, and hail. Similarly, although Neptune's atmosphere is primarily hydrogen, methane acts as the primary condensable gas for the visible clouds. These clouds form at extremely cold temperatures, near 60K (−213°C, or −352°F), and at a pressure level in Neptune's skies of about 1 to 2 bars, which is similar to Earth's ambient surface pressure (1 bar). In other words, the white puffy clouds are likely methane-ice crystals that have condensed out of the methane gas in Neptune's atmosphere, much like Earth's white puffy clouds condense from water vapor in our warmer atmosphere.

Newer models of the atmosphere include observations at near-infrared wavelengths, which scatter off high-altitude clouds. These models suggest that above the main visible cloud deck extends a thin aerosol haze, which reaches high up into the planet's stratosphere. This haze layer, unlike anything we see on Earth, is almost certainly due to photochemistry: Sunlight interacting with gases like methane creates other molecules composed of carbon, hydrogen, and oxygen — compounds such as ethane, acetylene, carbon monoxide, and diacetylene, all of which we've detected in trace amounts.

If we could strip away Neptune's outer layers to see what lies underneath, we would find yet another, deeper layer of clouds. This layer extends down to a pressure of about 5 bars, the same pressure experienced at the depth limit of recreational scuba diving. We think this deep layer is made of clouds of hydrogen sulfide (H_2S) as well as photochemical byproducts from the higher layers. These byproducts may rain down from above, or perhaps huge clouds in the deep layer

BEATRIZ INGLESSIS / S&T, SOURCE: A. SÁNCHEZ-LAVEGA ET AL. / *THE ASTRONOMY AND ASTROPHYSICS REVIEW* 2023

TRUE BLUE The intensely blue image released shortly after Voyager 2's flyby is a byproduct of efforts to enhance the visibility of atmospheric features *(left)*. It bears little resemblance to a recently reprocessed version of Voyager data, calibrated to estimate Neptune's true color *(right)*.



PATRICK IRWIN

punch upwards like thunderheads and then subside, dragging the compounds downward as they do. Hydrogen sulfide clouds would be consistent with radio-wavelength measurements that probe to these depths, which suggest the presence of sulfur-bearing compounds.

Giant Dark Storms

Neptune's dim color belies its remarkably dynamic atmosphere. The Voyager view in 1989 was dominated by a huge dark storm we unimaginatively called the Great Dark Spot. Voyager also revealed that the bright white clouds I had seen in the 1980s were companion clouds skirting the edges of this giant dark storm. My very first Neptune observations with Hubble's refurbished optics in 1994 were most exciting for what was missing: There was no hint at all of the huge dark spot that dominated the Voyager images! In just five short years, it had completely vanished.

Subsequent Hubble observations over the next 30 years have revealed many more dark spots that appear and then vanish. The lifetimes range from one to six years. Small, bright white clouds often accompany the dark spots, floating at higher altitudes above the dark spots' edges. These clouds may form when atmospheric gases flow up and over the dark spot, where the methane in the gas can cool and condense into clouds.

If the white clouds are methane clouds, then what are the dark spots? Our highest-resolution data come from Voyager's observations of the Great Dark Spot. That dark vortex seemed to be created by an absence of clouds: a wobbly gap in the 2-bar cloud deck that revealed a deeper, darker layer. New models of more recent dark spots, however, link their appearance not to holes but to variations in the aerosols in that deeper 5-bar layer.

We won't solve the mystery with current equipment. Hubble and the 10-meter Keck Telescopes, along with NASA's Infrared Telescope Facility and large 8-meter telescopes such as those at Gemini Observatory's two sites and the European Southern Observatory's Paranal Observatory, have all served as key tools for studying the ever-changing atmosphere of Neptune. Yet Neptune's disk is so small as seen from Earth that we are hard-pressed to even resolve these dark vortices, let alone to truly understand their details or dynamics. Thus, we are still unsure what is driving their remarkably changeable behavior. Finding the answers will have to wait for the upcoming generation of 30-meter telescopes (*S&T:* Nov. 2018, p. 14), or a large space telescope that senses blue wavelengths, or perhaps even a future spacecraft mission to Neptune.

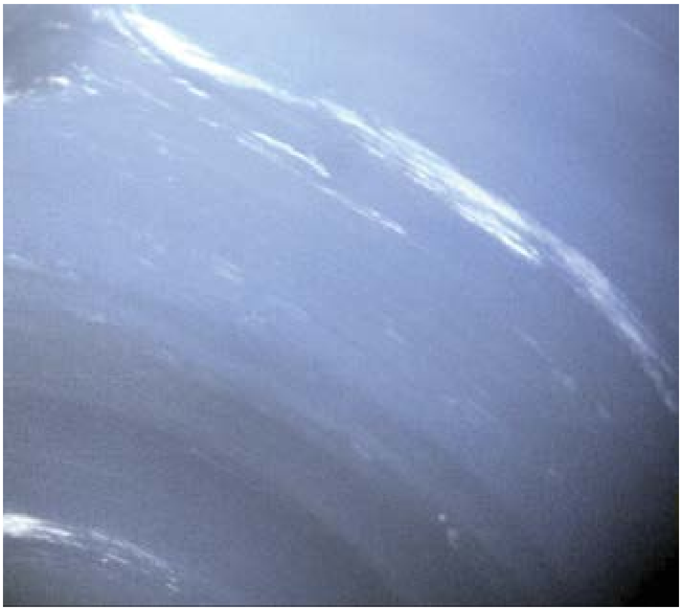
In the meantime, observations with the James Webb Space Telescope (JWST) will give us new insights into Neptune's atmosphere. JWST's first images of Neptune are spectacular and whetted our appetites, but the very best results — the spectroscopy — are yet to come.

A primary objective of our JWST studies is to untangle the complex interplay among different layers in Neptune's atmosphere. The layers interact both chemically and dynamically: Compounds move up and down, mixing and creating new molecules or being destroyed, all while wind currents shuttle gas to and fro and giant air cells rise and fall. In particular, JWST's ability to capture exquisite infrared spectra will enable us to study the composition and temperature variations of Neptune's atmosphere in unprecedented detail.

Neptune . . . and the Sun?

Until today's modern telescopes began to probe more deeply, Neptune's tiny disk as seen from Earth prevented nearly all atmospheric details from being seen. Nevertheless, beginning in the 1950s, astronomers at Lowell Observatory dutifully recorded the overall brightness of the planet, year after year, decade after decade. In recent years, amateur astronomers have also recorded these brightness changes.

The Lowell team noticed subtle changes in Neptune's brightness, which showed hints of being related to the



▲ **FESTOONS** White clouds scuttle across Neptune in this image from Voyager 2, processed to enhance the visibility of various features. The Great Dark Spot bleeds off the image's left edge.

planet's orbit around the Sun: Neptune's brightness steadily increased as it neared its solstice in 2005. But there also seemed to be a secondary signature imprinted on the data, and surprisingly it seemed to be correlated with the Sun's 11-year activity cycle.

Researchers suggested various solutions to this conundrum. The Sun emits significantly more ultraviolet radiation at the peak of its cycle than it does during solar minimum. This uptick in ultraviolet emission impacts the planets' atmospheres in various ways. Early on, some speculated that the variation in the Sun's output — even at distant Neptune — was somehow influencing the planet's upper tropospheric cloud cover.

Others speculated that high-energy particles from the surrounding galaxy might be a more important driver. The Sun's magnetic field usually shields the solar system from these particles, but that shielding effect weakens along with the field itself during the solar cycle's minimum. A fluctuating number of particles hitting Neptune's atmosphere could produce complex changes there. Yet another team of researchers suggested that solar maximum could lead to higher atmospheric temperatures, driving changes in a different way.

More recently, a new team reanalyzed all of Hubble's data on Neptune, starting with mine in the early 1990s and continuing through to the present day. They found a strong correlation between the number of methane-ice clouds and the solar cycle: As the Sun neared solar maximum, Neptune had more bright clouds.

The team hypothesized that the Sun's increased ultraviolet output triggered the formation of more photochemical products, which could in turn seed cloud formation. More clouds then increase the overall planetary brightness by reflecting more sunlight, explaining why Neptune looks brighter when the Sun is most active.

One thing that still puzzles us is how the feeble sunlight at Neptune's extreme distance could catalyze this change, since Neptune is 30 times farther from the Sun than Earth. This difference in distance would reduce what is blazing sunlight at Earth down to the light you might experience from an overhead office fixture. Perhaps all of the giant planets respond to the Sun this way, but the effect is swamped by the bright and dynamic cloud activity on Jupiter and Saturn and masked by the extreme seasonal variability of Uranus (*S&T:* July 2023, p. 14). Maybe only distant, cold Neptune is stable enough for this faint effect to be discernible.

This new study is probably not the last chapter in the story of Neptune's long-term variability. But it highlights the challenge of studying a planet whose seasons last for many decades: In my 39 years of studying Neptune, the planet still hasn't completed one full season. The first observations from Lowell Observatory were made when I was still in kindergarten, and some of the researchers doing the newest studies weren't even born yet when I was making the first Hubble observations of Neptune! The study of Neptune's atmosphere is by definition multi-generational.

Neptune in the Future

The many mysteries of Neptune's atmosphere continue to captivate me and my fellow planetary scientists. Why are its giant storms so short-lived? How can the feeble sunlight at Neptune's vast distance be driving atmospheric change? As described above, our current telescopes are chipping away at the planet's secrets, and soon JWST observations will usher in a new era in our understanding.

Neptune's secrets are crucial to today's burgeoning field of planetary science. With more than 5,000 exoplanets now known around nearby stars, we planetary scientists have a rich palette of planets to ponder. But to our surprise, the most populous class of planets seems to be one that is completely missing from our own solar system: worlds with sizes between those of Neptune and Earth (*S&T:* Feb. 2022, p. 20). To truly understand planets and planet formation, we need to know what these planets and their atmospheres are like.

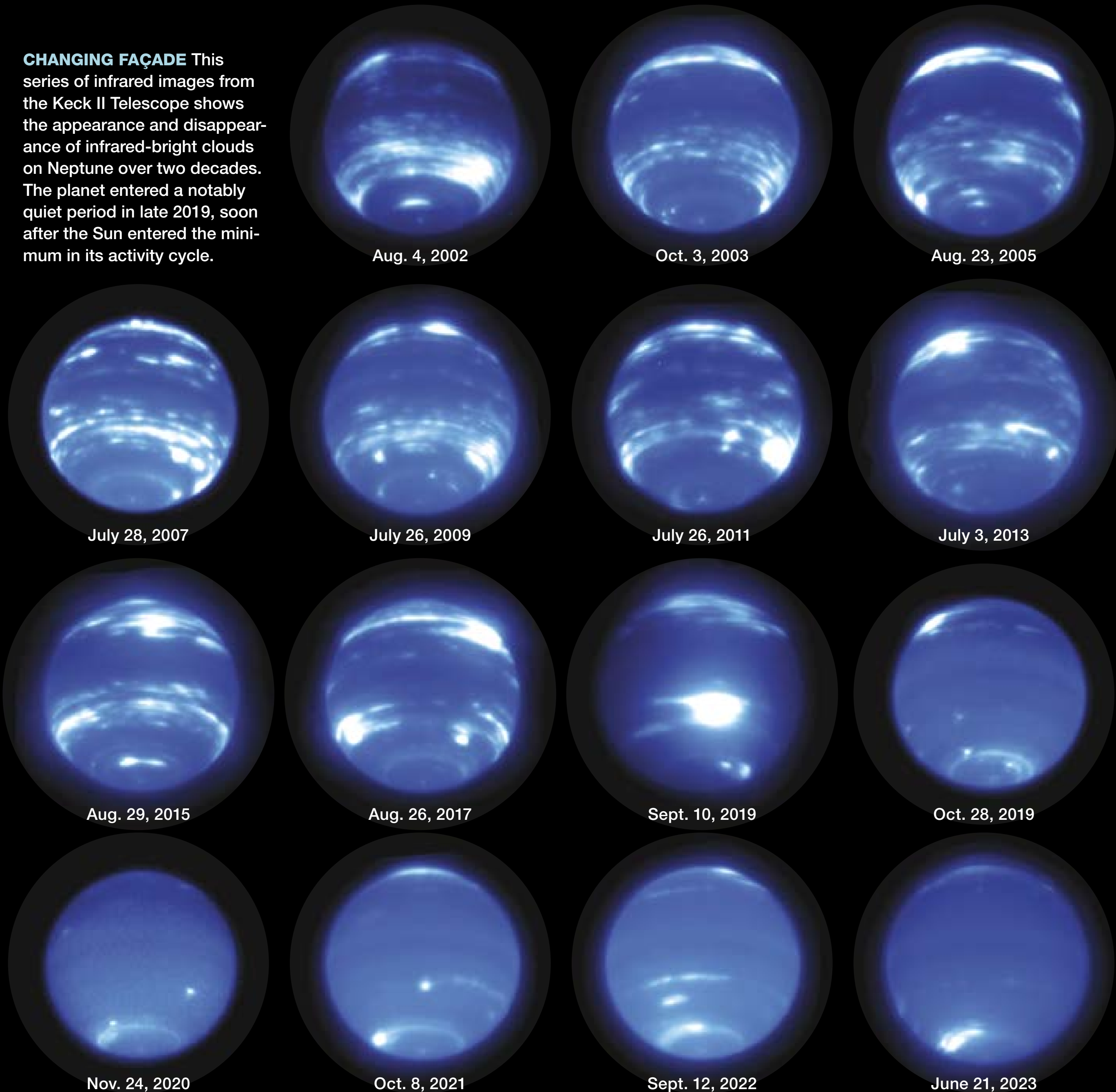
With no planets within this size range to study in the local neighborhood, our local "ground truth" is limited to extrapolation upward from Earth or downward from Neptune.

Looking ahead, I anticipate with keen interest the development of NASA's proposed Habitable Worlds Observatory. This telescope will be a "super-Hubble" that will open a brand-new chapter in Neptune exploration. It holds the promise of being able to deliver Voyager-quality images of Neptune's atmosphere any time it looks at this blue world!

Similarly, the new class of giant ground-based telescopes in development, which have mirrors measured in dozens of meters, may also reveal breathtaking details in Neptune's atmosphere.

Someday, we will send a modern mission to the Neptu-

NASA / JPL



CHANGING FAÇADE This series of infrared images from the Keck II Telescope shows the appearance and disappearance of infrared-bright clouds on Neptune over two decades. The planet entered a notably quiet period in late 2019, soon after the Sun entered the minimum in its activity cycle.

IMKE DE PATER, ERANDI CHAVEZ, ERIN REDWING (UC BERKELEY) / W. M. KECK OBSERVATORY

nian system, to do things that are beyond the capability of even today's finest telescopes. Such a mission could track the details of Neptune's variable clouds and perhaps even send a probe into the atmosphere. We learned so much with the Voyager 2 spacecraft, even though it was launched in 1977 with technology developed even earlier. Just imagine what a modern spacecraft might reveal with today's detectors and computational abilities.

The one thing we know for sure is that, whenever we do finally send a spacecraft to Neptune, the ice giant will put on a remarkable show for us. I can't wait!

■ **HEIDI B. HAMMEL** is the vice president for science for the Association of Universities for Research in Astronomy (AURA), which operates large telescopes for NASA and the U.S. National Science Foundation.

Testing Two Premium Refractors

Both new telescopes from Founder Optics have their strengths for visual and photo use.

Founder Optics Draco 62 and FOT86 Refractors

U.S. Price: $1,099 (Draco 62)
$1,399 (FOT86)
founderoptics.com

What We Like

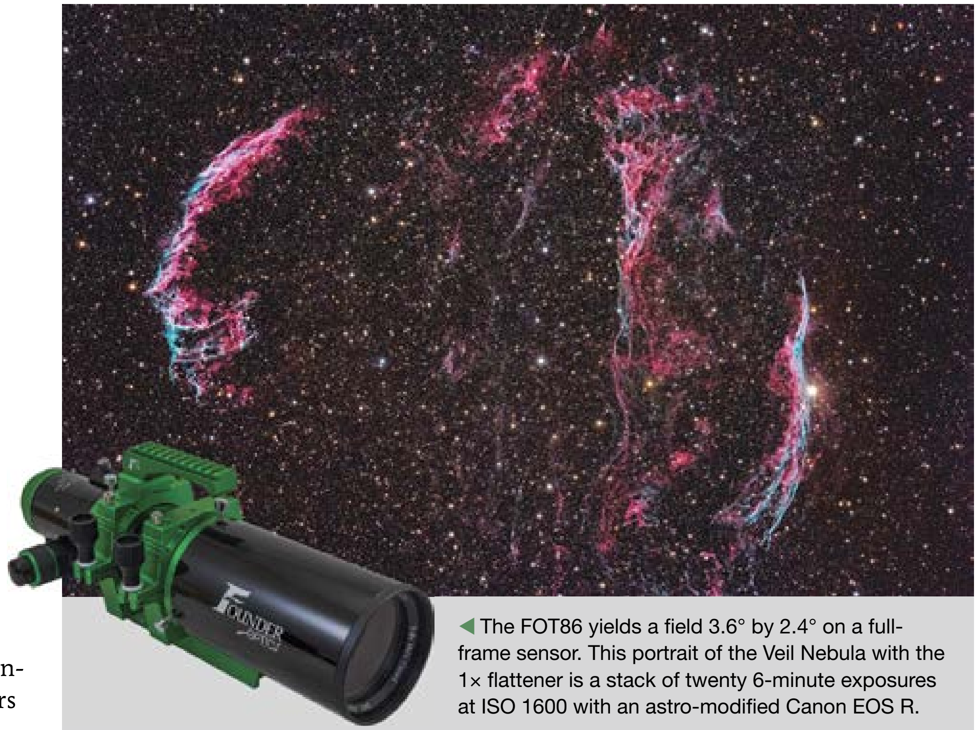
Corner-to-corner image sharpness

Very little vignetting on full-frame sensors

What We Don't Like

86-mm telescope's focuser is inadequate for imaging

62-mm could use a second dovetail shoe



◀ The FOT86 yields a field 3.6° by 2.4° on a full-frame sensor. This portrait of the Veil Nebula with the 1× flattener is a stack of twenty 6-minute exposures at ISO 1600 with an astro-modified Canon EOS R.

◀ The Draco 62 astrograph yields an expansive field of 8.2° by 5.5° when using its included 0.83× reducer. The wide field enabled framing the main parts of the Veil Nebula in Cygnus with the nearby cluster NGC 6940 in Lacerta, also with twenty 6-minute exposures but at ISO 800.

ALL IMAGES ARE COURTESY OF THE AUTHOR

WE ARE CERTAINLY enjoying an abundance of apochromatic (apo) refractors today. It seems a new company offering premium optics appears every few months. Among the latest crop is a relatively new name to the astronomy market, Founder Optics of Taiwan. Founder specialized in riflescopes and spotting scopes and recently began producing premium apo telescopes. I tested their two latest offerings — an 86-mm triplet, the FOT86, and a 62-mm quintuplet Petzval astrograph, the Draco 62. Both instruments were loaned to us by the manufacturer. While the telescopes are produced in Taiwan, Founder makes the point that the optics were designed by a renowned (though unnamed) Japanese lens designer.

Mechanical Impressions

Each telescope has Founder's signature livery of black tubes (in a glossy finish for the FOT86 and a matte finish for the Draco 62) with green anodized fittings for a striking appearance. My early impression, borne out after several nights of testing, is that the FOT86 is designed primarily as a visual telescope, but one that can be used as an astrograph. By contrast, the Draco 62 is first and foremost a photographic instrument that, unlike some competing small astrographs, can be used visually as well.

The FOT86 features a dual-speed (11:1), 2-inch rack-and-pinion focuser. The focus motion is beautifully smooth, steady, and precise. It holds 2-inch accessories with a twist-lock clamp or collet, rather than set screws pressing against a compression ring. While the twist-lock mechanism generally worked quite well, it didn't always hold accessories firmly. I often found a star diagonal and heavy eyepiece would still swivel when angled to one side even though I thought I'd tightened it sufficiently. I had to turn the clamp that extra bit, sometimes making it difficult to loosen again. It didn't quite have the same solidness as the rest of the focuser.

The entire focuser can rotate independently of the tube to place an eyepiece at a convenient position. However, it lacks any camera-angle adjustments for turning photo accessories independently of the focuser.

To use the scope for imaging, you have to install the included 1× field flattener. This accessory doesn't thread onto the focuser directly but instead is held by the twist-lock clamp like any visual accessory. Rotating the camera and flattener to frame targets without turning the focuser requires loosening the focuser's clamp — a process that inevitably shifts focus.

While I had no issues when shooting with my Canon cameras alone, those who use imaging trains that include off-axis guiders, filter wheels, and hefty dedicated astronomy cameras might find the attachment less secure than the threaded connections most dedicated astrographs employ.

Although the top handle is nicely sculpted to fit the hand, it lacks any threaded holes for bolting on accessories. It's milled with a dovetail rail, but it is the "Picatinny" standard commonly used for riflescopes. (The name derives from the Picatinny Arsenal in New Jersey that developed the mounting standard.) Only some red-dot finders repurposed from the hunting market incorporate such a mechanism. However, the focuser does have a single dovetail shoe that accepts the Synta-standard finders and guidescopes we astronomers use.

By contrast, the Draco 62's top handle is machined with a Synta-style shoe, though it comes with a separate Picatinny rail as well that can slide into that shoe. I doubt most astronomers would ever use that accessory. However, the Draco 62 lacks an accessory shoe on the focuser, nor does it have any place to mount one. As a result, like the FOT86, the Draco 62 has just the one Synta-standard attachment point. A second shoe is often useful for guidescopes, finders, and especially for those ride-along control computers so popular among astro-imagers today.

The Draco has a two-speed (again 11:1) focuser but of the Crayford design. This type of focuser can be prone to slippage — however the one on the Draco scope proved smooth and precise, with no slippage even when unlocked. While it offers only 25 mm (1 inch) of travel, I had no issues reaching focus with either its camera adapters or with 1¼-inch eyepieces using the supplied visual back.

The Draco's focuser does have a smooth camera angle adjuster that doesn't shift focus when turned. While the unit has a scale scribed in 1° increments, there's no index mark to aid setting the angle — an apparent oversight in the finishing. The focuser itself is non-rotating. With such a small scope, I never found this to be an issue. The tube can be rotated within its mounting ring for those who prefer the focuser knobs on top, perhaps to accommodate an electronic focuser.

The camera side of the Draco's focuser has four sets of opposing screws to adjust the tilt of the rear plate. Thankfully, I never had to fuss with those; out-of-the-box images were consistently sharp across a full-frame sensor.

Unlike the FOT86, the Draco's camera adapters screw into the focuser's M64 female threads. Two adapters are provided: one with M54 male threads on the camera side, and one with M48 threads. I always shot with the latter. Each uses a common adapter ring that accepts standard 2-inch (48-mm) filters. The front end of the Draco's dew shield accepts 77-mm lens filters, though they will be fully exposed to dew and glare, so would be useful only

▲ *Left:* A dedicated 1× field flattener and M48 and M42 adapter rings on the camera side are included with the FOT86. In addition, a 1¼-inch visual adapter is supplied but no star diagonal. *Right:* Accessories that come with the Draco 62 include a star diagonal and visual back, camera adapters with M48 or M54 camera-side threads, and a 0.83× focal reducer.

in the daytime when the scope serves as a telephoto lens.

Visual Performance

Both refractors came with documentation describing each particular unit's performance under a Ronchi test and a star test, which I assume was performed on an optical bench with an artificial star.

To verify the included test report, I conducted my own star tests. Such an evaluation can reveal aberrations that might go unnoticed in photos, and reveal the nature of flaws seen in star images. The FOT86 passed the star test handily, showing nearly identical stellar disks on either side of focus, with no sign of elongation from on-axis astigmatism. The extra-focal disks looked slightly asymmetrical, similar to the images in the test report, indicative of a minor level of spherical aberration. However, as Harold Richard Suiter states in his standard reference work *Star Testing Astronomical Telescopes* (Willmann-Bell/AAS, 1994), ". . . the star test for spherical aberration is almost too sensitive. It is so revealing that nearly any telescope fails casual inspection."

Out of curiosity, I compared the FOT86 with a new Astro-Physics Stowaway 92 — an instrument that many apo aficionados would consider the gold standard. The Stowaway exhibited identical extra-focal patterns on either side of focus, but the FOT86 was just a notch below that legendary refractor's performance. I'd give it an A– grade vs. the Stowaway's A+.

The FOT86's objective lens is an air-spaced triplet with one element made of Ohara FPL53 low-dispersion glass and one of FPL51 (as stated by Founder; I have no way to verify that claim). However, the FOT86 showed no false color fringing on the lunar limb or on bright stars, either in focus or when racking through focus. This level of correction is a cut above many of the new apos I've tested of late with undisclosed glass types, which, while very sharp, still showed some residual chromatic aberration.

As noted earlier, the Draco 62 astrograph can also be used visually. It comes with an excellent 1¼-inch dielectric-coated mirror star diagonal. Due to its Petval optical design, which places the focus point close to the rear flange of the focuser, you need to unscrew the diagonal's front nosepiece and thread it onto a supplied thin visual back in order to couple the diagonal as closely as possible to the telescope.

All the 1¼-inch eyepieces I tested reached focus, including dual-format models from the Baader Morpheus series and an 8-mm Ethos, the latter only just! A 24-mm 68° Panoptic eyepiece, which yields the widest field possible in a 1¼-inch barrel, was fully illuminated, which indicates the scope's baffling doesn't impinge on the objective's light path.

For star-test marks I'd give the Draco a B+. Star images showed a low level of spherical aberration, plus some false color on either side of focus. And yet, the Airy disks of bright stars in focus looked nearly textbook-perfect and color-free. The fact the Draco can be used visually is a welcome bonus when traveling to foreign skies and reduces the need to bring along a second scope. But unlike some competing 60-mm apos, it can't be used with 2-inch eyepieces.

Photographic Performance

From the photo tests I have little to report, as both telescopes yielded nearly flawless results. I tested the FOT86 with its included 2-element 1× field flattener. This optic was made specifically for the FOT86 and retains the telescope's native f/6.5 focal ratio and 560-mm focal length. A "universal" 0.8× reducer is offered as an optional ($135) accessory but was not supplied in our test package.

▶ The rack-and-pinion focuser of the FOT86 at right has a large lock knob, but the lack of threaded holes prevents adding an electronic focuser. However, the Crayford focuser of the Draco 62 (far right) can accept an electronic focuser, and the included instruction leaflet explains how. The FOT86's Vixen-style dovetail rail is 18 cm (7 inches) long; the Draco's is a generous 25 cm long.

▶ *Right:* The dew shield of the FOT86 extends by 100 mm, while its focuser has a range of 95 mm. The scope weighs 5.1 kg (11.2 lb) and when collapsed its tube length is 46 cm. The Draco 62's dew shield at far right extends by 65 mm, but its focuser has a range of only 25 mm. The tube weighs 3.25 kg and is 28 cm long when collapsed.

The Draco 62 incorporates an air-spaced triplet objective and a 2-element flattener integrated into its body for a quintuplet Petzval design. Natively, the Draco is f/4.8 with a 300-mm focal length, yielding a 6.8° by 4.5° photographic field. A 0.83× reducer is included with the scope which employs just a single, thick meniscus lens. Using it yields a focal ratio of f/3.9 and a focal length of about 250 mm.

Images shot with my full-frame Canon R and R5 cameras showed pinpoint stars out to the very corners with both scopes at their native focal lengths. Only the Draco 62 with its reducer exhibited a pixel-peeping level of astigmatism at the extreme corners. The corner-to-corner sharpness of both Founder refractors was as good as I've seen in any telescope at any price. On-axis I saw no odd bright flares often attributed to pinched optics in budget refractors. One proviso is that I did all my star testing on warm summer nights. Cold temperatures can introduce astigmatism from lens cells pinching optics, but I couldn't test for that issue.

What I found most impressive is the almost complete lack of any vignetting or light falloff at the corners with either telescope. Even with its little 0.83× reducer, images with the Draco 62 looked nearly uniformly illuminated across a full-frame sensor, with just some central brightening creating a mild gradient that was easy to deal with in processing. I don't know how the small reducer lens is able to accomplish field illumination as uniform as this. By contrast, at f/4 most telescopes, especially when that speed is achieved via a reducer, show significant light falloff across the frame.

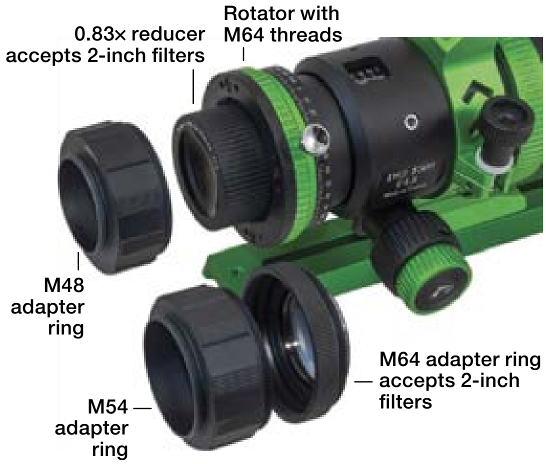
While the FOT86 works well photographically, I think its mechanics make it best paired with a light and simple imaging rig such as a DSLR or mirrorless camera. On the other hand, the Draco 62 is a superb choice for anyone shooting with a full-frame camera. Its performance prompted me to re-shoot photogenic star fields along the Milky Way, and I got my best results to date.

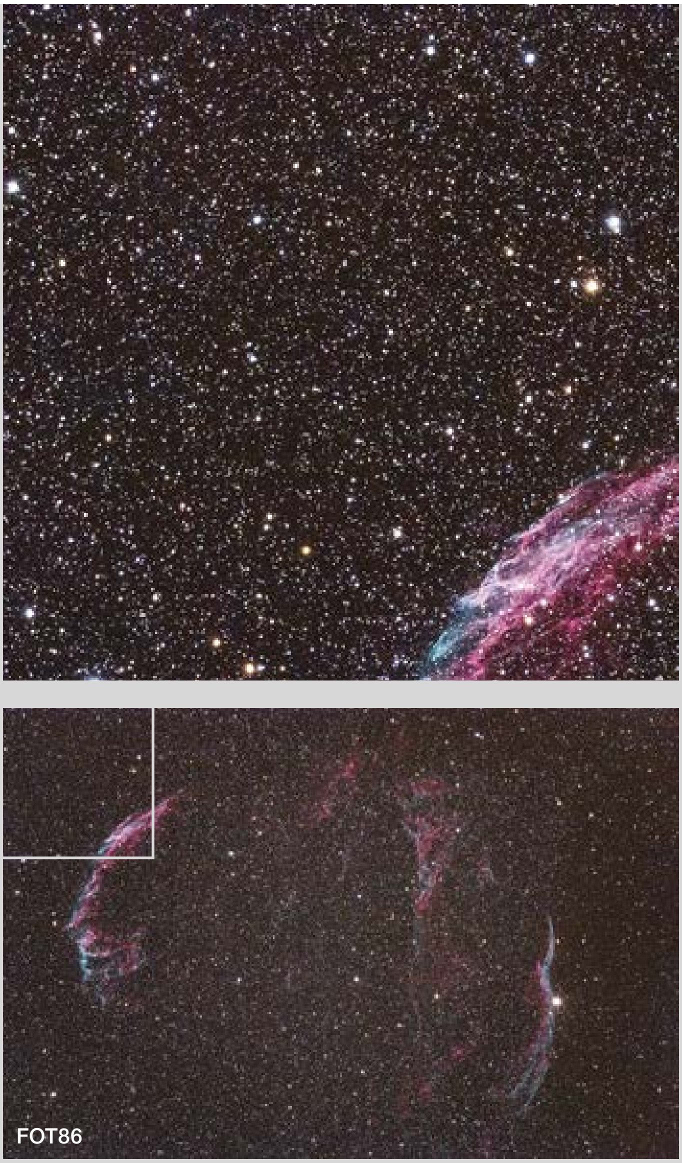
▲ The FOT86 seen at left comes in an aluminum case with places for all the accessories. While the handle is supplied separately, the telescope did fit into the case with it attached. The Draco 62 at right arrived in a cloth case, which itself is stored in a large backpack with room for a small star tracker head. Both scopes include well-illustrated and useful printed instruction manuals.

▲ *Left:* The top handle on the FOT86 accepts only Picatinny standard accessories, such as this red dot finder. The focuser does have a Synta-style finder shoe. *Right:* The Draco 62's handle has a Synta-style shoe, plus an accessory Picatinny rail. But the focuser lacks an additional shoe and provisions for mounting one.

▲ The air-spaced triplet lens of the FOT86 (left) is thoroughly multi-coated and in a tube that is blackened with four knife-edge baffles. The Draco 62's objective (right) is also a triplet, in a blackened and ribbed tube, with a doublet flattener integrated into the rear of the tube.

◀▶ *Left:* The FOT86's 1× flattener accepts 48-mm (2-inch) filters and comes with a choice of M48 and M42 camera-side adapter Rings. *Right:* The Draco 62 has two camera adapters, with M48 and M54 camera-side threads. The M64 ring is required when shooting at f/4.8, but not when using the reducer, which threads into the focuser. Either adapter ring then threads over it. The reducer and the M64 ring each accept 2-inch filters.





▲ The FOT86 with its 1× flattener at f/6.5 yielded pinpoint stars to the corners of a full-frame sensor. There was no sign of astigmatism distorting stars into birds! All corners looked the same, with no focal plane tilt.

▲ At its native f/4.8 focal ratio, the Draco 62 was virtually perfect across a full-frame sensor. This and the other test images are single fully developed RAW files from a stack used to produce a final image.

Recommendations

As of this writing, Founder Optics' dealer network is limited. Even their own website contains limited information about some of their products. But from my testing I can assure potential buyers that the two telescopes do perform very well, with image quality visually and photographically the equal of (if not a cut above) the competition in the crowded marketplace of apochromatic refractors.

The FOT86 would nicely serve visual observers looking for a top-quality, grab-and-go or travel telescope. It works well on a portable alt-azimuth mount or a smaller equatorial, such as a Sky-Watcher EQM-35. Its visual sharpness can compete with the best apos out there. While I was impressed with its photo capabilities, some users may find its shortcomings for attaching advanced imaging gear a deal-breaker.

The Draco 62, due to its fast speed yet sharp, flat field, quickly became my favorite astrograph for wide-field, deep-sky astrophotography. It worked well with my Sky-Watcher Star Adventurer GTi mount as a compact rig for use on the road. The Draco 62 proved to be the best of several telescopes in the 50-mm to 70-mm aperture class that I've tested in recent years. I applaud Founder Optics for entering the market with some excellent scopes to further tempt apo fans.

■ Contributing Editor **ALAN DYER** is co-author with Terence Dickinson of *The Backyard Astronomer's Guide*. Visit his website at **amazingsky.com**.

▲ With its reducer installed, the Draco 62 operates at a focal ratio of f/3.9. Only here did images show the slightest amount of astigmatism and lateral chromatic aberration at the extreme corners, but at a level the printed page might not show.

▲ These test photos framing the field around Vega were shot in twilight and moonlight to show the field illumination. They are single RAW files captured with a full-frame Canon R5 camera, but with the contrast boosted to exaggerate any light falloff and corner vignetting. Only the f/3.9 configuration of the Draco showed some light falloff.

The Itty Bitty Radio Telescope

Have great fun with a surprisingly small instrument.

RADIO TELESCOPES ARE huge things, right? We've seen dishes that dwarf the buildings around them, even fill entire valleys. We've seen arrays of dishes that spread for miles, or in the case of the Event Horizon Telescope that images the accretion disks around black holes, span the width of the entire Earth. Given the enormous size and investment of these behemoths, what chance does an amateur astronomer have of getting into radio astronomy?

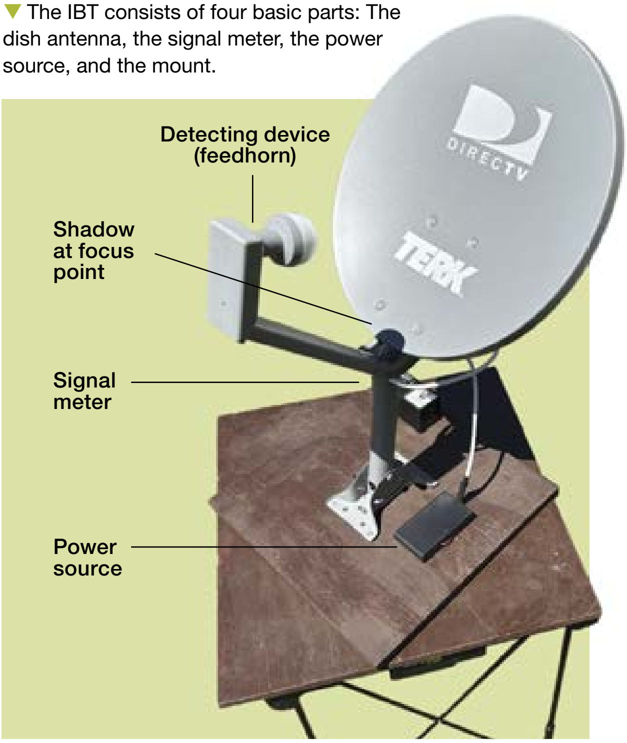
A very good chance, it turns out. Several years ago, Society of Amateur Radio Astronomers (SARA) members Chuck Forster and Kerry Smith came up with a design for a compact, even portable, and inexpensive radio telescope that you can build yourself. It's called the Itty Bitty Telescope (IBT), or sometimes the Little Bitty Telescope.

Oregon ATM Michael Caba recently built one, and he has had great success with it. Not in detecting black holes, but in getting people excited about radio astronomy at daytime outreach events.

How does the IBT work? The concept is pretty simple. It consists of a satellite TV dish, a signal meter, a power source, and a mount. When the dish is aimed at a radio source, the signal meter swings up the scale and (if the meter has an audio feature) a tone sounds.

What can you detect with it? The Sun, primarily. The Sun is by far the "loudest" radio source in the sky, and it has the added advantage of emitting visible light as well, so you can aim the IBT at the Sun simply by positioning the shadow of the feedhorn (the radio detector at the dish's focal point) at the geometric center of the dish. For a typical satellite TV dish, the geometric center is actually at its edge, which leads to some interesting discussions about geometry as well as radio astronomy. When the shadow falls on the sweet spot, the signal meter registers the influx of radio waves, and you know you've detected the Sun in the radio band.

▼ The IBT consists of four basic parts: The dish antenna, the signal meter, the power source, and the mount.



▲ The Itty Bitty Telescope is a popular item at daytime astronomy outreach events.

Which radio band, you might ask? The IBT is sensitive to signals between 12.2 and 12.7 gigahertz, which is the 2.5-centimeter band. Astute readers will recognize that this is in the commonly called "microwave" range of the spectrum, which is still considered radio.

You might think that aiming a dish at the Sun and watching a needle move on a gauge (and hearing a tone sound) would be pretty bland fare at an outreach event, but Mike reports that the IBT is often more popular than H-alpha or white-light views of the Sun. Because it's so simple to use, people love aiming it themselves and they're delighted to "find" the Sun with a scientific gadget.

Is your solar viewing event clouded out? No problem. The IBT can detect the Sun right through the clouds. Finding it is a bit trickier without the feedhorn's shadow, but the reward is that much more exciting.

It gets even better. Any warm object emits energy in the radio spectrum. That means the IBT will detect a warm tree or a building . . . or you! If you

ALL IMAGES COURTESY OF MIKE CABA

think people enjoy finding the Sun, just watch them pointing the dish at their friends and giggling as the meter detects their presence.

There are several online sources for instructions and parts to build your own IBT. The simplest is the SARA website at **https://is.gd/SARA_IBT**, where they sell a reasonably priced kit with all the hardware you'll need, minus the dish itself (which you can usually scavenge locally or purchase separately). You can also source the parts yourself, as Mike did, and build the telescope using instructions found at the National Radio Astronomy Observatory: **https://is.gd/NRAO_IBT**.

For those of you who get hooked on radio astronomy, SARA also sells a "Scope in a Box" that operates in the 2.5-gigahertz range and is capable of detecting the Milky Way as it sweeps overhead during the course of a night. You can find that here: **https://is.gd/SARA_ScopeBox**.

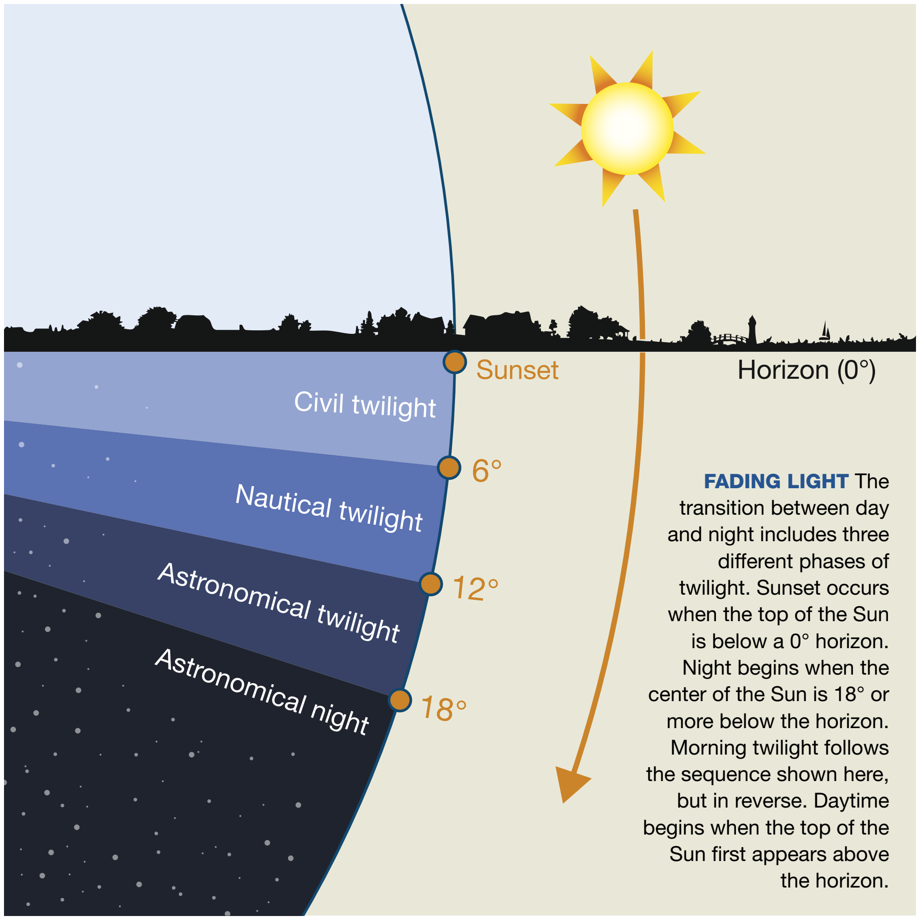
Note that the Astronomical League offers a Radio Astronomy Observing Program (**https://is.gd/RadioAOP**), and the IBT and Scope in a Box will help immensely with two of the five observing categories in which you can earn a certificate.

There's a ton of fun to be had in radio astronomy. So build yourself an Itty Bitty (radio) Telescope and get out there and have some!

■ Contributing Editor **JERRY OLTION**'s father built one of the first home satellite TV dishes out of chicken wire and wiring conduit.

▲ When the IBT is pointed at the Sun, the signal meter registers the influx of radio waves.

What is Twilight?



FADING LIGHT The transition between day and night includes three different phases of twilight. Sunset occurs when the top of the Sun is below a 0° horizon. Night begins when the center of the Sun is 18° or more below the horizon. Morning twilight follows the sequence shown here, but in reverse. Daytime begins when the top of the Sun first appears above the horizon.

FOR NIGHT-SKY ENTHUSIASTS, twilight is a time of anticipation — a seemingly interminable interval between sunset and when it's dark enough to start productively using a telescope. But there's so much more to it than that. I'll bet even some experienced observers don't know that there are three types of twilight or fully appreciate how it unfolds in different parts of the world. Let's delve into the topic a little deeper.

As with so much of astronomy, specific definitions apply to the condition we call twilight. The initial phase is known as *civil twilight* and is defined as the time between sunrise or sunset and when the center of the solar disk is as much as 6° below the horizon. Typically, you'll only see the Moon or Venus (assuming either is above the horizon) during this period. When the Sun is between 6° and 12° below the horizon, we experience *nautical twilight*. This is what most non-astronomers would simply refer to as nighttime. Towards the end of nautical twilight it's dark enough that you need a flashlight to see what you're doing, and you can trace out most of the brighter constellations. Lastly, there's *astronomical twilight*, which occurs when the Sun is 12° to 18° below the horizon. This is when the impatient among us uncover our scopes and start observing — it's not as dark as it can get, but it's still dark enough that planets and bright deep-sky objects look pretty good in the eyepiece. And when the Sun is more than 18° below the horizon, we enjoy *astronomical night*.

How long each phase of twilight lasts depends on your latitude. As a Canadian, I'm accustomed to long, lingering twilights. Indeed, from my home in southern British Columbia, astronomical twilight doesn't end at all for a few weeks around the summer solstice — the Sun is never 18° or more below the horizon. As a result, evening twilight merges seamlessly into morning twilight, skipping true night entirely. Yes, I can still use my telescope productively, but the observing window is very narrow. Indeed, it's not much of an accomplishment to pull an all-nighter during summer in southernmost Canada.

Of course, things could be worse too — the greater your latitude, the nearer you are to the Land of the Midnight Sun. Locations north of the Arctic Circle (or south of the Antarctic Circle) don't experience any twilight around the summer solstice — the solar disk never slips below the horizon.

Indeed, high-latitude spots are among the toughest places on the globe to be an amateur astronomer. For a good portion of the year it doesn't get dark, and for the rest of the time, the weather is often terrible! Conversely, for those who enjoy the night sky from locations near the equator, the three phases of twilight pass in rapid succession. For example, if you travel to Costa Rica to drink in the night sky around the summer solstice, you'll find that astronomical night arrives just 70 minutes after sunset. That same day-to-night interval takes a full 150 minutes from mid-northern (45° latitude) locations. Of course, this situation plays out south of the equator, too.

These differences are governed by the angle of the ecliptic (*S&T:* Sept. 2022, p. 74) in relation to the horizon. Far from the equator, that angle is very shallow. As a result, from my home in Canada, it takes much longer for the Sun to reach 18° below the horizon so that night can begin. However, from the tropics, the Sun seems to sink like a stone, following a path that's only a few degrees from being perfectly perpendicular to the horizon. ■

BEATRIZ INGLESSIS / S&T

CREPUSCULAR VILLA

Behyar Bakhshandeh

The colorful sunset above Carlsbad, California, is interspersed with dramatic crepuscular rays. In addition, supercooled water droplets in the cloud at right have suddenly frozen or evaporated, producing an intriguing phenomenon known as a fallstreak hole or hole-punch cloud.

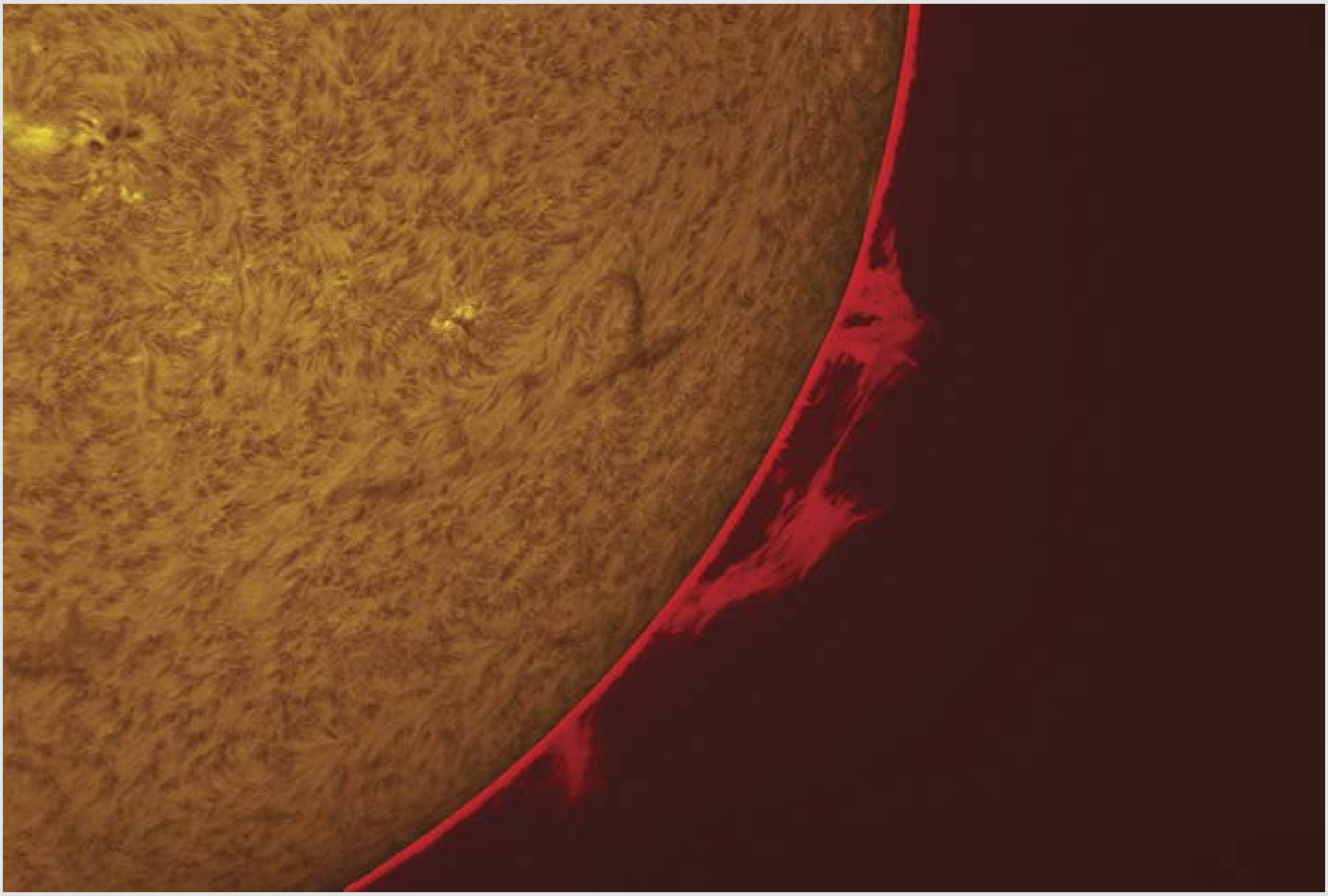
DETAILS: *Canon 5D Mark III camera and 105-mm lens. Total exposure: 1⁄30 second at f/4, ISO 100.*

THE KING'S DUSTY CROWN

Vikas Chander

The large, faint emission nebula in Cepheus designated IC 1396 is also home to the Elephant Trunk Nebula, VdB 142, seen just right of center.

DETAILS: *Takahashi FSQ-85ED refractor and ZWO ASI2600MC Pro DUO camera. Total exposure: 6.67 hours through a UV/IR-cut filter.*



△ PLASMA BRIDGE

Chris Schur

A large prominence is seen dancing along the solar limb on October 25, 2024. Minutes after this image was recorded, the prominence lifted off into space.

DETAILS: *Lunt LS100THa solar telescope and ZWO ASI183MM Pro camera. Stack of multiple video frames.*

◁ LOPSIDED REMNANT

Chris Schur

Located around 15,000 light-years away, Sharpless 2-224 in Auriga is a faint supernova remnant that dates back to an event that occured roughly 81,000 years ago.

DETAILS: *GSO 10-inch Ritchey-Chretien and Atik 16200 camera. Total exposure: 15 hours through narrowband and color filters.*

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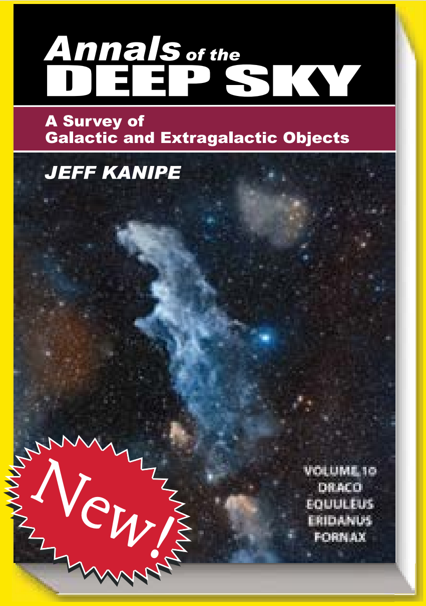

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Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

January 27–February 2
WINTER STAR PARTY
Scout Key, FL
scas.org/winter-star-party/?y=2025

February 7–8
EUROPEAN ASTROFEST
London, England
europeanastrofest.com

February 21–23
DEATH VALLEY DARK SKY FESTIVAL
Death Valley National Park, CA
https://is.gd/DVDSF

March 1
TRIAD STARFEST
Jamestown, NC
https://is.gd/tristar

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/GlobalAstroMonth

April 5–6
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 20–27
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

April 21–28
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 23–26
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 3
ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

June 19–22
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 21–28
GRAND CANYON STAR PARTY
Grand Canyon National Park, AZ
https://is.gd/GrandCanyonStarParty

June 24–29
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

June 25–28
ASTROCON 2025
Bryce Canyon National Park, UT
https://is.gd/astrocon2025

June 25–28
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 25–29
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

• For a more complete listing, visit https://is.gd/star_parties.

It's Time for Africa

Africa hosted the International Astronomical Union's General Assembly for the first time in August 2024.

IF SOMEONE WERE to ask you which parts of the world are the major players in professional astronomy, chances are that North America, Europe, and eastern Asia (specifically, Japan and China) would spring to mind first.

Well, that has to change, according to Kevin Govender (South African Astronomical Observatory). Govender chaired the National Organizing Committee of the 32nd General Assembly of the International Astronomical Union (IAU), which was held in Cape Town, South Africa, in August 2024. "This has been a great opportunity to showcase to the world what we're capable of," he says. "It's time for Africa."

It was the first time in the IAU's 105-year history that the triannual General Assembly was held on the African continent. During the opening and closing ceremonies at the Cape Town International Convention Centre, more than 2,000 astronomers from 105 countries across the globe were treated to traditional Zulu warrior dances and performances by the iThemba Youth Choir. But most importantly, the numerous scientific symposia often highlighted important African contributions.

Astronomy is not new to what was once pejoratively known as "the Dark Continent." The Royal Observatory at the Cape of Good Hope, established in 1820, was the first modern scientific institution in Africa; it evolved into the current South African Astronomical Observatory. Since the start of the 21st century, several projects have called Africa home. Namibia hosts the HESS gamma-ray observatory. In 2005, the 9.2-meter (effective aperture) Southern African Large Telescope, the largest optical instrument in the Southern Hemisphere, received first light. And last July saw the construction of the first 15-meter dish of SKA-Mid, the mid-frequency part of the Square Kilometre Array radio observatory, which will incorporate the existing 64-dish MeerKAT facility.

But for most of its history, African astronomy projects were initiated, operated, and funded by foreign organizations, usually former colonizing countries. This has only started to change over the past decades, says South African astronomer and former trade unionist Bernie Fanaroff. For instance, local artisans are largely responsible for the construction of MeerKAT and SKA-Mid, while government money has been invested to attract the best teachers to the high school in the nearby village of Carnarvon, where they train young people in science and technology. Fanaroff hopes and expects that other African countries will follow this example.

The 64-dish MeerKAT radio telescope in the Northern Cape region of South Africa forms an integral part of the Square Kilometre Array, which is being built on two continents.

SKAO / SOUTH AFRICAN RADIO ASTRONOMY OBSERVATORY

With the abolishment of apartheid in 1994, South Africa became a fledgling democracy. Back then, the government issued a white paper on the desired approach to science and technology. "Astronomy has been an essential part of that growth," says Govender. "In a sense, the ambitions of 30 years ago have led up to the IAU General Assembly being held here. This conference is the culmination and the celebration of three decades of investment."

Govender, who is also the director of the IAU's Office of Astronomy for Development, strongly believes that astronomy is the gateway to foster broader interest in STEM (science, technology, engineering, and mathematics) among young children and high-school students. That's why he made sure that each and every session of the IAU meeting was (and still is) freely accessible online, and why so many school visits were organized alongside the conference.

To the astronomers, space scientists, and instrument builders who flocked into Cape Town in August, Africa has certainly been put on the map as a major player in the field. The IAU's next General Assemblies, in 2027 and 2030, will be held in Rome (Italy) and Santiago (Chile), respectively. But as Takalani Nemaungani, the chief director for astronomy at the Department of Science and Innovation in South Africa, says, "I want to believe this is not the last time this event is coming to Africa, and it will surely no longer take another hundred years."

■ Contributing Editor **GOVERT SCHILLING** attended the IAU's 32nd General Assembly in Cape Town with the support from the VWN Trip Fund.


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