**WEBB UNCOVERS GALAXIES IN THE EARLY COSMOS** p. 36

SEPTEMBER 2024

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SPECIAL REPORT

# TOTAL SOLAR ECLIPSE

**Complete field reports from the sky event of the year!** p. 14

## PLUS

THE ANDROMEDA GALAXY IN MANY COLORS p. 24

HOW TO CREATE PRO IMAGES FROM WEBB DATA p. 38

THIS MONTH'S GREATEST CELESTIAL EVENTS p. 28

SECRETS TO SUCCESSFUL AUTOGUIDING p. 42

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# CONTENTS

42


SEPTEMBER 2024
VOL. 52, NO. 9


### ON THE COVER

Streamers festoon the Sun during totality on April 8. High, thin clouds over Torreón, Mexico, didn't prevent stunning views and images. BRENT BOWEN

## FEATURES



## COLUMNS



## IN EVERY ISSUE



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FROM THE EDITOR

# Living in the Moon's shadow

The total eclipse of April 8 provided a stunning spectacle for millions of viewers, as here captured from Colbrook, New Hampshire. GEORGE KONKOV

It's always an electric feeling standing under the Moon's shadow. A solar eclipse is a big-time astronomical event like few others, and many astronomy enthusiasts count their experience in the hobby by the number of "stripes" they have representing total eclipse viewings. When I awakened on the early morning of April 8 in Dallas, though, the situation looked bleak. Of the dozen total eclipses I had seen before, two of them had been socked in with clouds. There's nothing to bring down your spirits like seeing a total eclipse by watching the clouds get dim and then brighten again.

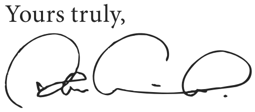
But this would not be my third disappointment. I was set up at Dallas Love Field, the historic airport facility, along with a slew of friends and associates from Celestron, as well as the folks from The Weather Channel. I spent most of the day off and on camera with the dynamic meteorologist Alex Wilson, and she demonstrated constant energy and enthusiasm. Almost miraculously, as we gazed southward where our weather was coming from, a large vertical clearing moved in, and we saw the entire eclipse with no problem at all. It was almost as if we had engineered it by special order.

It always amazes me how people watching total eclipses, especially those who are witnessing their first, become emotional when they see it happen. We've known about the precision clockwork of the heavens since the days of Johannes Kepler, but counting down, second by second, to the start of the first diamond ring and the start of totality always mesmerizes viewers. It's magical.

This issue contains our editors' reports on the big event. Alison Klesman was south of me in Ingram, Texas. Mark Zastrow and Daniela Mata were well south, in Torreón, Mexico. You can read about their exciting experiences and more in this package (page 14).

I hope you are looking forward to future eclipses, including the most exotic one to come in our lifetimes: Aug. 2, 2027, when the Moon's shadow will pass over the Temple of Luxor in Egypt.

Yours truly,



David J. Eicher
Editor

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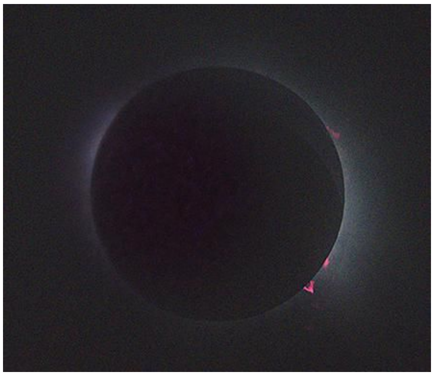


Though taken through clouds, this photo of the eclipse nonetheless shows glimpses of detail.
DAVID COPLEY

### Never give up

We spent thousands of dollars to drive the 1,200 miles to Texas to view the eclipse near Concan, Texas — and we were clouded out. We would get glimpses of partial phases, but during totality, my images showed only blackness. But I never gave up, and after a lot of post-processing magic, I was able to coax at least a little detail through the clouds. The image at left shows our sky during totality and what I was able to get through that dense natural filter, a stack of about 12 images during the last few seconds of totality. Then we saw nothing until just after third contact (then a bit of rain). We never saw the corona, which was my goal.

This was my first total (not annular) eclipse, and I have been waiting for over 50 years to see one (since I was 12). The last item on my bucket list is to see one. I'm hopeful for Australia, since it will take years to save up enough for the trip. **—David Copley,** Grand Junction, CO

*We welcome your comments via email to* **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

### Eclipsing event

My wife and I traveled from the Boston area to Waterbury, Vermont, for a three-day stay with old friends. When we made the reservations months ago, people there said we were nuts to expect clear skies in April, but in the end we had a fine layer of cirrus that didn't obscure meaningfully, and we got a good view of the corona. And the unusual color of the brief dusk and dawn, no red or orange tint, was just weird. As so many commentators have said, and we now understand in our hearts: No amount of description, and no photos, can prepare you for the utterly unique event. Two and a half minutes seemed forever then, and now seem like a moment. **—David Brooks,** Boston, MA

### Finding black holes

I do hope that you will continue to publish articles by Yvette Cendes. Her article on black holes (May 2024) was well written and understandable — quite an amazing feat for such a complex subject. Generally, when I read articles in *Astronomy*, I've had the feeling that they are written for a professional astronomer. Please keep nonacademics in mind in future issues. **—Jeannie Tabor,** Ripley, ME

SNAPSHOT

# COSMIC SEA CREATURES

## Euclid reveals active star formation, rogue planets, and more.

The reflection nebula M78 showcases in exquisite detail its luminous stellar nursery and bright blue stars inside the stomach of a large complex of star-forming dust and gas, giving the appearance of a pregnant seahorse. Young stars and planets previously hidden by dust have come to light thanks to the piercing ability of the European Space Agency's Euclid space mission.

M78 is an active star-forming region located about 1,600 light-years from Earth in Orion. Euclid has now unveiled 300,000 new objects in and around M78, including free-floating planets a few times heavier than Jupiter — a potential candidate for dark matter. The image shows another nebula, NGC 2071, at the head of the seahorse at top, along with an additional filament of star formation near the bottom of the image and a dark nebula that gives the seahorse its tail.

— SHARMILA KUTHUNUR

ESA/EUCLID/EUCLID CONSORTIUM/NASA, IMAGE PROCESSING BY J.-C. CUILLANDRE (CEA PARIS-SACLAY), G. ANSELMI. BOTTOM FROM LEFT: NASA; ANDREY SHELEPIN/NASA; MINETTI ET AL., *ROYAL SOCIETY OPEN SCIENCE*, 2024

## » HOT BYTES

**HISTORIC ASTROIMAGER**
The photographer of the famed Apollo 8 "Earthrise" image, William "Bill" Anders, was killed when the small plane he was piloting crashed on June 7. He was a NASA astronaut and U.S. Air Force Major General.

**HUMANITY'S SPACE ENDURANCE**
Cosmonaut Oleg Kononenko became the first human to spend 1,000 days in space, as of June 5. When he returns to Earth Sept. 24, he will have accrued 1,111 days, or more than 17,300 orbits.

**HORIZONTAL STUNTS**
Astronauts could use a cylinder motorcyclists call the Wall of Death to stay fit on the Moon, a study says. Participants using bungee cords to simulate lunar gravity showed that horizontal jogging generates enough force to prevent bone and muscle degeneration.

# ASTRONOMERS MEASURE A SUPERMASSIVE BLACK HOLE'S SPIN

X-rays from wobbling material around a black hole have allowed researchers to clock its spin — a first.

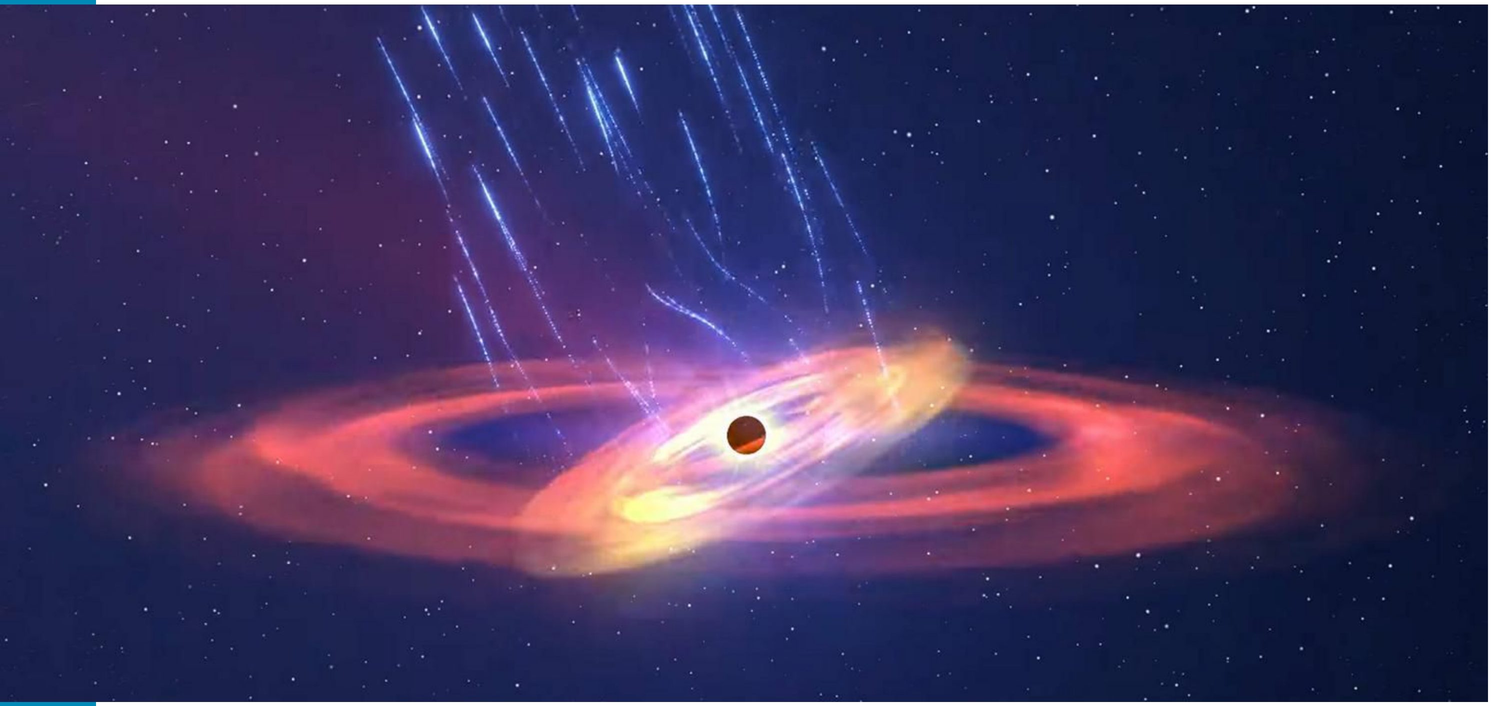


**PLATE OF LEFTOVERS.** As matter falls toward a black hole, it forms an accretion disk that revolves around the same axis around which the black hole spins. But when a supermassive black hole shreds a star, the resulting close-in accretion disk may be misaligned relative to the axis of any preexisting accretion disk, as well as the spin of the black hole. MIT

» Supermassive black holes lie in the centers of all large galaxies. A group of astronomers including researchers from MIT and NASA have, for the first time, measured how fast one of these behemoths is spinning. They did so by analyzing the aftermath from the black hole's recent meal of star stuff.

The team pioneered a technique that makes use of tidal disruption events (TDEs), which occur when a star passes too close to a black hole and is torn apart. This feeds the formation of a bright, rotating disk of stellar material around the black hole, known as an accretion disk.

The team, led by MIT astrophysicist Dheeraj "DJ" Pasham, spent several months tracking X-ray flashes from the black hole, which lies about 1 billion light-years away. Those flashes, they concluded, were generated as the newly created accretion disk bobbled back and forth under the influence of the central black hole's own spin. That's because as a black hole spins, it drags the adjacent fabric of space-time with it, which can affect nearby objects — such as an accretion disk. By working out the nature of that influence, the team could ultimately calculate how fast the black hole is spinning: less than 25 percent the speed of light. Relatively speaking, that's pretty slow.

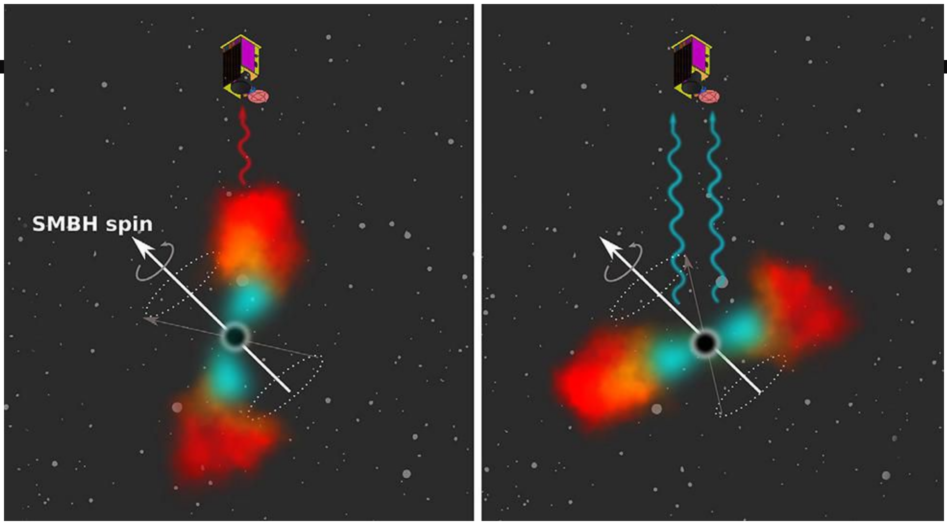
The team published their results May 22 in *Nature*.

Now the method can be applied elsewhere to perhaps hundreds of other nearby black holes, according to Pasham. In a press release, he said that "by studying several systems in the coming years with this method, astronomers can estimate the overall distribution of black hole spins and understand the longstanding question of how they evolve over time."

## HOW TO GROW A BLACK HOLE

Supermassive black holes range in mass from hundreds of thousands of times the mass of the Sun to millions or even billions of solar masses.

"Black holes grow in two ways: either




**A WOBBLY VIEW.** The team deduced that the X-ray flashes were the result of the misaligned accretion disk wobbling, or precessing, around the supermassive black hole (SMBH), shrouding its hot inner disk (blue-green) from view at times (left) but revealing it at regular intervals (right). COURTESY OF MICHAL ZAJACEK & DHEERAJ PASHAM

by accreting gas or by merging with other black holes," says James Miller-Jones, of Curtin University in Perth, Australia, who wasn't involved in the new study. But exactly how and when supermassive black holes grew to their current size isn't clear. "It is challenging to grow the most massive observed black holes in the time available," he says.

Better understanding black hole spins could provide clues. Black holes that simply accreted material from a stable disk should spin quickly. But "more chaotic accretion, such as from tidal disruption events, where the initial orbit of the shredded star could have been in any direction, is expected to lead to lower spins," says Miller-Jones.

The latter effect is because "some [TDE] episodes would spin the black hole in one direction and others in the opposite direction," says Adam Ingram, an astrophysicist at Newcastle University in the U.K. who wasn't involved in the new work. "This study finds that the supermassive black hole has a fairly modest spin, implying that it grew via many short, sharp episodes."

## A VALUABLE STEPPINGSTONE

Being able to measure the spin of a black hole and understand how it affects the space-time around it is a key test of general relativity and astrophysics, says Rob Fender, an astrophysicist at the University of Oxford in the U.K. who wasn't involved in the new study.

"It is hypothesized — and even accepted as a paradigm in some quarters — that you need a rapidly rotating black hole to produce the powerful relativistic jets we see with radio telescopes. If more studies like this can convincingly measure the spins of black holes and compare them to independent estimates of jet power, this is an important advance," Fender says.

Of course, black holes are notoriously difficult to study, notes Michael Nowak, an astrophysicist at Washington University in St. Louis who wasn't involved in the new study. "Black holes give us so few 'dimensions' to work with — pretty much just mass and spin, and secondarily age, and maybe thirdly the kind of galaxy it is in — that trying to tease apart their differences to understand their formation is really tough," he says. "The better we can get a handle on mass, spin, age, and location — and spin is by far the trickiest of those four to identify and measure — the better our prospects of understanding their formation."

Miller-Jones thinks the technique developed by Pasham's team holds "great promise" for the future. "Black holes are extreme objects that we cannot recreate in a lab here on Earth. Any improvement in our understanding of black holes tells us more about the behavior of mass and gravity at the most extreme densities," he says.

Plus, he adds, this study complements current gravitational-wave work to detect merging black holes, while future observations from the anticipated Laser Interferometer Space Antenna, set to launch in about a decade, might be able to directly detect merging supermassive black holes.

"Combining the information about black hole mergers from those gravitational-wave observatories with that from electromagnetic studies such as this X-ray technique should significantly improve our understanding of how supermassive black holes grow and evolve over time," he says.

— JOSEPH PHELAN

## QUICK TAKES

### SLEEPING GIANT
Astronomers processing ESA's Gaia mission data discovered Gaia BH3, the heaviest dormant black hole found so far in the Milky Way, at about 33 solar masses. It lies 1,900 light-years away in Aquila, also making it the second closest black hole to Earth.

### COINCIDENCE? I THINK NOT
A new study shows that as multicellular animals diversified and thrived during Earth's Ediacaran Period (635 million to 541 million years ago), the planet's magnetic field was fluctuating rapidly and at its weakest. Scientists believe these conditions may have increased oxygen levels and led to the explosion in life.

### NEW GALACTIC RECORD
JADES-GS-z14-0, observed by JWST, is the most distant galaxy yet known, appearing as it existed less than 300 million years after the Big Bang. The find is more evidence from JWST that galaxies in the universe formed much earlier than thought.

### RISING TO THE SURFACE
A new simulation of the Sun's magnetic field shows strong evidence that it is produced by activity at a shallow depth of 20,000 miles (32,180 km) below the surface, rather than deep in the star's interior, as previously believed.

### NOT DONE YET
Sixty years after Ed Dwight became America's first Black astronaut candidate for NASA's 1963 class but was unable to advance further, he finally logged time on a Blue Origin capsule. At 90, he's now the oldest person to enter space.

### EVIDENCE STACKS UP
The orbital characteristics of several more distant solar system bodies called extreme trans-Neptunian objects have lent further credence to the theory that a massive, distant Planet Nine circles our Sun. — DANIELA MATA

# Venusian volcanism spotted again

**CHASING LAVA FLOWS.** The volcano Sif Mons and its surroundings are shown in this image based on Magellan data of Venus' surface. The areas marked in red are the suspected lava flows in the region. IRSPS - UNIVERSITÀ D'ANNUNZIO

**A NEW ANALYSIS OF RADAR IMAGES** taken by NASA's Magellan mission to Venus in the early 1990s has revealed indications of lava flows reshaping the planet's surface, according to a study published May 27 in *Nature Astronomy*.

The work adds to a small but growing body of direct evidence that Venus is a volcanically active world. It follows a March 2023 study of Magellan archival imagery that found what appeared to be a volcanic vent that collapsed between images taken eight months apart in 1991.

Magellan was equipped with a radar imager that could penetrate the thick venusian clouds and was the first spacecraft to image the planet's entire surface. Although Magellan ended its mission by diving into Venus' atmosphere in 1994, the relative dearth of missions to the world since then means scientists keep returning to Magellan's archives.

In the new study, a trio of planetary scientists at D'Annunzio University in Pescara, Italy, and Sapienza University of Rome combed through Magellan radar data and compared data taken between 1990 and 1992. The planetary scientists searched for changes on the surface that would show up in measurements of radar backscatter — the reflection of radar waves that traveled back to Magellan — to find areas of recent lava flows. The amount of backscatter depends on the roughness and composition of the surface, which could be altered by lava.

"Interestingly, our analysis revealed significant increases in radar backscatter in two different areas: the western flank of Sif Mons, a broad shield volcano, and the western part of Niobe Planitia, a lowland area characterized by numerous shield volcanoes," Davide Sulcanese of D'Annunzio University, lead author of the study, says. "These changes are most likely due to new lava flows that occurred during the Magellan mission, providing evidence of ongoing volcanic activity on Venus."

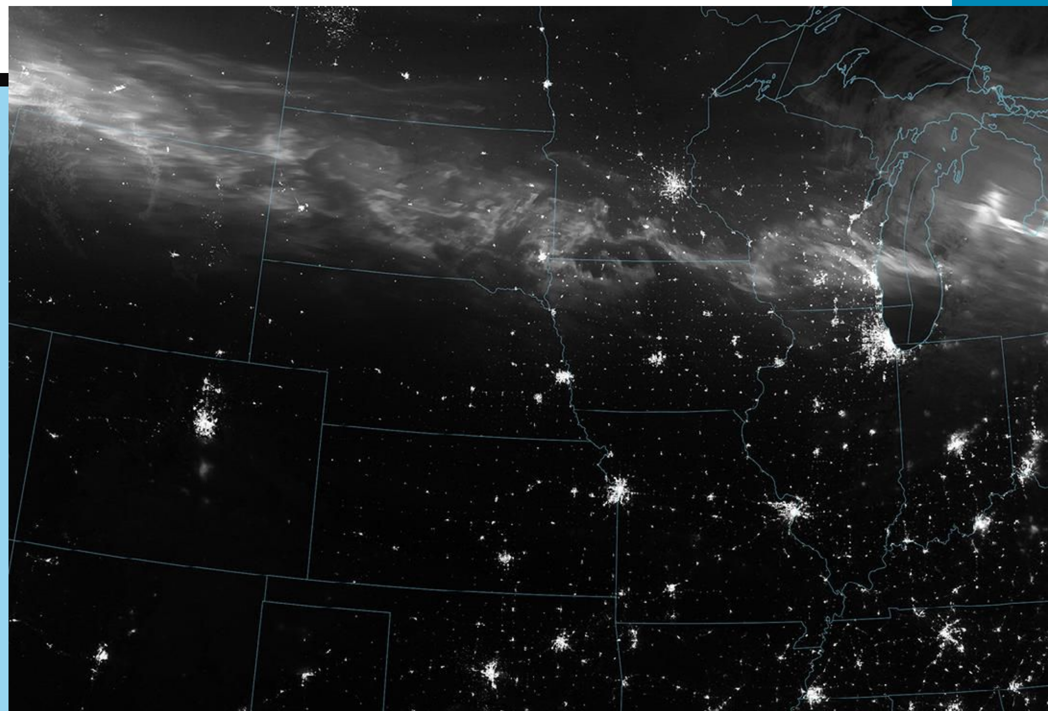
## VERITAS LIVES

Further understanding of Venus' volcanism is on the horizon. Early in the next decade, NASA plans to launch two important missions to Venus, DAVINCI and VERITAS. DAVINCI will drop a probe through Venus' atmosphere to both sample the air and create 3D infrared images of the surface at its landing site, while VERITAS will take a wealth of radar data.

VERITAS was postponed by three years as NASA's Jet Propulsion Lab scrambled during the COVID-19 pandemic to keep another mission, to the asteroid 16 Psyche, on track. NASA slashed VERITAS' budget for 2024 and was considering canceling the mission. But following the successful launch of the Psyche spacecraft in October 2023 — and a campaign of support from the planetary science community — VERITAS' budget was restored in March of this year and is currently on track for a 2031 launch.

"These missions will offer comprehensive data on Venus's volcanic processes, enhancing our understanding of terrestrial planets' formation and evolution," Sulcanese says. —JOHN WENZ

# A STORM YOU WANT TO STAY OUTSIDE FOR



NASA/NOAA/WANMEI LIANG

**THE AURORA BOREALIS** was seen as far south as the Bahamas and Florida in early May as Earth underwent the strongest geomagnetic storm it's seen in more than 20 years. The Visible Infrared Imaging Radiometer Suite on the Suomi National Polar-orbiting Partnership satellite captured this image of a large, bright band of aurorae stretching from Montana to Michigan at 3:20 A.M. CDT on May 11. On this particular night, Earth underwent a G5-level storm, the result of an intense sequence over the previous few days in which the Sun spat out half a dozen clouds of plasma — or coronal mass ejections — all originating from a massive sunspot group known as AR3664 that stretched some 125,000 miles (200,000 km) across, or 16 times the diameter of Earth. The satellite image may be in grayscale, but viewers across North America saw bands of green, purple, and even red during the atmospheric show. Many of our favorite reader-submitted images of the aurora during this solar storm appear in the August issue's Reader Gallery. – D.M.

INAF/LARGE BINOCULAR TELESCOPE OBSERVATORY/GEORGIA STATE UNIVERSITY; IRV-BAND OBSERVATIONS BY SHARK-VIS/F. PEDICHINI; PROCESSING BY D. HOPE, S. JEFFERIES, G. LI CAUSI

# Billowing volcanic plumes

Jupiter's moon Io was recently photographed by a new planetary camera called SHARK-VIS mounted to the Large Binocular Telescope on Arizona's Mount Graham. It captured the aftermath of two volcanoes spewing material onto the satellite's surface. The volcano Pele expelled a gaseous plume that left a 620-mile-wide (1,000 kilometers) ring of red sulfur deposits around it. And when a nearby volcano, Pillan Patera, erupted, it resurfaced the area with a combination of dark lava and white sulfur dioxide deposits. SHARK-VIS is part of a new wave of ground-based adaptive optics systems that work in visible light — rather than just infrared — to nearly eliminate the effects of Earth's turbulent atmosphere. Detailed images like these are necessary to identify eruptions and other changes not detectable in other wavelengths. – SAMANTHA HILL

# Starship passes reentry test for first time

SpaceX's Starship upper stage survived the fires of reentry to make its first-ever successful controlled landing, splashing down in the Indian Ocean June 6 at the conclusion of a 66-minute test flight. But the descent was not without drama, as the craft took damage to one of its flaps and its heat shield.

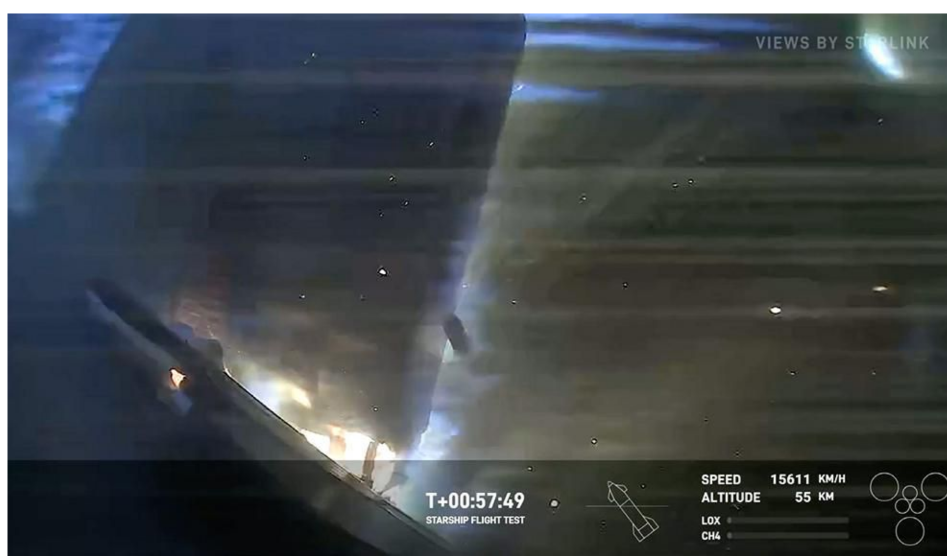
Cameras on the ship's exterior clearly captured the growing damage during reentry, as the heat and pressure began to eat away at one of the large movable flaps that controls Starship's orientation as it streaks through the atmosphere. The gasps and shouts of SpaceX employees could be heard on the company's broadcast as glowing chunks of debris flew off the flap, exposing skeletal mounting points below.

Minutes later, the gasps turned to deafening cheers as telemetry indicated that Starship had survived to reignite its engines for landing — the first time it had reached that point on a test flight. The splash of ocean water as the craft touched down could just barely be seen on the camera, whose lens had by now been nearly completely obscured by debris.

The flight, which lifted off at 8:50 A.M. EDT from Boca Chica, Texas, was the fourth test flight for the overall Starship

**FOURTH TIME'S THE CHARM.** Starship and the Super Heavy booster lift off on their fourth integrated test flight from SpaceX's launch facility at Boca Chica, Texas. SPACEX

**BURNING UP.** A hot spot forms near the base of one of Starship's flaps, as seen on SpaceX's broadcast. SPACEX



system, which consists of the Super Heavy booster and the Starship upper stage. The first three flights ended with the upper stage destroyed.

The farthest the upper stage had previously gotten was in its third orbital test flight on March 14, 2024, when it lost control during reentry and broke up. On that flight, the Super Heavy booster — designed to be reusable — also failed in its attempt to make a controlled test landing in the Gulf of Mexico.

On the fourth try, SpaceX succeeded on both counts — in addition to Starship's soft landing in the Indian Ocean, the Super Heavy booster made its first-ever controlled splashdown in the Gulf, simulating a landing back at its launch tower.

The twin achievements mark a major milestone for the company in its goal to make Starship the world's first fully reusable orbital launch system. SpaceX plans for the vehicle to ferry satellites and astronauts to Earth orbit and eventually put humans on Mars. The company has also been contracted by NASA to build a variant of the Starship upper stage that will serve as a lunar lander for Artemis crews. — MARK ZASTROW

**1,931**

**The number of unique proposal submissions for JWST's third cycle of observations, beginning July 1, 2024 — the world record for any telescope to date.**

**SECOND WIND.** The super-Earth 55 Cancri e (right) has a substantial atmosphere despite its extreme proximity to its host star, as shown in this artist's concept. NASA, ESA, CSA, RALF CRAWFORD (STSCI)

# JWST SPIES THICK AIR AROUND A ROCKY WORLD

**IN THE FIRST TWO YEARS** of results from NASA's James Webb Space Telescope (JWST), astronomers have mostly come up empty in their search for atmospheres around rocky exoplanets. Multiple planets in the intriguing TRAPPIST-1 system have been examined by NASA's new flagship observatory, with none revealing signs of an atmosphere.

But the dry spell is over: JWST has finally found strong evidence of a thick atmosphere around a rocky world.

The new observations, published May 8 in *Nature*, focus on super-Earth 55 Cancri e. It lies so close to its home star that it completes an orbit roughly every 17 hours — one of the fastest known orbital periods of any exoplanet. This leads to a molten surface with temperatures likely exceeding 3,000 degrees Fahrenheit (1,650 degrees Celsius) on a world that is intensely bombarded by radiation from its host star. As a result, the original atmosphere should be long gone.

Yet a team led by researchers at NASA's Jet Propulsion Lab (JPL) in Pasadena, California, discovered the likely presence of carbon dioxide and carbon monoxide gas around the planet.

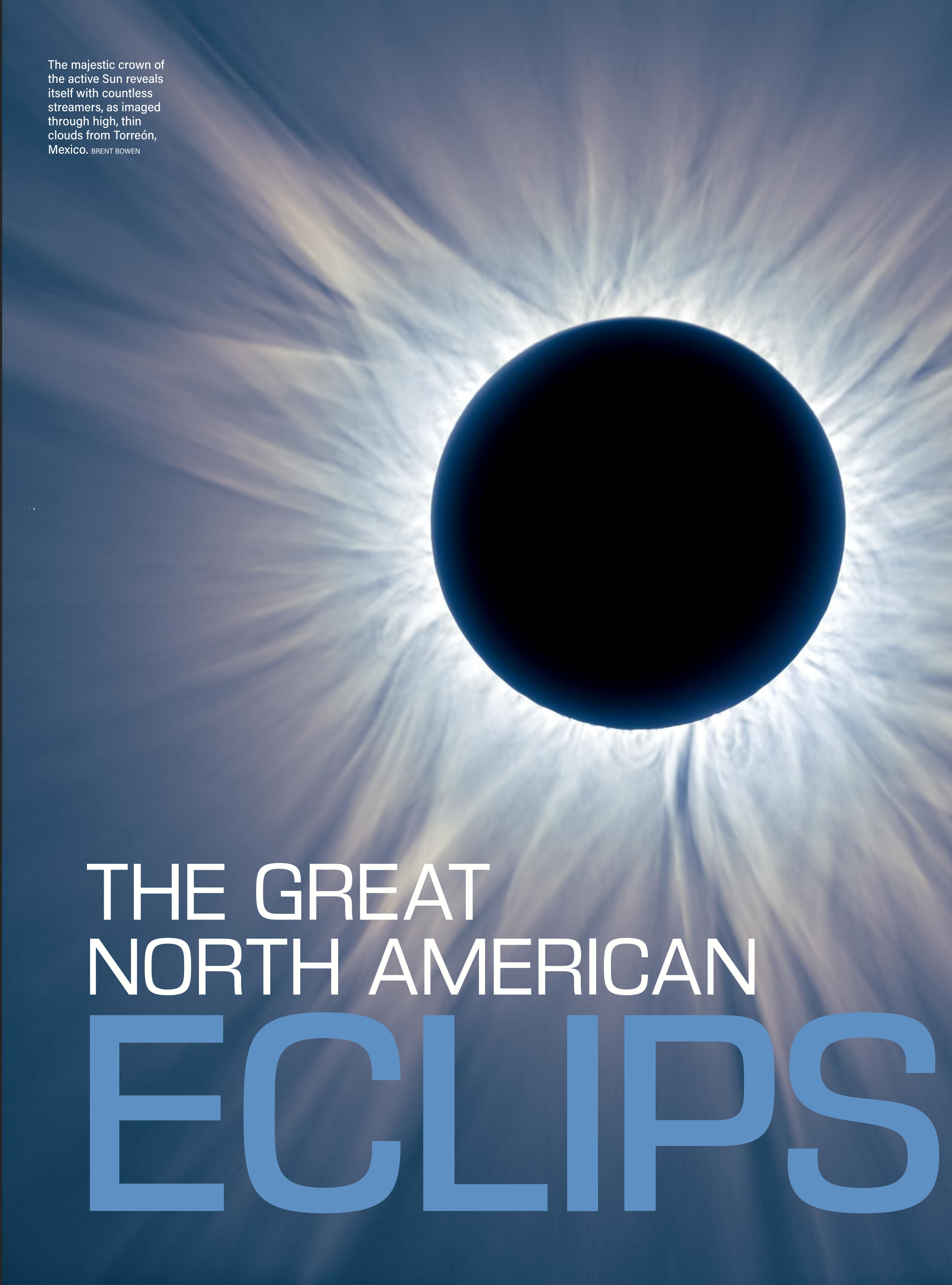
JWST's suite of instruments includes a set of spectrometers. But the atmospheric gases weren't detected by directly staring with them at the planet. The study instead made use of a technique called secondary eclipse spectroscopy, which is possible when a planet's orbit takes it behind its host star from our point of view. When the planet is eclipsed, astronomers can isolate the light coming from the host star and subtract it from observations of the system when the planet is also visible, leaving behind the only the light coming from the planet. The team then ran simulations on a variety of possible atmospheric types that would give off similar signals.

This analysis yielded no evidence for helium and hydrogen — the most common elements in the universe, which would have been part of the planet's initial atmosphere when it formed. This means that what JWST detected is likely the planet's secondary atmosphere. It seems that, despite the violent winds from its nearby star, continuous volcanic activity and the gravity of the planet have allowed the planet to regenerate and retain a relatively thick atmosphere.

The team found that the best match for their data was a mix of carbon dioxide, carbon monoxide, and nitrogen gas. This would also track with a planetary atmosphere driven in part by volcanism.

In short, 55 Cancri e shows that just because an exoplanet loses its atmosphere, that doesn't mean that it can't gain a new one.

Earth's atmosphere — as well as the atmospheres of Venus and Mars — are also secondary atmospheres, and knowledge of how common they are among exoplanets may impact our understanding of how common habitable planets may be in the universe. "I'm quite confident that JWST will provide a lot of information about the ability of rocky planets of various sizes and temperatures to develop a secondary atmosphere," says Renyu Hu, a planetary scientist at JPL and lead author of the paper. "We can use that to calibrate our models, and eventually, we will have a better understanding of the emergence of habitable worlds." — J.W.



The majestic crown of the active Sun reveals itself with countless streamers, as imaged through high, thin clouds from Torreón, Mexico. BRENT BOWEN

# THE GREAT NORTH AMERICAN ECLIPS

# E DELIVERS

*ASTRONOMY*: ROEN KELLY

From Mazatlán to Newfoundland and 14 U.S. states in between, totality graced millions with a view of the Sun's corona.

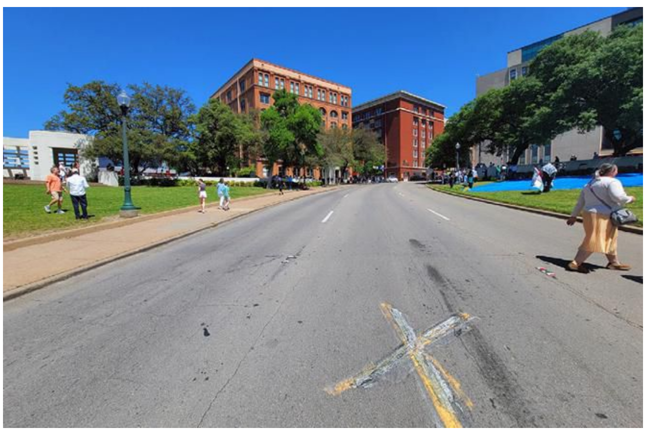
**BY THE STAFF OF *ASTRONOMY***

## THIS WAS THE BIG ONE.

Nearly seven years after totality crisscrossed the U.S. in August 2017, the Moon once again slipped in front of the Sun in the skies above North America on April 8, 2024. Making landfall in Mexico, the Moon's shadow swept across the continent, through the heart of the U.S. into New England and on to Canada. In the U.S. alone, over 31 million lived in the path of totality — two and a half times more than in 2017. It would not be an exaggeration to say that this was the most anticipated celestial event this magazine has seen since the return of Halley's Comet in 1985–86.

To cover the eclipse, the staff of *Astronomy* were scattered along the path of totality. Here's what we saw — and heard, and felt.

# DALLAS, TEXAS




## An eclipse victory at Love Field

Weather is a one-day event. For all the analysis of trends, of where clouds or Sun will mark the landscape, anything can happen on any given day. In Texas, the weather prospects for the Great North American Eclipse looked bleak. For days, it seemed a sure thing that storms, or at least thick clouds, would plague the Dallas region. And then came eclipse day.

My journey this year was centered on Dallas Love Field Airport, best known in recent history as the landing site for John F. Kennedy's ill-fated 1963 trip to the city. But the airport is still active and hosts a fantastic collection of aircraft and aviation artifacts in the Frontiers of Flight Museum. For the eclipse, the museum's team, led by President Abigail Erickson-Torres and facilitated by their energetic director of education, Rosalie Wade, assembled a wonderful day of programming that welcomed some 2,500 members of the public onto the grounds.

We also partnered with our good friends at Celestron, who turned out in force. Corey Lee, Kevin Kawai, Ben Hauck, Stephanie Schroeter, and others were on hand, setting up telescopes the day before the eclipse. And that wasn't all: Partners from The Weather Channel were also there broadcasting live, with meteorologist Alex Wilson taking the lead on camera and a big team led by producer Mike Jenkins coordinating the whole process. It was an extreme pleasure working with Wilson. She is such a smooth pro that it was effortless to talk about the science, the observations, and the meaning of it all as we prepared to look skyward and witness the alignment of worlds.

But when I drove to Love Field at 5 A.M. on eclipse day, it looked like a washout. I had experienced a dozen total eclipses before this one, two of them underneath a solid blanket of clouds. Believe me, that's not a good way to see an eclipse.

As dawn broke, the sky was still sketchy and the forecast less than great. At one point, The Weather Channel proclaimed that the place with the best chances for clear skies was Maine. Mexico seemed troubled too. As we looked to the south, past Parkland Memorial Hospital on the horizon, walls of clouds seemed to be destined to move our way as the morning continued.

I spent the waning moments of pre-eclipse in the museum auditorium with a packed house, explaining everything everyone needed to know to view and photograph the eclipse. When I walked out into the field again at noon, with first

**TOP TO BOTTOM:**
The Command Module of Apollo 7 — the first crewed Apollo mission — is on display at the Frontiers of Flight Museum at Dallas Love Field. DAVID J. EICHER

An X marks the spot on Elm Street where President John F. Kennedy was fatally shot in downtown Dallas. DAVID J. EICHER

Our friends at Celestron were out in full force, with a presence as a vendor and also as a supplier of a live TV feed for the Weather Channel using a modified C8 optical tube assembly. DAVID J. EICHER contact approaching, the situation had changed. Clouds were less dense, and hope appeared. Amazingly enough, as we awaited first contact, we had significant holes and could get a good view of the Sun, some 60° high in the sky. We would see the start of things, at least.

As always happens, people screeched out in joy as the first little bite out of the Sun's disk became visible. Although we've had precise knowledge of the motions of the solar system since the days of Johannes Kepler, it always seems a bit like magic to many people when we count down by the second and an eclipse starts, right on schedule.

Although thick clouds were visible way down to the south, we had a long, vertical corridor of clear sky that seemed to favor us as totality approached. It dawned on us that we were going to defy the odds and see this thing. With a fresh burst of excitement,

**TOP:** Weather Channel meteorologist Alex Wilson and producer Mike Jenkins refuel during a busy day of broadcasting. DAVID J. EICHER

**ABOVE:** Eclipse day meant an early start on camera for *Astronomy* Editor Dave Eicher and Weather Channel meteorologist Alex Wilson. DAVID J. EICHER

Wilson and I narrated much of what was happening on The Weather Channel. The rapid darkening of the sky during the final moments before totality always amazes, and we felt rapid cooling of the air, too. And then: the diamond ring! Glasses off! We had totality — and it looked spectacular!

Our Love Field site experienced 3 minutes 51 seconds of totality, and we saw the whole thing perfectly. The corona seemed large, flower-like, and with some pretty good brushes and rays, too, expected from the current cycle of solar activity. We had some nice prominences as well, especially one at bottom right (as we faced south) that was incredibly bright near the end of totality. Venus popped out immediately and Jupiter too, after a bit of cloud passed it. We did not expect to see Comet Pons-Brooks, nor waste time with binoculars searching for it. The chromosphere seemed bright around the Moon's rim but lacked the color we saw in 2017. It was a beautiful eclipse, however, and we felt very lucky to have seen it so well.

It's always struck me as funny that as soon as totality ends, the interest in the rest of the eclipse kind of fades away. But everyone was elated, celebrating a great view, and the party started. We had an airport full of very happy people on a natural high and already talking about other eclipse adventures — Iceland and Spain in 2026, and the most amazing one to come, Egypt in 2027.

I hope that you also experienced a great eclipse; nothing quite equals seeing the worlds align. And remember that the Moon is inching away from us a little bit every year. We have only 600 million more years to catch total eclipses, and then they will be a thing of the past.

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**David J. Eicher** *is editor of* Astronomy*, author of 26 books on science and history, and a board member of the Starmus Festival and of Lowell Observatory.*

## ECLIPSE PERFECTO

**WHEN I TELL PEOPLE I'VE WITNESSED** 13 total solar eclipses, most of them think there can't possibly be anything I haven't seen before. But April 8 proved that there's always something new under the Sun.

The most impressive of these novel sights were twilight colors that circled the entire horizon. From our vantage point on the center line an hour's drive east of Mazatlán, Mexico, the Sun stood 69° high during totality — close enough to the zenith that we could see sunlight scattered into the umbral shadow in every direction. The second unusual sight: a brief glimpse with averted vision of the magnitude 0.5 star Achernar hanging low in the south.

Despite the few seconds it took to spot this southern gem, I spent most of the 4 minutes 26 seconds of totality exploring the Sun and its immediate surroundings. The most stunning sight was a large prominence seen near the 4 o'clock position on the Sun's face. The fiery tongue of hot plasma grew more conspicuous as the Moon slid eastward during totality.

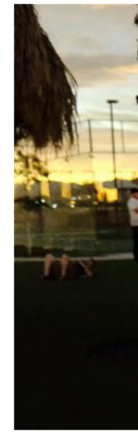
It and several smaller prominences reached into a solar corona that appeared more symmetrical than we expected. The culprit may have been the high, thin clouds above our observing site. Farther away, Venus and Jupiter shone brightly on opposite sides of the eclipsed Sun.

I joined 80 other eclipse chasers on a MelitaTrips tour to Mexico. We all enjoyed seeing sharpened shadows, more intense colors, and projected images of the crescent Sun during the partial phases. And we all felt the 10-degrees-Fahrenheit (6 degrees Celsius) temperature drop from first to third contact. It was a truly memorable experience for the final North American total eclipse until 2044. *— Richard Talcott, contributing editor*

Pinpoint projection can be used to view an eclipse's partial phases — and also create photographic mementos. EVELYN TALCOTT

The totally eclipsed Sun stands at an altitude of 69° over Mazatlán, Mexico. RICHARD TALCOTT





## Totality in Torreón

Ever since we arrived in Mexico on April 3, Associate Editor Daniela Mata and I had been watching the weather models. But we may as well have not paid them any heed. After all, based on historical satellite data, our chosen location of Torreón was supposed to be not just a good place to view the eclipse — it was the single *best* major city to view the eclipse near the center line, with an average cloud fraction of just 20 percent. If we somehow managed to have the lousy luck to be clouded out, what more could we have done?

For a while, it seemed that dreaded scenario might come to pass, as patches of clouds were forecast to build in a low-pressure trough hanging over the country. Still, there were grounds for optimism: These were high-level clouds, compared to the low cloud cover that observers in the continental U.S. would have to contend with.

When eclipse day dawned and we arrived at our observing site — a restaurant on an artificial pond alive with birdsong ringing from all directions — we had a thin cloud layer at 10,000 feet (3,050 meters). But as first contact approached, we were being squeezed between a broken layer of clouds at 20,000 feet (6,100 m) spawning west of us and more clouds building to the east.

Then, at 11:30 A.M., about 45 minutes before totality, a breeze came in and a clearing appeared, leaving just high, wispy clouds through which the thinning crescent of the Sun was clearly visible. The energy in the crowd — around 50 with our tour group, led by Eclipse Traveler CEO Cengiz Aras, and perhaps 100 more locals — was electric.

As the eclipse deepened, twilight set in all around us, and as the light played off the clouds, it bestowed on them a remarkably stormy appearance. The effect was to create the illusion of being in the eye of a storm, with a threatening lavender hue that would have prompted me to seek cover on a steamy summer Midwest afternoon

## AN ECLIPSE WITH HERITAGE

**I COULD READ ALL ABOUT** what a total solar eclipse entails, and the same goes for a trip to Mexico. But nothing could've prepared me for my first experiences of both of these events converging this April on Eclipse Traveler's program to Mexico City and Torreón.

I was born and raised in America but with Mexican culture, so I didn't know what to expect from going to Mexico for the first time. As we explored Mexico City's busy streets, I lost count of the number of vendors gently smiling at me as I passed them, even with no intention of buying anything. Every citizen was walking and moving with determination and warmth; observing this made me proud to be Mexican. A sense of familiarity washed over me as I recognized objects and toys for sale that I knew from my childhood, and when I heard stories I grew up with repeated by our tour guides.

We visited multiple UNESCO World Heritage sites, including Mexico City's historic center and the colorful district of Xochimilco. We also made a day trip to the Pyramid of the Sun and the Pyramid of the Moon in the ancient city of Teotihuacán. Archaeologists think the Pyramid of the Sun is aligned to directly face the sunset on the 11th of August and the 29th of April, purposely separated by 260 days, the same length as the Aztec ritual calendar.


MARK ZASTROW

There aren't words strong enough to describe the extraordinary spectacle that is a total solar eclipse — especially your first one. But the best words I can think of are: sensationally phenomenal, spiritual, harmonious, and just absolutely breathtaking! As soon as totality began, the collective shouts of pure excitement and awe made my heart pound and flutter.

The improbability of getting the opportunity to be on this luxurious trip, surrounded by astronomy enthusiasts, and having the clouds clearing up perfectly on time, allowing all of us to gaze upwards (at an altitude of 70°) at the perfect alignment of the Sun-Earth-Moon system, made me want to raise my arms, fall to my knees, and start praying to the eclipse and universe. I completely understand why civilizations felt like they had to make some kind of sacrifice during the eclipse.

Up next are the total solar eclipses in August 2026 and 2027 — they can't come soon enough! *— Daniela Mata, associate editor*



**THE MOST UNUSUAL VISUAL ASPECT OF THIS ECLIPSE FOR ME WAS HOW THE CLOUD LAYER ACTED AS A PROJECTION SCREEN FOR THE MOON'S SHADOW.**

— and in Fortnite would have prompted me to desperately spam the sprint button.

Birdsong — which had been constant in the morning — largely disappeared as the sky dimmed. With just a few minutes before totality, a lone duck wandered through the crowd, pausing in our midst to groom itself.

And then totality arrived at 12:16 P.M. CST, to cheers and gasps. To the unaided eye, the corona had a largely even appearance, without strong spikes or streamers. I also wouldn't claim with certainty to have seen any Baily's beads, perhaps due to the cloud layer. However, Torreón tour member and astroimager Brent Bowen would prove that there was plenty of detail to be captured in photographs; you can see the results of his work at the beginning of this story and on the cover of this magazine.

What was plainly visible was a trio of brilliant prominences. The first appeared on the left limb of the Sun and then, as the Moon continued sliding from right to left, another pair revealed themselves on the right — including an especially purple one at 4 o'clock. Jupiter and Venus shone brightly in the darkness, but I could not locate Mars or Saturn amid the clouds.

In retrospect, the most unusual visual aspect of this eclipse for me was how the cloud layer acted as a projection screen for the Moon's shadow, allowing us to see the umbra racing toward us at some 1,500 mph (2,400 km/h) — and, after third contact, speeding away from us, ushering in the day's second dawn.

After a week of weather anxiety, we were thrilled to have had a successful viewing. Still coming down from the high, we retired to the restaurant for lunch — and Coronas of a different type.

**LEFT TO RIGHT:**
The twilight glow of totality lent clouds in our vicinity a dramatic, stormlike appearance.

Members of our expedition relax at our viewing site outside of Torreón before the partial phases begin.

*Astronomy* Associate Editor Daniela Mata and Eclipse Traveler CEO Cengiz Aras gaze skyward at the eclipsed Sun during totality.

A young local eclipse viewer gets a chance to see the partially eclipsed Sun through binoculars.

**TOP TO BOTTOM (AT RIGHT):**
The Angel of Independence victory column in downtown Mexico City was built in 1910 to commemorate the 100th anniversary of the start of Mexico's war of independence.

A mariachi band serenades our group as we dine onboard colorful trajinera boats at Xochimilco.

The beautiful town of Taxco was a hub of commercial silver mining in the Hispanic colonial era and is still known for its silverwork today.

The eclipse was front-page news across Mexico.

The Pyramid of the Moon at the ancient city of Teotihuacán outside of Mexico City stands 140 feet tall. Its construction — along with the even taller Pyramid of the Sun (not pictured) — dates to nearly 2,000 years ago, predating the Aztec civilization. At its peak, Teotihuacán was the largest city in the Americas. ALL PHOTOS BY MARK ZASTROW

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*Senior Editor* **Mark Zastrow** *has spent 333 seconds in the umbra of the Moon and is hungry for more. He is really bad at Fortnite.*

# INGRAM, TEXAS

## Earning the eclipse from Ingram

**LEFT TO RIGHT:**
Eclipse viewers spread out in a field in Ingram, Texas. ALISON KLESMAN

This partially cloud-obscured view of the partial phases was typical of those who saw the eclipse in Texas. ALISON KLESMAN

*Astronomy* Senior Editor Alison Klesman uses a solar filter to photograph the eclipse's partial phases with her phone. ALISON KLESMAN

Like many, I suspect, I spent the weekend of April 6–7 reading weather reports, refreshing forecasts, and googling "What can you see if there are clouds during an eclipse?" I didn't know firsthand what a clouded-out eclipse would be like. But looking at the predictions, I wondered if I'd soon find out.

As part of *Astronomy*'s partnership with Eclipse Traveler, I joined their U.S. eclipse tour in San Antonio and spoke to the group of nearly 70 eager skywatchers Sunday evening about what to expect and how to safely view the eclipse. Then, we would set out early Monday morning for our viewing site in Ingram, Texas, for 4 minutes 26 seconds of totality.

In my presentation, I covered what to expect, including what to focus on if clouds did mask the view — how the temperature drops and the wind changes, how the sky goes dark. Still, we remained hopeful that we would get to see the corona lighting up the sky.

Monday dawned only partly cloudy — a good sign, I hoped. On the highway outside San Antonio, we passed people setting up telescopes, lawn chairs, blankets, and grills. Hope began to grow.

Our viewing site in Ingram was outside Citywest Church, where we enjoyed an early catered lunch and live music as we set up. Hope soared as the Sun continued making appearances through the clouds. First contact arrived, and we celebrated as the clouds remained mostly at bay.

Unfortunately, as the eclipse progressed, clear patches came with decreasing frequency. It was definitely getting cloudier. This made watching the latter partial phases leading up to totality both more difficult and more rewarding. Every second of waning sunlight was precious.

In the half-hour before totality, the light started to change. Every few minutes, we paused our search to feel what the weather was doing.

## DRAMA IN THE HEAVENS

**HAVING ALREADY SEEN 14 TOTAL SOLAR ECLIPSES** all over the world, of course my wife, Holley, and I weren't going to pass up one within driving distance of our house. So we, along with her parents and four friends from Tucson, booked a house in San Antonio that would serve as our base. Early on eclipse day, we headed to our chosen location: Kerrville, Texas.

For several years, the Kerrville Parks and Recreation Department had been planning a huge festival at Louise Hays Park in the city. When I contacted one of the people in charge about our group coming to the event, I was asked to speak to the visitors before the eclipse. In return, we would be provided two choice parking spots and a tent.

Climate statistics had led me to choose a location in Texas. But the week prior to the eclipse proved the old adage, "Climate is what you expect. Weather is what you get." As April 8 approached, our location had a less than 40-percent chance of being clear. But no nearby (reachable) place seemed much better. So, Kerrville it was. Lots of other people thought so, too. The city's Convention & Visitors Bureau reported 64,000 visitors throughout the weekend. A preliminary count put more than 20,000 of them in the park on eclipse day.

First contact, the moment when the Moon begins to cover the Sun's brilliant disk, occurred during my talk. For the next 78 minutes, thick clouds came and went. Every time they parted to reveal a more-obscured crescent Sun, a huge roar would erupt from the crowd. Everyone — including me! — hoped it would clear enough for us to see totality.

The tension was palpable. "Look! There's the Sun 90 percent covered." Then clouds. Then it was 94 percent. More clouds. Then 98 percent. As totality approached, darkness covered us like someone pulling a colossal blanket over the park. And then, just seconds before totality, when the Sun's illuminated portion was the thinnest possible crescent, the sky around our daytime star cleared. "Diamond ring!" I screamed. At this point, both Holley and I were observing through binoculars. We saw Baily's beads for a few seconds. Then the crimson-red chromosphere appeared. And finally the star of the show — the Sun's magnificent corona — was there for all to see. This was drama of the highest level.

We all saw the first 45 seconds of totality, and then clouds once again obscured the view. But it was enough, and the many people I talked to afterward were amazed and thankful that we had been able to witness such sublime celestial geometry. *—Michael E. Bakich, associate editor*

Admittedly, it was hard to say whether the change was due to the incoming storm front or the approach of totality, but it had to be at least a little of both, right?

The moment totality would begin — 1:32 P.M. CDT — was almost upon us. And then, as we counted down the last minute, a cloud covered the Sun completely. "That's OK!" I shouted. "The clouds are still moving! We might get a hole!" And with clouds in the sky, I reminded all of us, darkness should fall quickly and completely.

That darkness did fall — profoundly — as the shadow swept in and totality began. With the eclipsed Sun still behind a cloud, we were plunged abruptly into night. On some nearby houses, porch lights popped on.

For at least the first minute of totality, the Sun was completely covered. We got no Baily's beads and no diamond ring. But we did get a very clear 360° sunset effect and we now felt the temperature plummet.

Then, suddenly, a group down the road from us began cheering. A hole had opened up right over them, revealing the eclipsed Sun, and it was coming to us.

Seconds later, it was our turn to cheer. There it was — the dark Moon, blotting out the Sun like a hole punched in the sky, with a bright, almost uniformly circular corona blazing around it like a sunflower. The corona was dazzlingly bright. It was a breathtaking sight.

The next cloud moved in, again obscuring totality. But now we were energized, excited, and ready for the next break in the cloud cover. At least two more holes crossed overhead, giving us those glimpses of totality that our group had traveled to see. We were ecstatic, hungry for every moment of it.

The final seconds of totality were also lost behind cloud cover, and day dawned over us on fast-forward. Totality was over. But we'd done it. We'd seen it. "We *earned* it," Nikolas Xexenis, who'd traveled from Australia to see his first eclipse, said triumphantly.

While our eclipse wasn't picture perfect, in a way, I think that's OK. Compared to a clear-sky viewing, we saw a much more marked difference in light at totality's onset and end, and could take the time to fully explore this strange environment.

We often say that eclipses are all about seeing totality. But a total eclipse is a full sensory experience, not just a visual one. Our group truly experienced totality in every way possible.

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*Senior Editor* **Alison Klesman** *would like to dedicate this story to her late father, Mark Klesman, with whom she saw her first total solar eclipse in 2017.*


**TOP TO BOTTOM:**
Eclipse Traveler's nearly 70-strong Texas expedition poses at their post-eclipse celebration banquet. URI LEDER

The Sun's corona makes an appearance through a break in the clouds during totality. ALISON KLESMAN

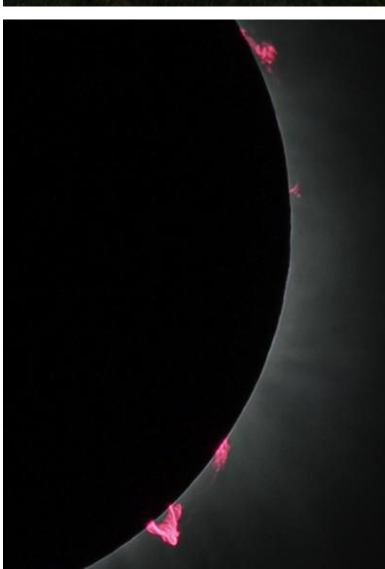
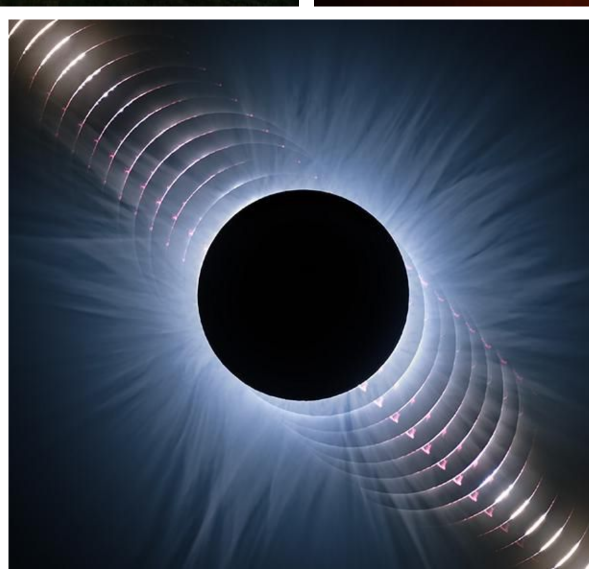
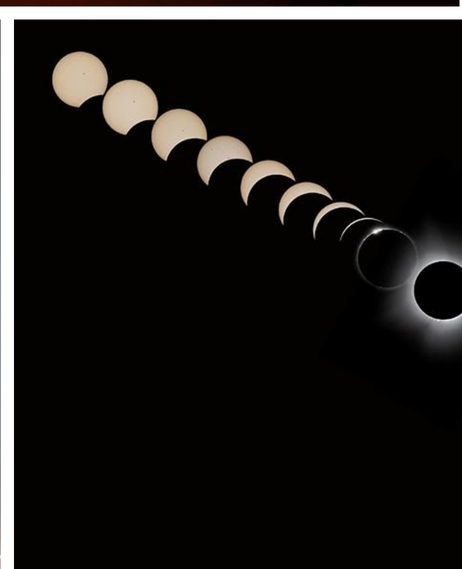
While glimpses of the corona were fleeting, photographers among the group were still able to capture the stunning prominences along the edge of the Sun. ALISON KLESMAN

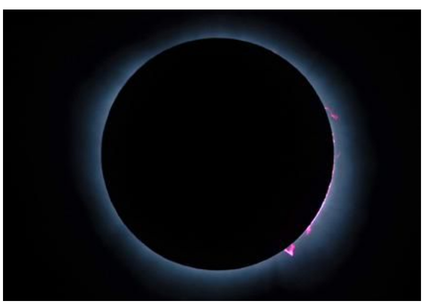
Those who experienced this tour are sure to remember much more than just the Alamo. ALISON KLESMAN

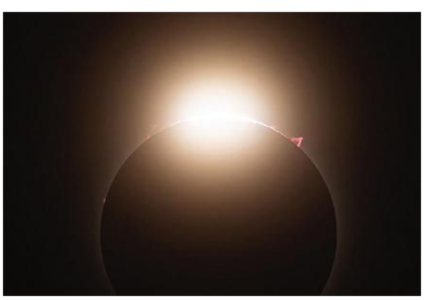
# NORTH AMERICA

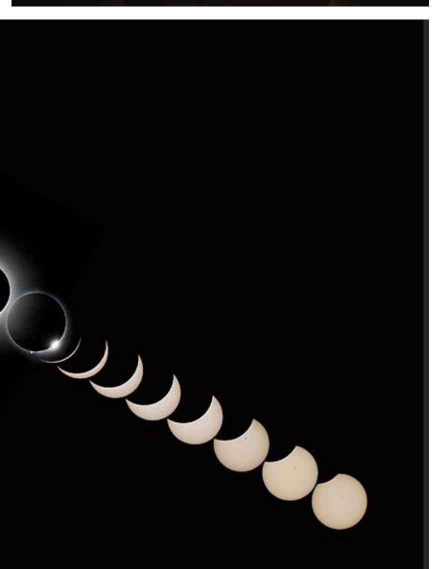










**CENTER:** An airliner transits the Sun during the partial phases of the eclipse in this shot taken from North Potomac, Maryland. ALLAN COBB

**OUTER IMAGES, CLOCKWISE FROM UPPER LEFT:** The full progression of the eclipse is captured in this composite taken from Peace Valley, Missouri. DERRICK DIXON

Earthshine — sunlight bouncing off the face of Earth — illuminates the nearside of the Moon in this composite image taken during totality from Colbrook, New Hampshire. GEORGE KONKOV

For many viewers along the path of totality, glimpses of the eclipse came in fleeting moments through breaks in the clouds. This photographer was still able to snap a dramatic image of the diamond ring through thin clouds with an iPhone 15 Pro Max. TAYLOR HOOTEN

The thin magenta chromosphere is visible on the right limb of the Sun as Baily's beads begin to emerge at third contact in this shot taken in Mazatlán, Mexico. CHARLES PEVSNER

The diamond ring at the end of totality pokes through the lunar lowlands in this shot taken from Wapakoneta, Ohio. JASON GUENZEL

The eclipse's partial phases, the Sun's corona, and a diamond ring and Baily's beads on either side of totality are all part of this composite taken from Lac Mégantic in Québec, Canada. PHILIPPE MOUSSETTE

As the disk of the Moon slid over the Sun, multiple prominences on each side became visible — first on the left and then, as the Moon continued its march, on the right, captured in this composite taken from Torreón, Mexico. BRENT BOWEN

The largest prominence visible during this eclipse is shown at the lower right limb of the Sun in this image captured from Batesville, Arkansas. JEFFREY A. MACQUARRIE

**UPPER RIGHT:** Many observers reported a remarkably uniform appearance to the corona. This was particularly true if they were observing through a high, thin cloud layer. But it may also have owed in part to the fact that the Sun is near the peak of its 11-year activity cycle, and streamers were emerging from the Sun in all directions — not just along the equator, as is common during lulls in activity. DAVE FULLER

Bryan C. Pijanowski (center) and his graduate students at Purdue University spent the day observing the solar eclipse in Butlerville, Indiana. PURDUE UNIVERSITY/TOM CAMPBELL

## LENDING AN EAR TO THE ECLIPSE

**AN ECLIPSE CAN REVEAL MORE** than meets the eye: Its arrival can change the sounds of the environment. On April 8, in a remote forest near Butlerville, Indiana, I waited with a group of Purdue University wildlife researchers who were intent on not just witnessing the eclipse, but also listening in.

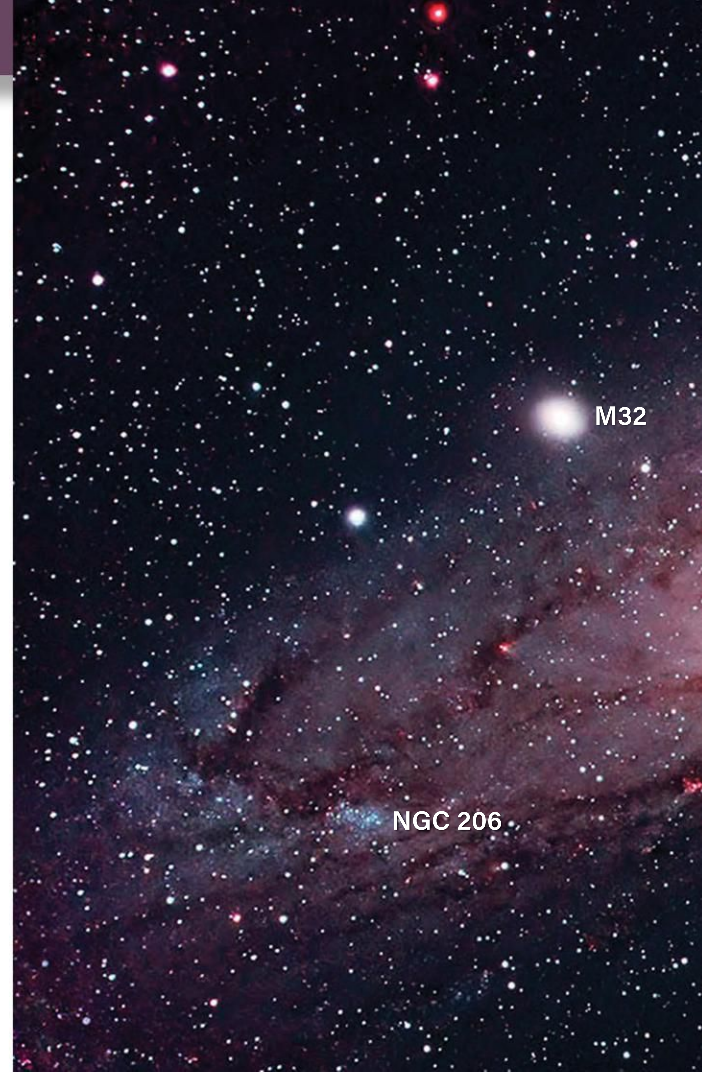
To capture the changes in the natural soundscape, the team set up sound recorders on trees and in ponds. About three hours before totality, the forest was filled with the repetitive calls of the tufted titmouse, cackles of eastern bluebirds, squawks of red-bellied woodpeckers, trills of northern parulas, and tweets of song sparrows. As totality approached, many birds fell silent and only the lone calls of robins, cardinals, and the seconds-long croaks of frogs echoed through the forest before fading away. The temperature dropped, and the chill of the Moon's approaching shadow blew through the woods. The scientists listened on.

Spring peepers announced the arrival of totality. Their rhythmic croak was the soundtrack to the black disk in the sky, illuminated by a ring of white light. Fish in the nearby pond jumped and splashed, and we heard an owl's hoot. The research team celebrated the sounds quietly in the shadowy forest, flashing thumbs-ups to each other. Then all was interrupted by a round of fireworks. Still, they had gotten the data they came for.

As the Moon's shadow departed, the forest radiated with oranges and yellows and the sky returned to its usual blue, but the spring peepers (and fireworks) chorused on. It was an otherworldly experience, and I can't wait to observe the next one.

*— Elizabeth Gamillo, staff writer*

# THE SPIRAL GALAXY NEXT DOOR




Over decades of observations across a broad range of wavelengths, Andromeda has unlocked our understanding of the vastness of the universe. BY KLAUS R. BRASCH

**THE FAMED ANDROMEDA GALAXY,** or M31, draws attention at public star parties not only because it is the nearest major member of the Local Group to our Milky Way, but also because most people are aware that it is set to collide with our galaxy.

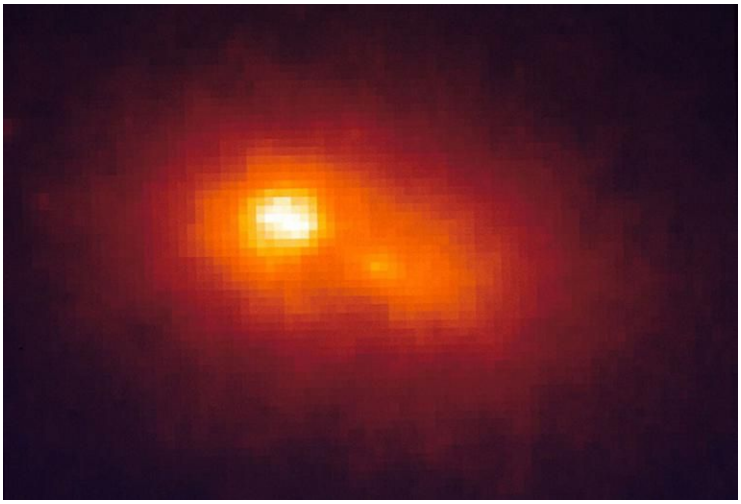
Some people become anxiously curious about what that collision is expected to look like, and most importantly, when it will occur. Any astronomer on site can reassure them, though, that the merger will not happen for billions of years and will be gradual rather than an abrupt crash.

For the time being, Andromeda lies 2.5 million light-years away. Amazingly, light from the inclined galaxy's front reaches us about 65,000 years before that from its rear. In short, we are observing an image distorted in both space and time.

On dark, moonless nights, Andromeda may first appear as a faint and fuzzy oval with a brighter center through an amateur telescope, but a prolonged look reveals its central core, foreground dust lanes, and hints of a spiral structure.


LEFT: The author took this digital color image of the Andromeda Galaxy and its two main satellites with a 5-inch apochromatic refractor, Canon R mirrorless camera, and IDAS LPS 4 filter. The total exposure time was 18 minutes at ISO 4000. KLAUS R. BRASCH

BOTTOM LEFT TO RIGHT: Isaac Roberts' superb photograph of the Andromeda spiral nebula, as well as its main satellites M32 (middle left) and M110 (bottom right), was taken in 1888 with his 20-inch reflector — part of his twin telescope designed by Howard Grubb of Dublin. YERKES OBSERVATORY ARCHIVES



The two baffling components of M31's nucleus are shown in this Hubble Space Telescope image. The dimmer one on the lower right contains the galaxy's supermassive black hole. NASA/ESA

Hot, blue, young stars, as well as the gas and dusty cocoons in which they are forming, are on display in this UV view of Andromeda captured by GALEX. NASA/JPL-CALTECH

## Deciphering Andromeda

Andromeda's existence has been known since antiquity. It was initially deemed a nebula, a term applied to all deep-sky objects that could not be resolved into stars. Nebulae were believed to lie within the Milky Way, and the systems that exhibited spiral patterns (such as Andromeda) were termed spiral nebulae and thought to be actively forming stars. William Herschel identified M31 as "undoubtedly the nearest of all the great nebulae" and estimated its distance to be about 18,000 light-years. Coincidentally, in 1783 his sharp-eyed sister Caroline, an accomplished astronomer herself, independently discovered M110, one of the two main satellite galaxies of Andromeda.

A better understanding of spiral nebulae was not possible before the development of spectroscopy and photography. In 1864, English astronomer William Huggins, known for his pioneering work in astronomical spectroscopy, showed that unlike the pure gas emission characteristics of the Orion Nebula (M42), Andromeda's spectrum displayed starlike features, including dark absorption lines. In 1912, M31's spectra captured by American astronomer Vesto Slipher at

Lowell Observatory showed the object had an approaching radial velocity of 186 miles (300 kilometers) per second, highly unlikely for a Milky Way object, since it was the highest velocity ever measured.

The first detailed photograph of Andromeda and its two satellites, M110 and M32, was taken in 1888 by wealthy Welsh engineer and amateur astronomer Isaac Roberts. Like his contemporaries, Roberts thought it was a star system in the making. He took Andromeda's photograph with his twin telescope — a 20-inch reflector and a 7-inch refractor on a shared mount — from his private observatory near Liverpool.

Roberts was a true pioneer of deep-sky photography and realized that long exposures were needed to record details in faint nebulous objects. He developed a method that we now call piggyback photography for wide-field imaging by using portrait cameras mounted atop a guiding telescope for accurate tracking. In this way, he obtained some of the first high-resolution pictures of prominent deep-sky objects such as the Pleiades (M45), Andromeda, the Triangulum Galaxy (M33), the Veil Nebula, and dozens more. Many of these photos were subsequently published in 1893 and 1899, in a two-volume book set titled *A Selection of Photographs of Stars, Star-clusters, and Nebulae.*

However, Roberts' images and the known facts about Andromeda weren't sufficient for scientists to agree on the galaxy's classification or distance measurement. The arguments reached their peak in 1920 when astronomers Heber D. Curtis and Harlow Shapley faced off in the Great Debate over the scale of the universe. Curtis argued that spiral nebulae were beyond and not part of the Milky Way, while Shapley maintained the opposite. The debate was irrevocably settled a few years later in 1923, when Edwin Hubble resolved a Cepheid variable star (used to measure cosmic distances) in photographs of Andromeda taken with the largest telescope in the world at the time, the 100-inch reflector at Mount Wilson Observatory. Using this distance indicator, he essentially proved M31 was a galaxy well outside our Milky Way.

## A new set of eyes

Tremendous advances have been made in the century since Hubble and his contemporaries opened the door to modern cosmology. Perhaps nothing illustrates that more graphically than the evolution of imaging technology.

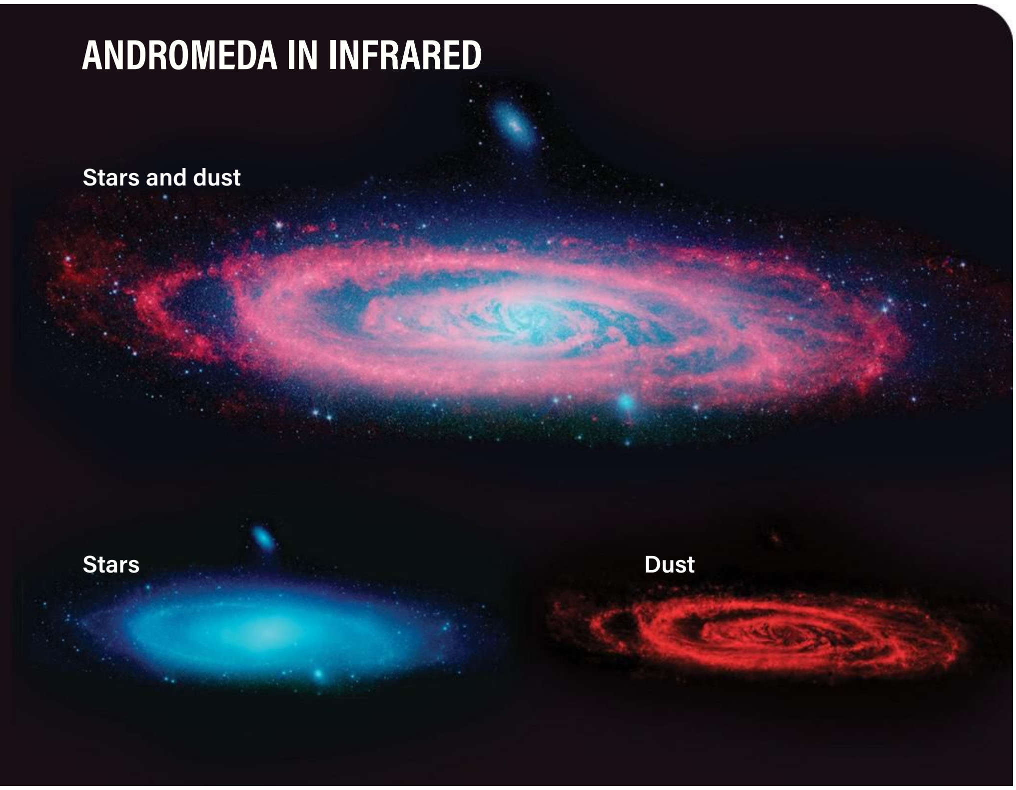
Roberts' historic photo of Andromeda (page 24) required a four-hour hand-guided exposure using the very slow and grainy glass photographic plates available during that time. Nonetheless, it revealed an huge amount of unprecedented detail and not only revolutionized astronomical photography, but also provided the first pictorial indication that spiral nebulae were more than mere gaseous clouds.

Today, some 130 years later, a full-color image of M31 (pages 24–25, largest photo) can easily be taken with a 5-inch apochromatic refractor and spectrally modified Canon R digital camera. Additionally, it only requires a total of 18 minutes of autoguided exposure time to record equally faint stars and gather sharper detail in the galaxy itself. Moreover, thanks to the use of narrow bandpass filters — which preferentially transmit wavelengths emitted by ionized hydrogen, H-alpha (Hα, red) and H-beta (Hβ, blue), and doubly ionized oxygen (OIII, blue) — the modern image reveals scattered pink emission nebulae along the galaxy's spiral arms, areas of interstellar dust (reddish brown), and hot young stars (blue).

A prominent region of such young stars resides in NGC 206, clearly resolved at the bottom left of both images. This immense star-forming region appears blue due to its extra-hot and luminous O- and B-type stars and light-scattering interstellar dust. It is readily visible in a medium-sized scope.

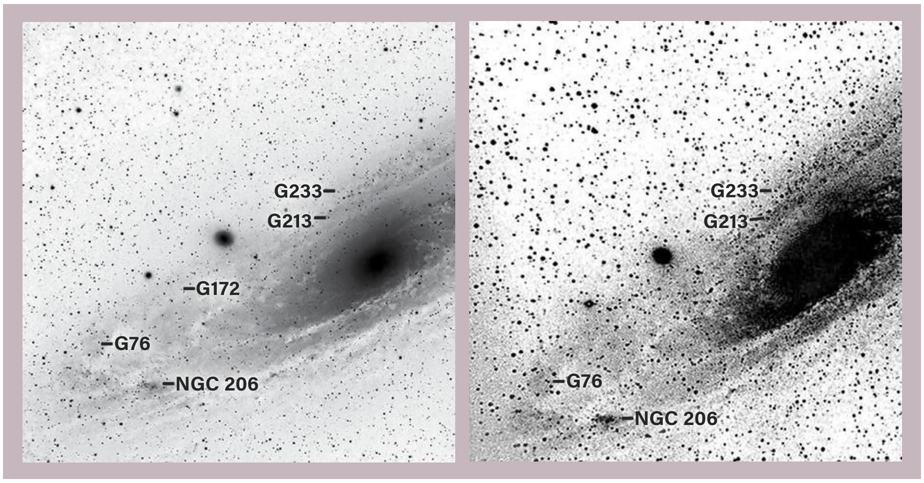
## Looking inside

The Andromeda Galaxy hosts about 500 globular clusters of various ages, sizes, and stellar compositions. In comparison, the Milky Way only has about 160 globulars. What accounts for this huge disparity between the two galaxies remains unclear, but it clearly reflects differences in their evolution over time. Some of the larger and brighter globulars in M31 can be resolved with medium-sized telescopes. In my experience, a quality 10-inch scope, dark skies, and a proper identification chart make spotting globulars a challenging but fun project. (Phil Harrington's *Cosmic Challenge: The Ultimate Observing*




A composite image (top) of M31 taken with IRAC on the Spitzer Space Telescope distinguishes between the stars (blue) and dust (red). NASA/JPL-CALTECH/P. BARMBY (HARVARD-SMITHSONIAN CFA)/NOAO

Streamers of hydrogen gas (red) are pulled in from intergalactic space on the left edge of Andromeda's disk in this composite image of M31, which combines far-infrared and radio wavelengths. Cold dust is indicated in green and the warmer dust is colored blue. ESA/NASA/JPL-CALTECH/GBT/WSRT/IRAM/C. CLARK (STSCI)/SKA OBSERVATORY/MPI RADIOASTRONOMIE/CARDIFF UNIVERSITY




A few of the brightest globular clusters (labeled with Gs) and the massive star-forming region NGC 206 in M31 appear in these images taken recently with a modern-day 5-inch refractor (left) and with a 20-inch reflector in 1888. LEFT: KLAUS R. BRASCH; RIGHT: ISAAC ROBERTS

*List for Amateurs* [Cambridge University Press, 2019] provides several such challenges, available at www.philharrington.net/cc01.htm.)

Roberts would be astounded to learn that his historic photo of M31 also recorded NGC 206 and several globular clusters. A side-by-side comparison of the negatives of his image and the modern-day one (bottom two photos above) shows that clearly. The globular cluster G76, located in the galaxy's southwest arm, has the greatest apparent brightness. Given the low sensitivity and grainy nature of the state-of-the-art photographic plates available in 1888, Roberts' accomplishment is truly extraordinary.

Our understanding of Andromeda's structure, composition, and evolution is improving rapidly thanks to advanced technologies and space telescopes, which make it possible to obtain data across a broad range of wavelengths including far ultraviolet (UV) and infrared (IR) — neither of which is accessible with ground-based telescopes. For example, NASA's Galaxy Evolution Explorer (GALEX) space telescope captured images in far- and near-UV light, revealing hot, young stars forming in the spiral arms (bottom-right image on page 25).

Similarly, IR images from the Spitzer Space Telescope (page 26) unveiled yet more layers of information about this massive galaxy. In addition to highlighting its waves of dust (red), the IR data also reveal older stars (blue). Images like this let astronomers estimate the mass of galaxies by measuring their total IR brightness. From such data, researchers deduce that M31 contains about a trillion stars — the Milky Way has 400 billion.

## In the arms of Andromeda

When it comes to Andromeda's inner structure, Spitzer images indicate that two possibly segmented spiral arms extend outward from a central bar, thereby classifying it as a barred spiral. Indications based on Hubble Space Telescope images suggest the galaxy has not just one, but two components in its nucleus. The mysterious, brighter one is dubbed P1 and the dimmer one is P2; P2 contains a supermassive black hole. It is now known that while P2 is indeed the true center of M31, the brighter component is actually an elliptical ring of old reddish stars orbiting the black hole. Computer simulations have tested different scenarios to better understand how such an arrangement could have formed, but the details remain uncertain.

The most complete summary to date about the structure and evolutionary history of the Andromeda Galaxy has been obtained by combining data from several diverse sources, such as the European Space Agency, NASA, the National Radio Astronomy Observatory, and IRAM radio telescopes (top image).

Future observations with the James Webb Space Telescope and other state-of-the-art instruments will undoubtedly provide us with an even more detailed evolutionary picture of this great galaxy — and, by extension, our Milky Way.

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**Klaus R. Brasch** *is co-editor with William Sheehan of the new book* The Space Age Generation *(The University of Arizona Press, 2024).*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

**BY MARTIN RATCLIFFE AND ALISTER LING**


Even late-summer clouds don't have to ruin an observing session — Saturn (at opposition in 2017) is visible at the center of this image in a patch of clear sky. ALAN DYER

# Saturn at opposition

Venus lingers after sunset. Saturn reaches opposition Sept. 8 and Neptune reaches opposition on the 20th. Jupiter dominates Taurus and Mars improves as it passes into Gemini. Mercury makes its best morning appearance in the Northern Hemisphere and the last week of September could offer a naked-eye comet.

**Venus** is visible in the west for up to an hour after sunset. At magnitude –3.9, it's easy to spot. On the 4th, a waxing crescent Moon is less than 5° west of Venus. The following evening they switch places, now 7° apart with the Moon southeast of Venus. The pair is still 5° high 30 minutes after sunset.

By mid-September Venus remains quite low after sunset and is 3° from 1st-magnitude Spica — can you spot the star south of Venus, whether with your eye or binoculars? Venus moves into Libra in the last few days of September. It stands 7° high in the western sky 30 minutes after sunset and remains visible for nearly another hour.

Through a telescope, Venus exhibits a 91-percent-lit disk spanning 11" on the 1st. The phase reaches 85 percent by the 30th, with a slight increase in diameter to 12".

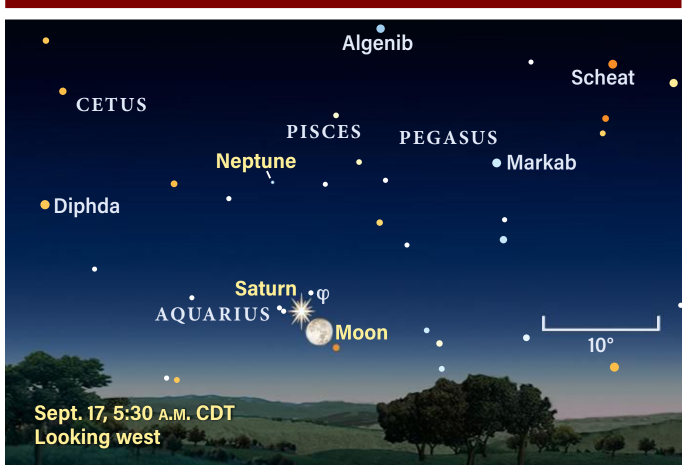
**Saturn** is visible all night, rising soon after sunset. It reaches opposition on the 8th. The planet stands 1.5° south of 4th-magnitude Phi (ϕ) Aquarii. Saturn's retrograde motion carries it westward to a point 3° east of Lambda (λ) Aqr by the end of the month. The planet reaches its peak magnitude for the year, briefly shining at magnitude 0.5 around opposition. At that time, Saturn lies 805 million miles from Earth.

An exciting event occurs the morning of Sept. 17, as Saturn is occulted by the Full Moon from central and western Canada and the U.S. In the Mountain time zone, the event occurs soon after 5 A.M. MDT, with the Moon about 10° above the western horizon. The Moon is 20° high on the West Coast, where the event occurs around 4 A.M. PDT. It takes almost 30 seconds for the disk of Saturn to be covered. The rings will appear very faint against the brilliant Moon. The International Occultation Timing Association's website lists timing from various cities: www.lunar-occultations.com/iota/planets/planets.htm.

Saturn is stunning through a telescope. Its disk spans 19". Our viewing angle increases from 3.5° to 4.5° as Earth's orbit carries us slightly above Saturn's ring plane. Early next year is the ring-plane crossing; before then, Saturn's rings reach a peak tilt of just over 5° before declining.

The major axis of the rings now spans 43.5". Watch for the two evenings on either side of opposition to see if you notice the rings are brighter than normal — exactly at opposition, the ring particles' shadows are "hidden" from view due to the alignment, resulting in a brightness boost. Known as the Seeliger effect (after German astronomer Hugo von Seeliger), the effect is

## Lining up




Early on Sept. 17, the Moon will cover Saturn for some observers in the U.S. and Canada. This chart shows the sky from the Midwest, about an hour before the event. Note that binoculars are needed to view Neptune. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

## OBSERVING HIGHLIGHT

The **FULL MOON** occults **SATURN** early on Sept. 17, visible across much of Canada and the U.S.

also enhanced by backscattering of sunlight off the fine particles.

On Sept. 1, the eastern half of the U.S. sees Saturn rise with Titan just a few arcseconds off its southern limb. Titan shines at magnitude 8.4 and orbits in 16 days. It stands near the planet again on the 9th, 17th, and 25th.

On Sept. 2/3, 10th-magnitude Tethys and Dione transit Saturn. The small, faint moons are hard to spot against the bright disk, making this a challenging observation requiring larger telescopes. Alternatively, high-speed video capture under high magnification can record the rare event. In the Mountain time zone, the pair are in transit as Saturn rises. Tethys leaves the disk around 12:20 A.M. EDT (Sept. 3 in the Eastern time zone only), with Dione following just under an hour later.

Iapetus reaches its greatest eastern elongation Sept. 3, when it appears near 12th magnitude. It stands 9.3' due east of Saturn. The moon then moves toward inferior conjunction early on the 23rd, brightening by a full magnitude. U.S. observers will see Iapetus just 53" north of Saturn on the evening of the 22nd.

**Neptune** starts the month just over 12° east of Saturn. It reaches opposition on the 20th, when it stands 2.69 billion miles from Earth. Shining at magnitude 7.7, it's an easy target when viewing through binoculars. A telescope reveals a 2"-wide disk with a distinctive bluish hue.

Neptune is southeast of the

— *Continued on page 34*

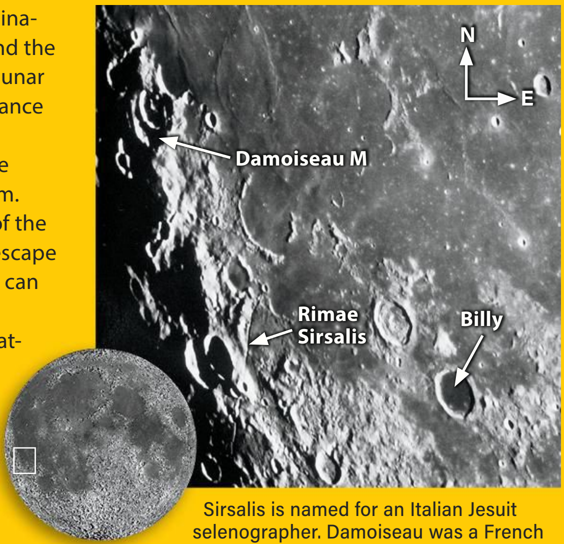
## RISING MOON | Double craters and rilles

**TAKE ADVANTAGE** of September's mild evenings to take a break from the deep sky and marvel at the detail along the Moon's terminator. Once you get past Tycho's great rays and the bright spot of Aristarchus, zoom in on the lunar southwest. Higher power reduces the brilliance of the moonbeams.

On the 15th, the Sun has illuminated the southwestern shore of Oceanus Procellarum. The smooth-centered crater Billy has one of the darkest floors on the Moon, managing to escape the mottling of multiple lava flows that we can see nearby.

Sitting near the terminator is the fascinating double crater Damoiseau M. The terrain's complexity is revealed by the low Sun angle — tomorrow night it won't be quite as impressive. A little more eye-catching just to the south is another double crater. In this pair, the eastern one clearly formed later — it has sharper features and has blown away the other's rim. More intriguing is the broad rille Rimae Sirsalis, a long, straight valley created by the land pulling apart, possibly due to the Orientale impact still hiding on the western limb. It should still be visible on the 16th, but the shorter shadows are less effective in revealing the depth. If you can, look closely on the 15th and then come back after a couple of hours to see how the lighting has changed.

### Damoiseau M and Rimae Sirsalis




Sirsalis is named for an Italian Jesuit selenographer. Damoiseau was a French astronomer who came a generation after Messier. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

## METEOR WATCH | Follow the ecliptic

### Encompassing planets

**THERE ARE NO** major meteor showers during September. However, a pre-dawn glow caused by millions of tiny dust particles filling our inner solar system can be observed on clear moonless nights from very dark locations. This zodiacal light shines with similar or a bit fainter brilliance than the Milky Way and is located along the ecliptic, which is angled steeply to the horizon this month, improving your chances of seeing it.

The zodiacal light is a faint cone-shaped glow with a broad base in Leo that narrows higher in the sky through Cancer and Gemini. With a New Moon on the 2nd, the first two weeks of September are the most favorable time this month to view this elusive phenomenon. Any glow from cities to your east will limit the view.

The zodiacal light often spikes up through the positions of the Moon and several planets, as in this shot. ALAN DYER

# STAR DOME

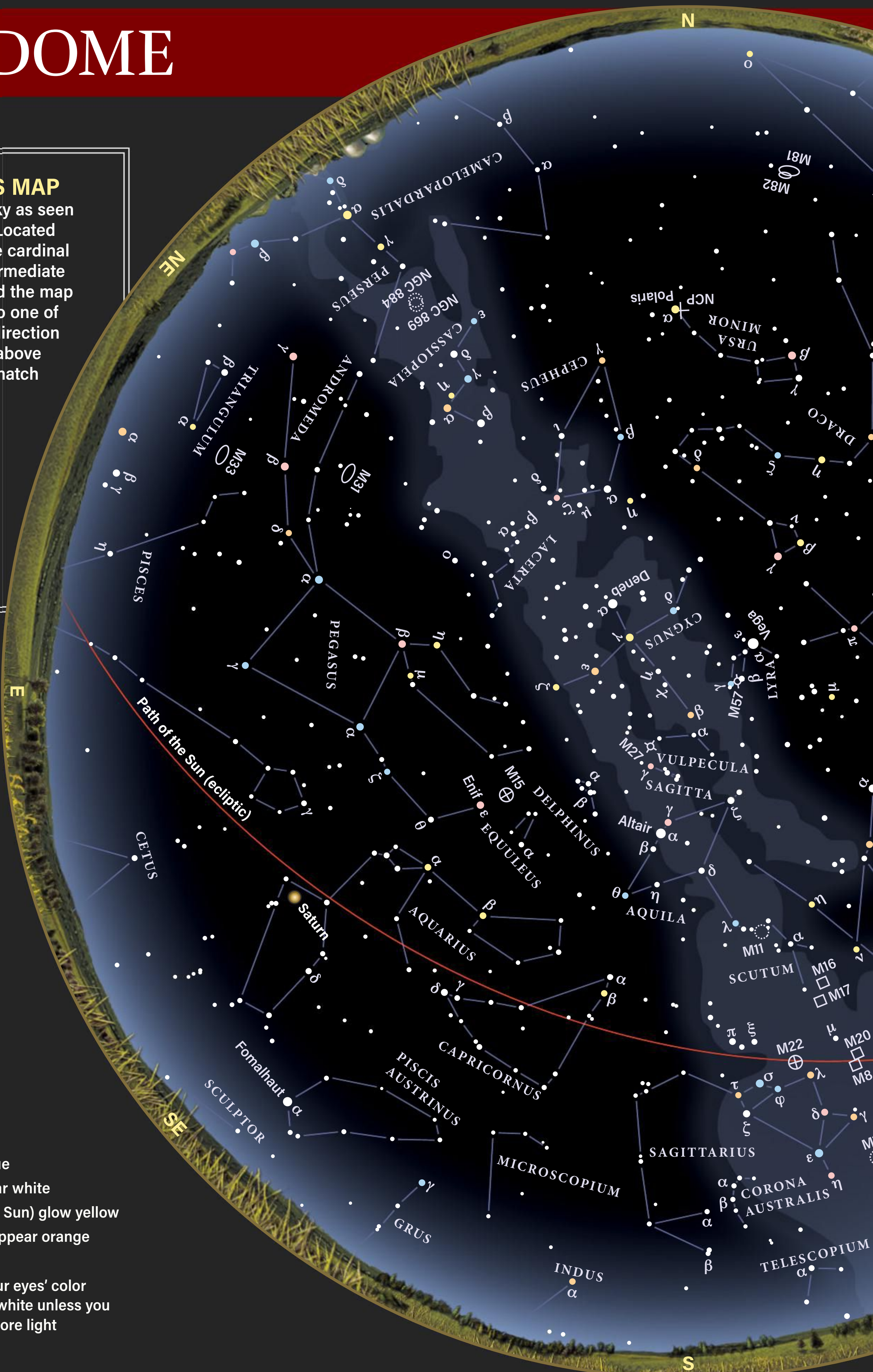
## HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth




## MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

## STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


## SEPTEMBER 2024

| SUN. | MON. | TUES. | WED. | THURS. | 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 | | | | | |

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

**1** The Moon passes 5° north of Mercury, 5 A.M. EDT

Uranus is stationary, noon EDT

**2** New Moon occurs at 9:56 P.M. EDT

**4** Mercury is at greatest western elongation (18°), 11 P.M. EDT

**5** The Moon passes 1.2° south of Venus, 6 A.M. EDT

The Moon is at apogee (252,408 miles from Earth), 10:54 A.M. EDT

**6** The Moon passes 0.5° north of Spica, 1 P.M. EDT

**8** Saturn is at opposition, 1 A.M. EDT

**9** Mercury passes 0.5° north of Regulus, 3 A.M. EDT

**10** The Moon passes 0.1° south of Antares, 9 A.M. EDT

**11** First Quarter Moon occurs at 2:06 A.M. EDT

**17** The Moon passes 0.3° north of Saturn, 6 A.M. EDT

Venus passes 3° north of Spica, 9 A.M. EDT

Full Moon occurs at 10:34 P.M. EDT; partial lunar eclipse

**18** The Moon passes 0.7° north of Neptune, 4 A.M. EDT

The Moon is at perigee (222,007 miles from Earth), 9:22 A.M. EDT

**20** Neptune is at opposition, 8 P.M. EDT

**22** The Moon passes 5° north of Uranus, 3 A.M. EDT

Autumnal equinox occurs at 8:44 A.M. EDT

**23** The Moon passes 6° north of Jupiter, 7 P.M. EDT

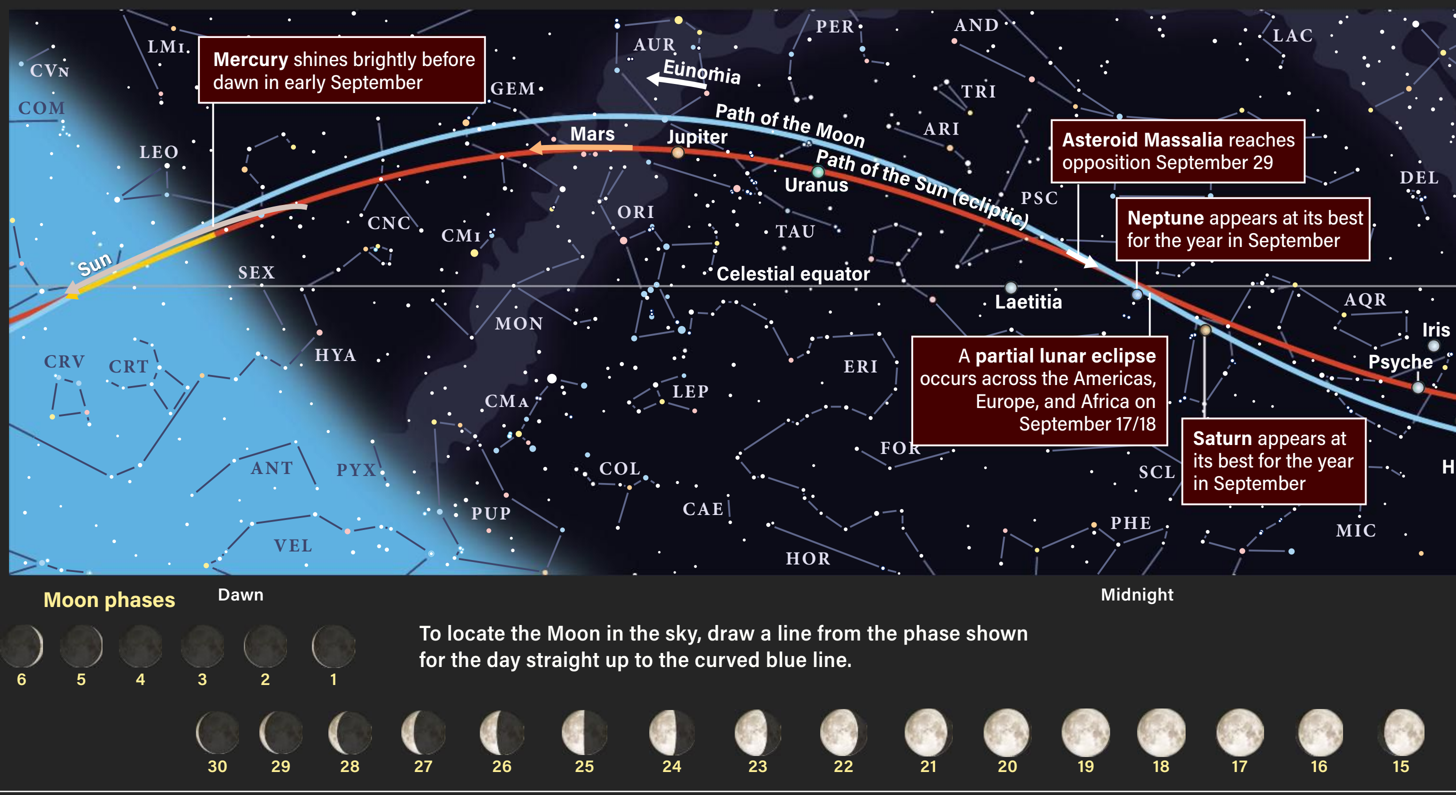
**24** Last Quarter Moon occurs at 2:50 P.M. EDT

**25** The Moon passes 5° north of Mars, 8 A.M. EDT

**29** Asteroid Massalia is at opposition, noon EDT

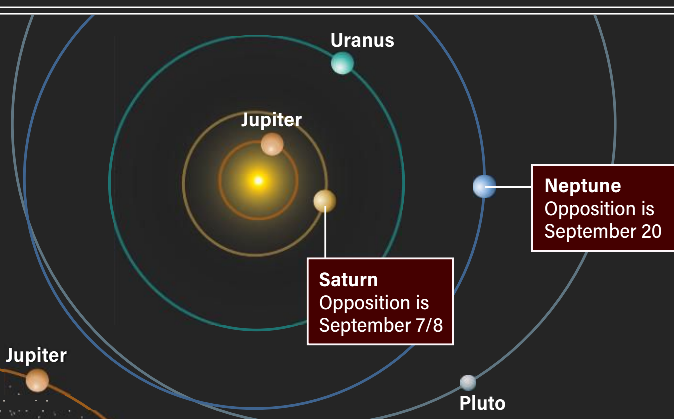
**30** Mercury is in superior conjunction, 5 P.M. EDT

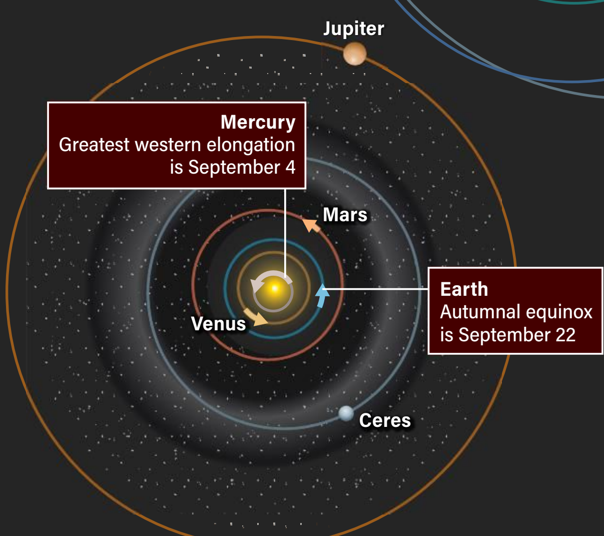
# PATHS OF THE PLANETS




## THE PLANETS IN THEIR ORBITS

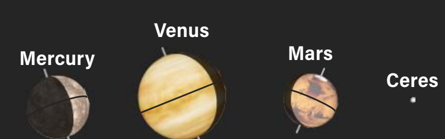
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.




## THE PLANETS IN THE SKY

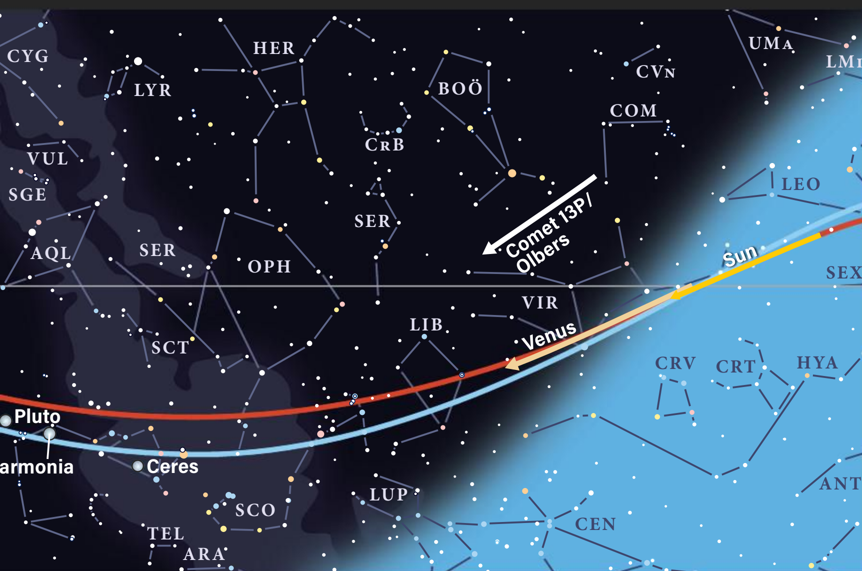
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



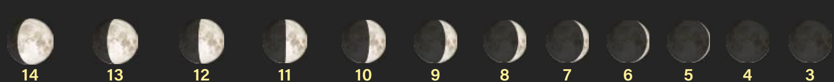

| PLANETS | MERCURY | VENUS |
|---|---|---|
| Date | Sept. 1 | Sept. 15 |
| Magnitude | 0.5 | –3.9 |
| Angular size | 8.2" | 11.5" |
| Illumination | 28% | 88% |
| Distance (AU) from Earth | 0.819 | 1.449 |
| Distance (AU) from Sun | 0.329 | 0.725 |
| Right ascension (2000.0) | 9h35.0m | 13h13.8m |
| Declination (2000.0) | 13°13' | –7°16' |

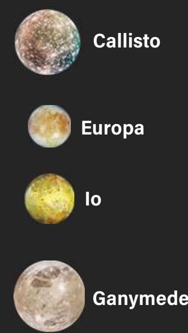
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

# SEPTEMBER 2024



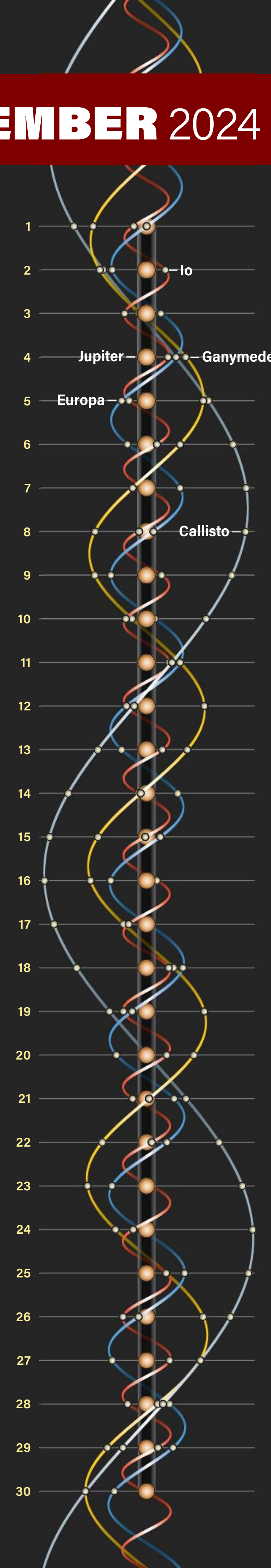

Early evening

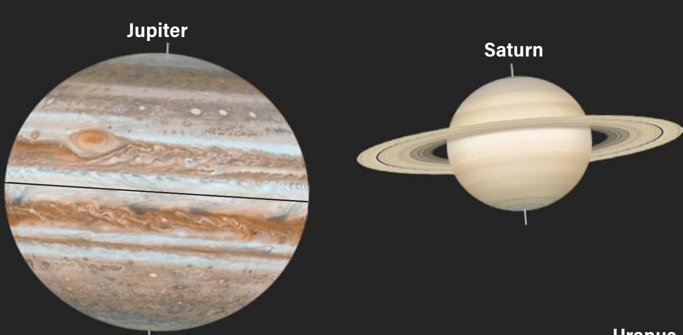


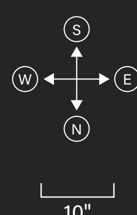



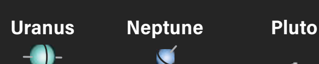

## JUPITER'S MOONS

Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.




| MARS | CERES | JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|---|---|
| Sept. 15 | Sept. 15 | Sept. 15 | Sept. 15 | Sept. 15 | Sept. 15 | Sept. 15 |
| 0.6 | 8.7 | –2.3 | 0.6 | 5.7 | 7.7 | 15.2 |
| 7.0" | 0.5" | 40.2" | 19.2" | 3.7" | 2.4" | 0.1" |
| 88% | 97% | 99% | 100% | 100% | 100% | 100% |
| 1.346 | 2.501 | 4.908 | 8.665 | 19.118 | 28.897 | 34.482 |
| 1.482 | 2.939 | 5.049 | 9.663 | 19.571 | 29.897 | 35.098 |
| 6h24.7m | 18h38.1m | 5h16.9m | 23h08.8m | 3h28.4m | 23h56.0m | 20h09.5m |
| 23°29' | –30°46' | 22°21' | –7°52' | 19°11' | –1°53' | –23°27' |

 — Continued from page 29

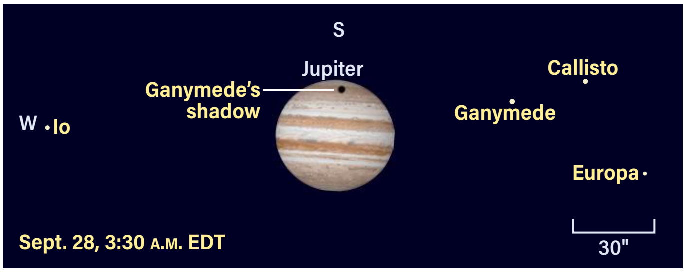
## WHEN TO VIEW THE PLANETS

**EVENING SKY**
Venus (west)
Saturn (east)
Neptune (east)

**MIDNIGHT**
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (south)

**MORNING SKY**
Mercury (east)
Mars (east)
Jupiter (southeast)
Saturn (west)
Uranus (south)
Neptune (west)

### Oncoming shadow




Ganymede's huge shadow will cross the southern polar regions of Jupiter more than once this month. Note in this case, Ganymede itself is far from the planet during its shadow transit.

Circlet in Pisces, just a short distance from a parallelogram of four 4th- and 5th-magnitude stars. Neptune stands 3° north-northwest of the northwestern-most star (27 Piscium). The Full Moon passes within 2° of Neptune on the 18th.

**Uranus** stands 5° southwest of the Pleiades (M45) all month after reaching a stationary point Sept. 1. It rises shortly before 11 P.M. local daylight time on the 1st and two hours earlier by the 30th. The planet's retrograde motion slowly picks up, carrying it some 20' west during the month. There's a nice pair of 6th-magnitude stars, 13 and 14 Tauri, similar in brightness to Uranus (magnitude 5.7) about 4.5° due south of the Pleiades. Uranus is within 1.5° to the pair's southwest. Through a telescope, Uranus' disk spans 4".

**Jupiter** is a brilliant object in Taurus, rising around midnight early in the month. The gas giant dazzles at magnitude –2.3 and sits 10° northeast of Aldebaran, Taurus' brightest star, on the 1st. A 20-day-old Moon joins in on the 23rd and 24th.

The finest views occur when Jupiter is highest above the horizon in the hour before dawn. Telescopes reveal dark bands straddling the equator as well as the four Galilean moons. The disk grows from 39" on the 1st to 42" by the end of the month.

Europa transits Jupiter Sept. 1 between about 2:45 A.M. and 5:15 A.M. EDT. The start of the event is only visible from the Mountain time zone eastward. On Sept. 8, Europa's shadow transits between 2:40 A.M. and 4:08 A.M. EDT. Europa begins a transit about 15 minutes after the shadow transit ends.

Sept. 14/15 finds Io and its shadow transiting as Jupiter rises across the western half of the U.S. The shadow transit begins shortly after 1:10 A.M. EDT on the 15th; Io follows around 2:30 A.M. EDT. The shadow exits at 3:20 A.M. EDT and Io exits at 3:41 A.M. EDT.

Ganymede's expansive shadow transits for the eastern half of the U.S. on Sept. 20/21. The event is underway as Jupiter rises and ends around 12:45 A.M. EDT on the 21st. On Sept. 27/28, the moon's huge shadow crosses Jupiter's south polar region from about 2:45 A.M. to 4:40 A.M. EDT on the 28th. The curvature of the planet is evident in the shadow's elliptical shape.

Callisto does not transit, due in part to the inclined angle of the plane of its orbit to our line of sight. Instead, it skims near the poles; an example of this occurs overnight on Sept. 19/20.

**Mars** glows at magnitude 0.7 between the horns of Taurus as September opens. It crosses into Gemini on the 6th, when it stands 16° north of Betelgeuse, Orion's brightest star. Mars rises shortly before 1 A.M. local daylight time on the 1st and about 40 minutes earlier by the 30th. It's best observed in the predawn hours when it stands high in the sky.

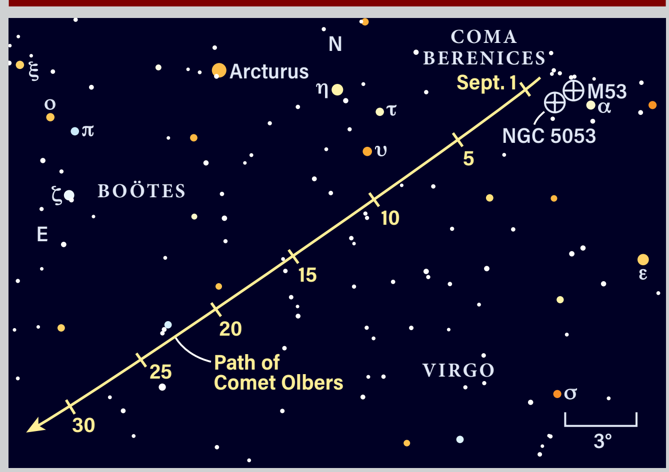
The Red Planet sits 0.9° due south of M35 on the 8th. Three

## COMET SEARCH | See you next time?

**CATCH YOUR LAST LOOKS** of Comet 13P/Olbers as darkness sets in. Plan to be away from city lights, set up during twilight, and have a decent northwest horizon. Sinking below 15° in altitude, fuzzballs like this lose contrast as their light attenuates through more of Earth's atmosphere. You'll want a 4-inch scope to spy its soft 9th-magnitude glow.

Start at magnitude 4.3 Alpha (α) Comae Berenices, shift north 1° to hit the bright globular star cluster M53, then east another degree to see the fainter NGC 5053. At the start of September, the comet is a bit farther east, but is likely easier to spot than NGC 5053 because that globular is more diffuse. Take time to note their shapes and structures.

### Comet 13P/Olbers

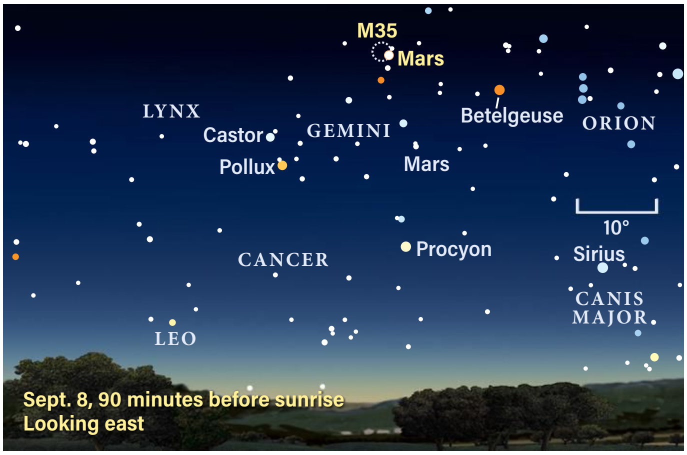



If you're young, you'll be in a select group that can see Comet Olbers now and during its return in 2094.

Imagers will get a chance to see the coma's carbon emission shut down. As the comet crosses the orbit of Mars, our Sun just isn't strong enough to trigger the classic green glow any longer.

Meanwhile, we're anticipating a super sight in October from the up-and-coming C/2023 A3 (Tsuchinshan–ATLAS).

## Visiting the Twins




Mars is making its way through Gemini this month, passing close to the open cluster M35 on the 8th.

days later (the 11th) it stands 1° due north of Eta (η) Geminorum, then takes three more days to stand 1° due north of Mu (μ) Gem on the 14th. The planet ends the month in the middle of Gemini; at magnitude 0.5 it outshines all the Twins' stars.

Mars is tiny, spanning just 8" by the 30th. During the last three months of the year, it will almost double in apparent size as it heads for an early 2025 opposition. The easiest feature to see when Mars is this tiny is dark, delta-shaped Syrtis Major, visible in the pre-dawn hours the first week of September.

September begins with a wonderful crescent Moon adjacent to **Mercury** in the morning twilight. They are well above the eastern horizon an hour before sunrise. Mercury shines at magnitude 0.5 just over 4° to the lower right (south) of the Moon.

Mercury reaches its greatest elongation west late on Sept. 4. It has brightened to magnitude –0.2 by dawn on Sept. 5. Now is Mercury's best morning apparition for observers in the Northern Hemisphere.

By the 9th, Mercury stands roughly a Moon's width (30') from Regulus and shines at an easy magnitude –0.7, compared with Regulus' magnitude 1.4. It's a lovely sight.

Mercury continues brightening, reaching magnitude –1 by the 12th, when it is 5° high in the eastern sky 45 minutes before sunrise. By the 19th you should still be able to follow the planet, now 3° high just 30 minutes before sunrise but magnitude –1.3. Nonetheless, you'll likely need binoculars to spot it in bright twilight. Mercury quickly dips out of view, heading toward superior conjunction Sept. 30.

But even as the morning sky loses a planet, it gains a comet! C/2023 A3 (Tsuchinshan-ATLAS) climbs in the eastern sky before dawn and stands 14° south of a waning crescent Moon on the 30th. The comet is 5° high in the east about 45 minutes before sunrise. If the comet follows predictions — always a big *if* — it could be near magnitude 1, perhaps sporting a tail.

A partial lunar eclipse occurs Sept. 17/18, starting at 8:41 P.M. EDT, shortly after moonrise in the Midwest. Most observers across the continental U.S. will see first umbral contact at 10:12 P.M. EDT. Prior to this, if the Moon is up, the duskiness of its northern limb will be apparent in twilight soon after sunset. This is the penumbral shadow, which the Moon entered at the start of the eclipse.

At its peak, the eclipse will cover 8 percent of the Moon for nearly 63 minutes, with maximum eclipse at 10:45 P.M. EDT. It will be visible across the U.S. (except for Alaska), South America, and most of western Europe and western Africa on the morning of the 18th. The eclipse ends at 12:47 A.M. EDT on the 18th.

The autumnal equinox occurs at 8:44 A.M. EDT on Sept. 22 as the Sun, moving along its annual path, dips below the celestial equator.

**Martin Ratcliffe** *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*



## LOCATING ASTEROIDS

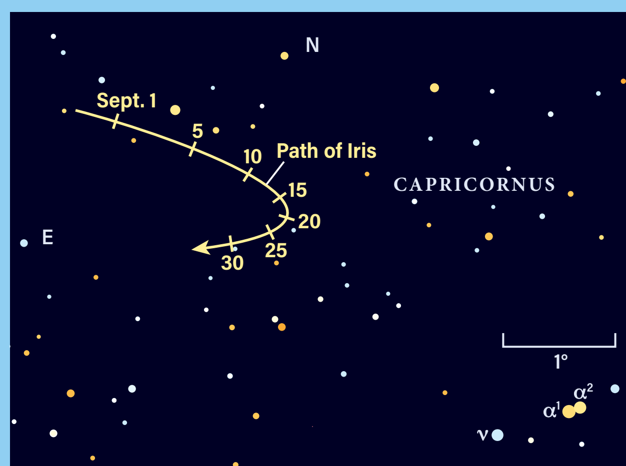
### In the clear

**7 IRIS STANDS OUT WELL** from its surroundings this month, making it easy to identify. Not counting a handful of brighter stars, the 9th-magnitude main-belt asteroid outshines the rest of the field except for the last week of the month, when it arcs through a richer field for a masquerade party.

Instead of jumping right to our target, begin at Alpha$^1$ ($\alpha^1$) and Alpha$^2$ ($\alpha^2$) Capricorni, the outstanding pair on the northwestern point of the Sea Goat. Can you split them with the unaided eye? In any scope they are two striking gold stars. Then move northeast to find Iris.

John Russell Hind picked up Iris in 1847, naming it for the Greek rainbow goddess. Like him, compare the view through a small scope to a chart to see which dot doesn't belong, then return another night to confirm it has moved. The last two weeks of September are particularly good for dropping five dots onto a circle in a logbook and adding Iris once you've found it. When the Moon passes by on the 14th, it may not interfere because it is far below the ecliptic, while Iris is above it. When the asteroid reaches perihelion in 2028, it will shine at an easy binocular magnitude of 7.

#### Golden lights




Iris is located near the gold-colored double star Alpha Capricorni this month.

# EXPLORING A CLUSTER CONUNDRUM

JWST probes the multiple generations of stars in globular cluster NGC 6440. BY RICHARD TALCOTT

**DESPITE WHAT SOME JADED AMATEUR** astronomers might claim, not all globular clusters are alike. Sure, they all contain 100,000 or more stars held together by mutual gravity and packed into a tight sphere. And those in the Milky Way, at least, all date back to the galaxy's early days.

But the similarities end there. Many globular clusters show evidence of multiple stellar populations, meaning not all their stars formed at the same time. And though every cluster possesses a higher percentage of hydrogen and helium than do stars like the Sun, some of them have surprisingly elevated levels of heavier elements (what astronomers call metals).

## A RARE CLUSTER

To better understand how globular clusters formed and evolved, researchers turned the powerful eye of the James Webb Space Telescope (JWST) on NGC 6440. This cluster lies in western Sagittarius just 1° from that constellation's border with Scorpius. The stars within NGC 6440 are an average of 1 light-year apart, though near the center they crowd within a few light-days of one another. And the cluster lies about 28,000 light-years from Earth but only 4,000 light-years from the Milky Way's center.

This places NGC 6440 firmly within the galactic bulge, a roughly spherical collection of old stars about 12,000 light-years across that's centered on the galaxy's heart. Although about 150 globulars call the Milky Way home, only 15 or so reside in the bulge. The rest occupy the much larger halo, which stretches beyond the galaxy's broad disk.

Bulge globulars are particularly significant because they contain more metals than their halo cousins. But their location within the bulge makes them difficult to observe. Thick dust both obscures the view into this region and reddens the starlight that does pass through. The crowded central regions of the galaxy also contaminate the scene with an abundance of noncluster members.

While visible-light telescopes struggle with these challenges, JWST shines. Its 6.5-meter mirror provides a resolution high enough to separate individual stars within the congested cluster environment. And the near-infrared radiation JWST detects passes through dust relatively unscathed.

Although this Hubble Space Telescope view of NGC 6440 looks stunning in its own right, it doesn't resolve as many stars as JWST. NASA, ESA, C. PALLANCA AND F. FERRARO (UNIVERSITY OF BOLOGNA), AND M. VAN KERKWIJK (UNIVERSITY OF TORONTO)

## CLUSTER CLOSE-UP

A team of astronomers led by Mario Cadelano of the University

Globular cluster NGC 6440 packs hundreds of thousands of stars into a sphere just 50 light-years across. This JWST portrait homes in on the cluster's core. Astronomers used these ultradeep observations to detect subtle chemical differences among the globular's stars.
ESA/WEBB, NASA & CSA, P. FREIRE

of Bologna in Italy targeted NGC 6440 with JWST's Near-Infrared Camera. Using two of the camera's filters, the scientists plotted a color-magnitude diagram (also known as a Hertzsprung-Russell diagram) that included more than 10,000 cluster members. Because different abundances of light elements affect a star's temperature (color) and luminosity (magnitude), these diagrams can separate stars with subtle compositional differences.

The researchers distinguished two noteworthy variations along the cluster's main sequence, where stars spend most of their lives converting hydrogen into helium. The brighter stars showed a pronounced split in the quantity of helium in their atmospheres, while dimmer ones revealed an equally strong divide in the abundance of water, a molecule that exists in the atmospheres of cool red dwarfs and traces the amount of oxygen.

The findings confirm that NGC 6440 experienced multiple bouts of star formation in its earliest days. And the unique ability of JWST to explore these different episodes in the realm of the galactic bulge opens a new frontier in exploring the composition, birth, and evolution of these enigmatic globular clusters.

*Contributing Editor* **Richard Talcott** *wrote about JWST's contribution to the ongoing Hubble tension debate in the August issue.*

The Southern Ring Nebula (NGC 3132) was one of James Webb Space Telescope's first targets after launching summer of 2022. Using the available data and processing software, anyone can create their own unique image.

# Process JWST images like a pro

With photo-editing software and this story, you can turn Webb's raw data into your own cosmic creation.

STORY AND IMAGES BY WARREN KELLER

In this remarkable age, space is becoming ever more accessible to the general public, and citizen scientists are enriching the field of professional astronomy with their contributions. NASA's latest flagship spaceborne observatory, the $10 billion James Webb Space Telescope (JWST), is no exception: Following the tradition set by the Hubble Space Telescope, NASA releases data from JWST to the public, much of it immediately after it has been gathered. Here is a quick start guide on how to access that data and use it to create your own stunning celestial images.

## Getting the data

Begin by searching for "MAST Portal" in your web browser, or by visiting the following link: MAST stands for the Mikulski Archive for Space Telescopes, named for Barbara Mikulski, a former U.S. senator from Maryland who played a pivotal role as an advocate for space exploration funding during her tenure between 1986 and 2017.

Click on the blue Advanced Search link at the top of the page, where a new window will pop open. There, locate the Mission box near the top-right corner, type "JWST," and press Enter. On the left-hand side under Columns, choose Release Date and scroll down to find the corresponding box on the right-hand side.

For this story, our specific target is NGC 3132, known as the Southern Ring Nebula. It was one of the earliest sets released. To find it, set the end date to "2022-07-13 16:00:00" [Fig. 1]. Clicking Search at the top-left corner will reveal the individual records.

In the blue Filters column on the left side (not to be confused with the Filters box in that column), find the Instrument box and select near-infrared images by ticking the checkbox next to NIRCAM/IMAGE. Depending on the width of your monitor and browser window, you may need to scroll with the blue bar at bottom until you reach the Target Name column. Also note the Filters column. Through my experimentation, I found that the filters F187N, F356W, and F470N (also listed with filter F444W) proved to be the most striking. Click on the floppy disk icons corresponding filters to download the zipped folders to your computer [Fig. 2].

## Organizing the data

After extracting a record, navigate to the parent folder, with an identical MAST name, finally entering the JWST directory. Next, open the folder with NIRCAM in the name, discarding all files except the one with the Flexible Image Transport System (FITS) extension ending in "i2d." Double-clicking this file opens seven individual files in your chosen image-processing application, mine being Pleiades Astrophoto's PixInsight (PI). Of these files, the first one to open will bear a _SCI suffix and is the only file required. When you're done opening the data you will have three files ready for post-processing,

FIG. 1

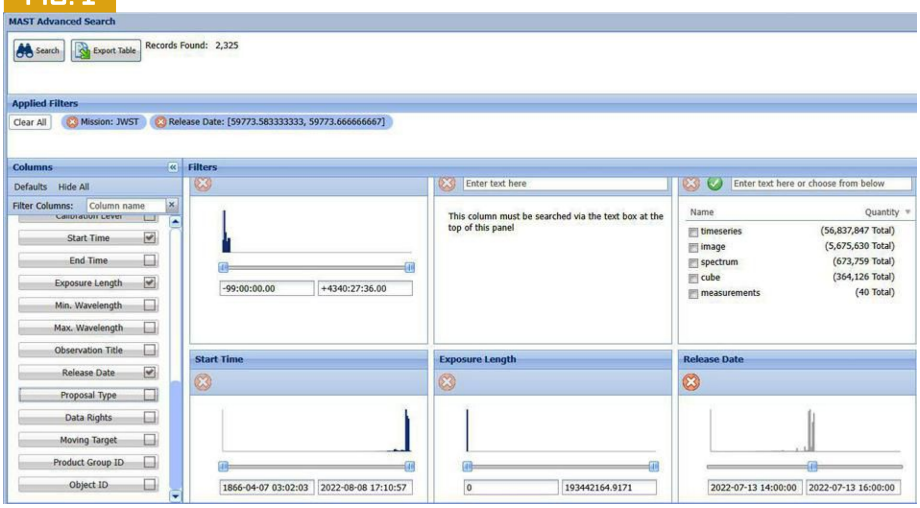



FIG. 2

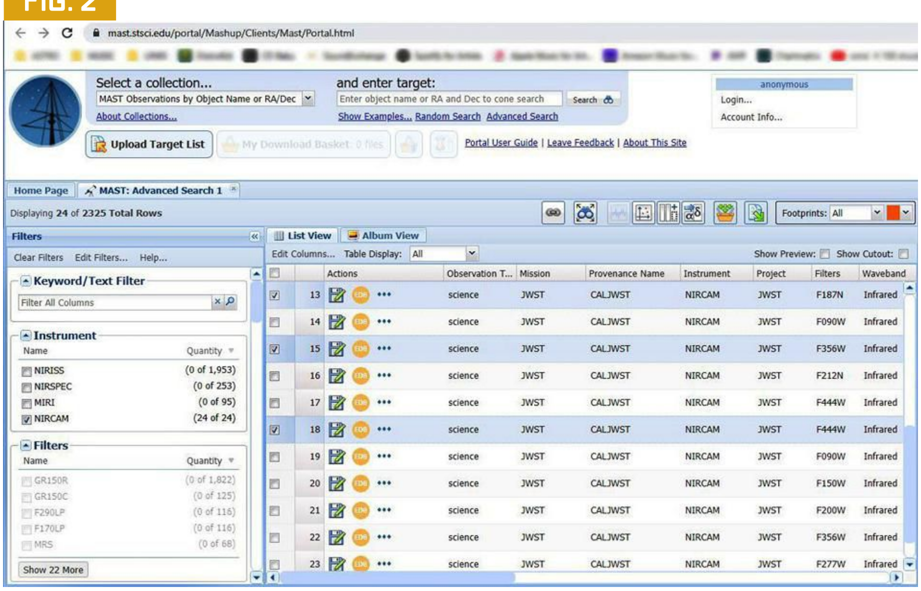
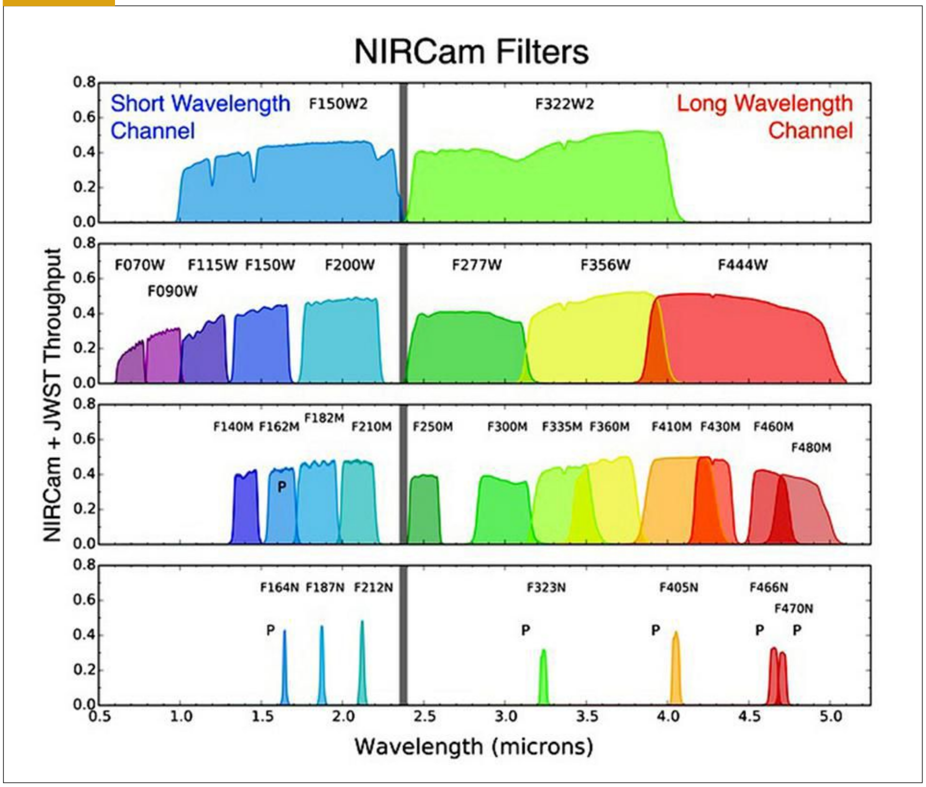
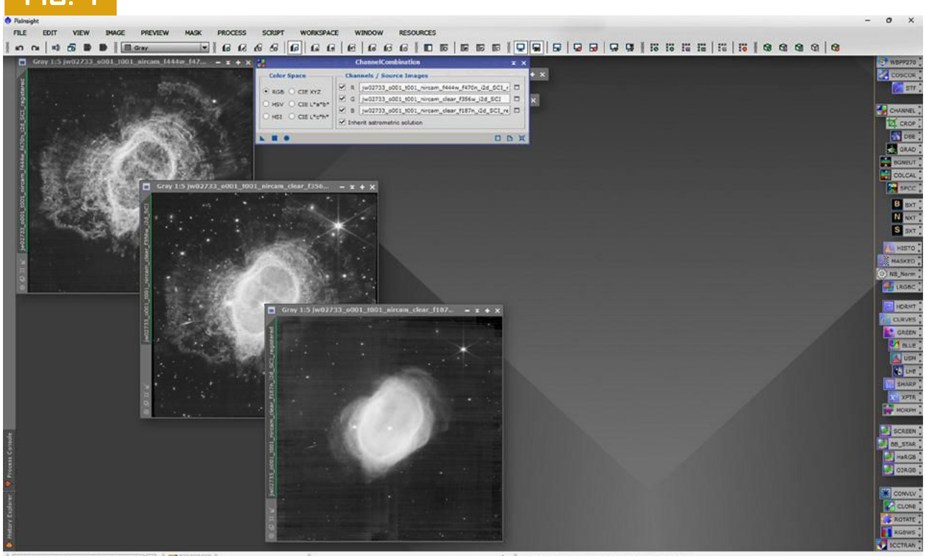


FIG. 3




The chart shows all 29 JWST NIRCam bandpass filters s in the short wavelength (0.6–2.3 µm) and long wavelength (2.4–5.0 µm) channels. Filters marked "P" are located in the pupil wheel, requiring transmission through a second filter in the filter wheel, either F150W2, F322W2, or F444W.

FIG. 4



each ending in "i2d_SCI" with the filter names: f444w_f470n, f356w, and f187n.

For those who process narrowband images, the technique of assigning invisible data to perceivable colors is a familiar concept. Because JWST can see outside the visible range, we have to assign colors to each of these filters we're using, assigning them to red, green, and blue channels. Determining the most suitable assignment of these filters is important. To assist in this process, search the web for "NIRCam filters – JWST user documentation." This resource includes a comprehensive set of plots showing the transmission lines of each filter, spanning from short to long wavelengths [Fig. 3].

While you don't have to follow the wavelength order, I did find it the most visually appealing. I chose to assign the shortest wavelength data (F187N) to the blue channel, the long wavelength data (F470N) to red, and the medium wavelength data (F356W) to green.

## Processing the data

As the three files were not registered to one another, I applied PI's StarAlignment process to the f444w_f470n and f187n frames, using the f356w image as the reference image since it offered the strongest star contribution. After marrying the three aligned files with the ChannelCombination process [Fig. 4], I cropped the image's edge artifacts with DynamicCrop. Skipping a few steps (such as gradient removal and color calibration) only required for ground-based, broadband images, I applied the BlurXTerminator (BXT) deconvolution plugin to enhance the nebular detail and tighten the stars; I found that BXT also greatly reduced the multipoint diffraction spikes caused by JWST's segmented mirror.

While the image's background noise was not objectionable, my attempts to further reduce it proved to be a challenge. RC Astro's NoiseXTerminator plugin is usually terrific, but in this case it was not useful — perhaps because its AI algorithm has not yet been trained on much JWST data. I then turned to PI's native MultiscaleLinearTransform program for the task. While its noise-reduction tool did a great job of smoothing the noise, its onboard Linear Masking feature did not provide enough protection for the fine detail of the outer parts of the nebula. Nevertheless, it's worth repeating that even without any noise reduction, the image was in good shape and ready for delinearization, better known in astroimaging as stretching. (Users of traditional photo-editing software like Photoshop and Lightroom can think of this as using levels and curves to control the image tones and enhance contrast.)

Transferring an unlinked AutoStretch from the ScreenTransferFunction (STF) to the HistogramTransformation (HT) process and applying it to the image, results in a permanent, nonlinear stretch with great, initial color. The only adjustments I made to the transferred curves before applying HT were to independently raise the black points of the R, G, and B channels to increase the contrast.

I then applied Subtractive Chromatic Noise Reduction (SCNR) to reduce a strong green cast in the stars and background galaxies. Changing the protection method from the default setting to Maximum Neutral prevented the nebula's core from turning too blue [Fig. 5]. While the degree of color saturation for any given image is strictly a matter of taste, I felt that the existing amount was about perfect.

This is the point where I generally remove the stars from an image so I can focus on processing the deep-sky object by itself, adding the stars back in later. (See my article "Erasing stars with AI tools" in the April 2023 issue for more on this technique.) However, in this case, I found that doing so removed too much of the nebula's fine, filamentary detail, so I decided to skip this step. Instead, I used PI's RangeSelection tool to create a mask that targeted the nebula and ignored the stars.

To increase local contrast, rather than using Local Histogram Equalization (LHE) — as is practically de rigueur in astroimaging — I used UnsharpMask as an alternative with a large standard deviation (40) and a tiny amount (0.11). LHE as well as MultiscaleMedianTransform (MMT) would be great choices for further increasing contrast and sharpness. The image was already so tack sharp that I added just a touch of wavelet-based MMT sharpening.

To bring out more of the structure of the nebula's core, I used the scaling to intensity setting of the HDRMultiscaleTransform process with a mask [Fig. 6]. This compressed the brightness level, revealing hidden detail while adding some color saturation.

With what I felt was a completed picture, I turned to a touch of cleanup with the CloneStamp (CS) tool. If you have an astute eye, you'll note two cosmetic problems. One is a greenish, vertical stripe in the lower-right quadrant of the image. You can use CS to cover it well enough so that it is less noticeable. Second, there are the odd magenta dots at the cores of a few saturated stars, and with a bit of finesse, CS will again solve that problem.

As with any image-processing software worth its salt, there are myriad options, and you may find other approaches that work better for creating your own masterpieces. Don't be afraid to explore.

FIG. 5

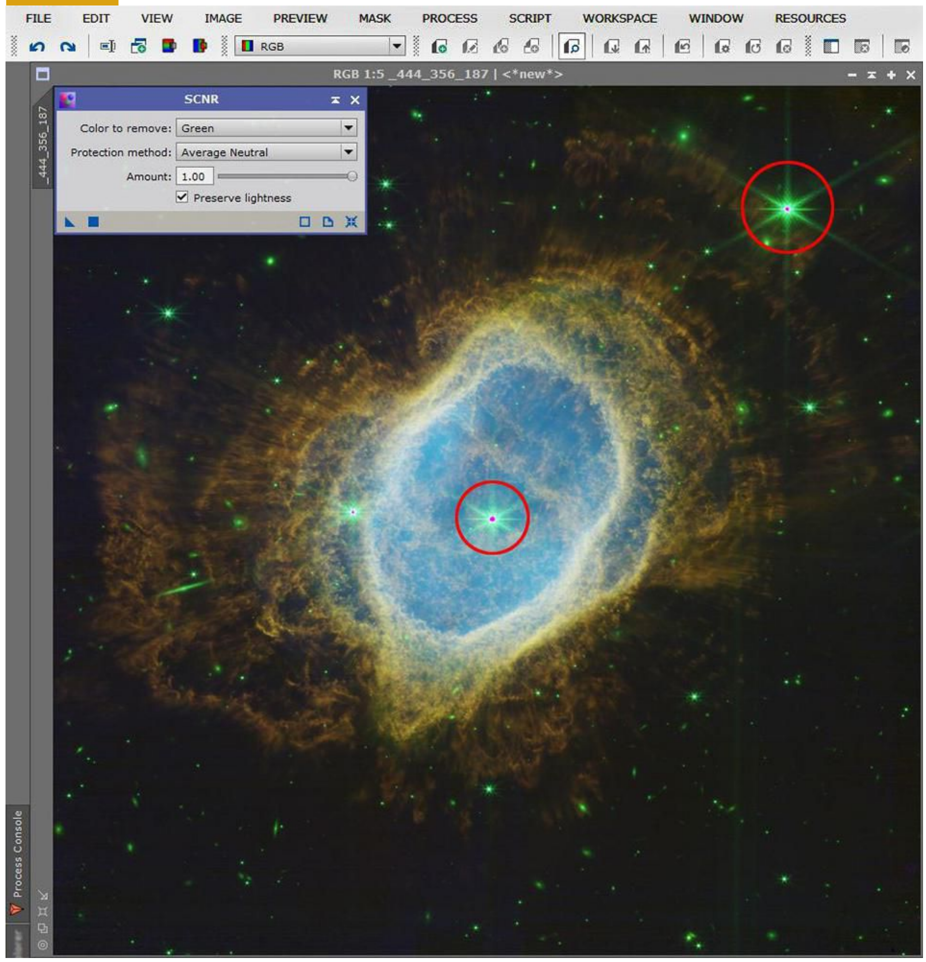
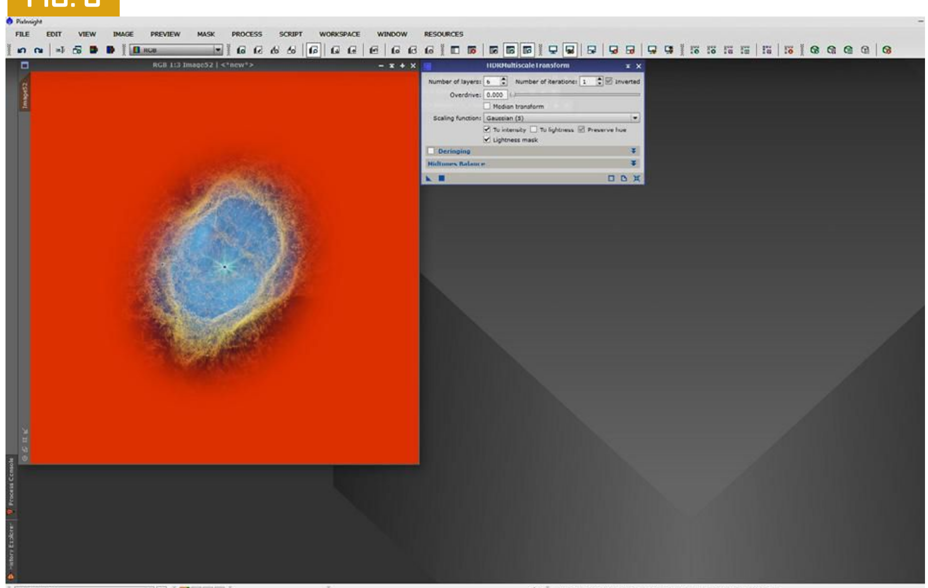
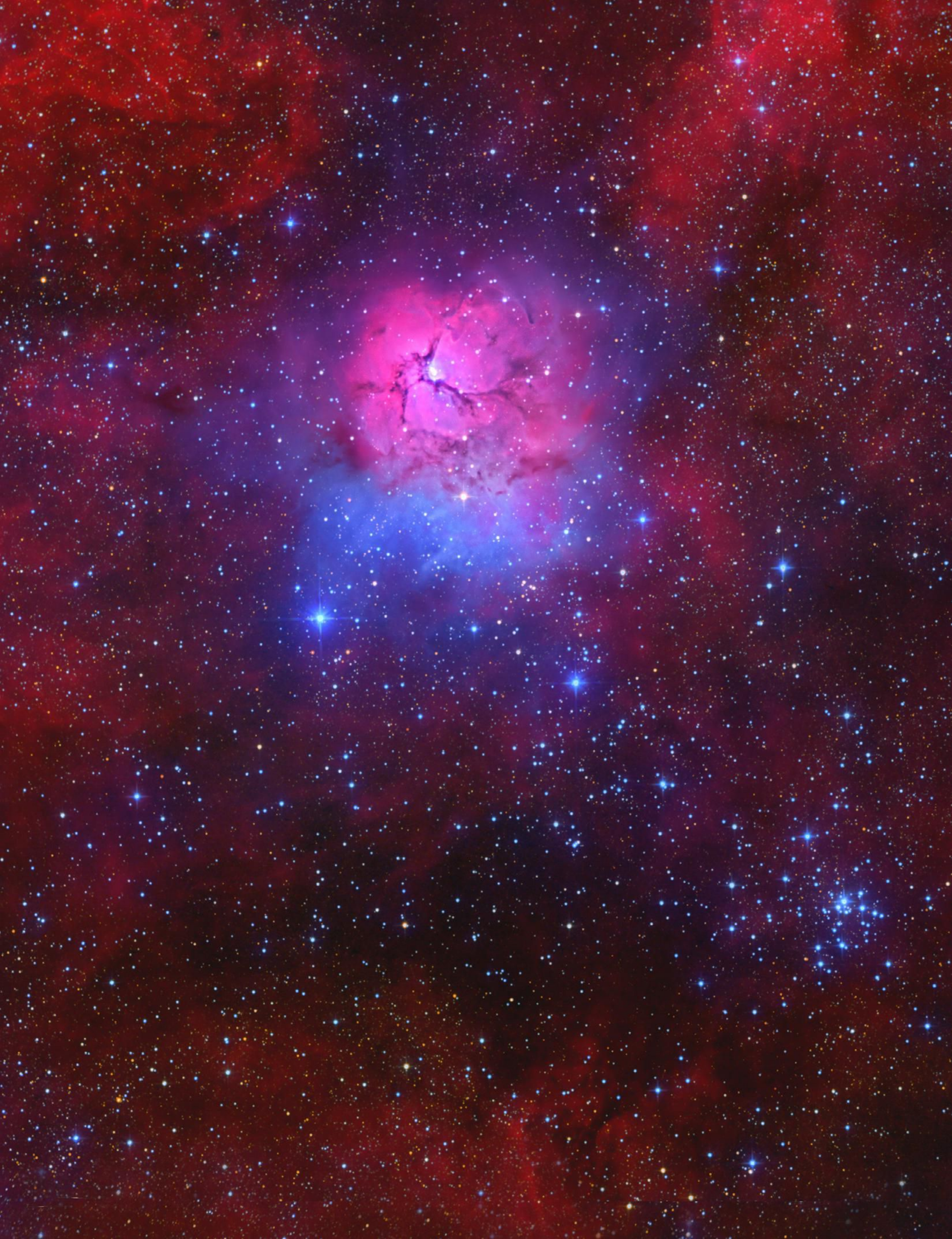



FIG. 6




➤ **For those who use Photoshop for their images, Nico Carver has an excellent tutorial, "Can I process the JWST data better than NASA?" at his *Nebula Photos* YouTube channel (https://www.youtube.com/watch?v=DVuonz26P0w).**

**Warren Keller** *is the author of the seminal book* Inside PixInsight (Springer Nature), *and has taught the art and science of astrophotography to thousands since 2005.*



# SECRETS of successful autoguiding

The most beautiful celestial scenes can be marred by streaky stars. Here's how to avoid this novice pitfall. BY CHRIS SCHUR

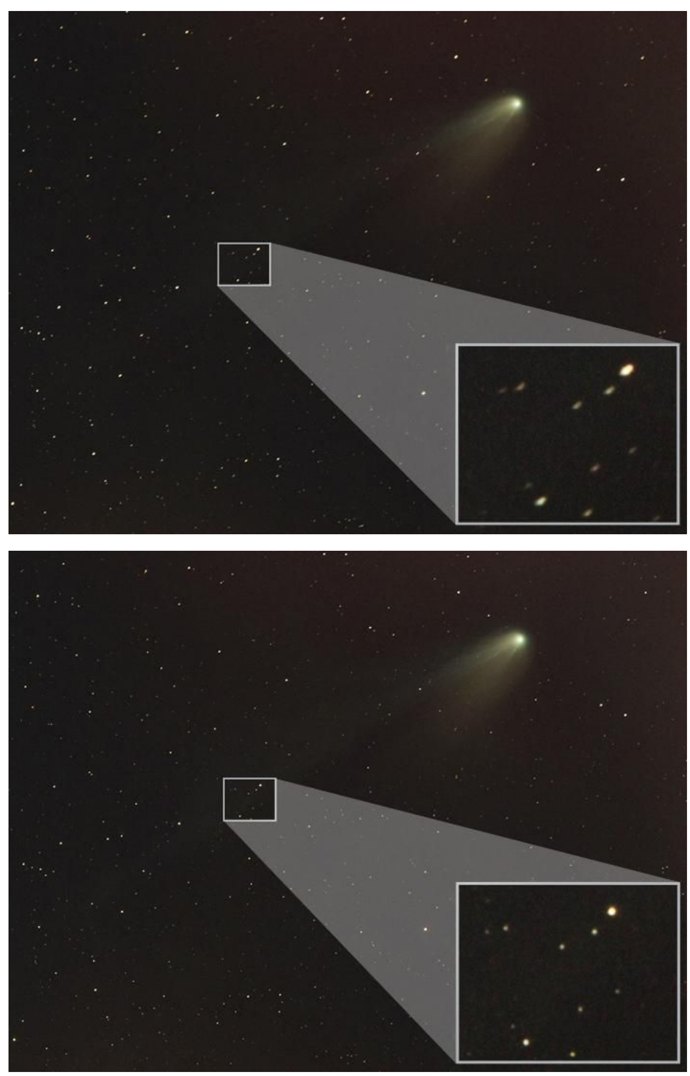
**We all gaze in awe** at beautiful deep-sky images, marveling at how the best imagers make it look so effortless to produce perfectly framed masterpieces. Such photos always seem to have perfect, pinpoint-round stars forming the foreground for the subject: the gauzy glow of a faint nebula or galaxy.

What we *don't* see are the results of the remaining 99 percent of imagers, who tried and failed to create such images because of trailed and blurred stars marring their carefully framed shots.

Autoguiding comes to the rescue by keeping your telescope pointed precisely where you want it, overcoming this novice shortfall and getting you on the road to producing your own celestial masterpieces. So keep reading for everything you need to know about the types of guiding methods and how to select a guide scope, guide camera, and software. I'll also explain how to balance your telescope and analyze your results. I even provide my suggested workflow to optimize your chances for success.

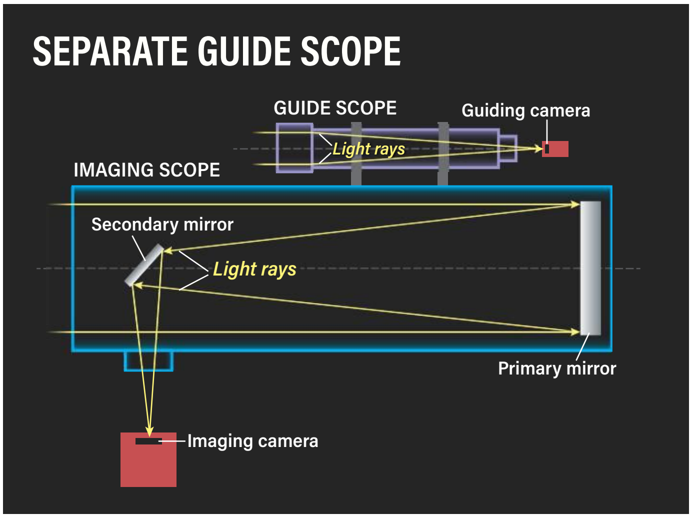
## Why guide?

Accurate tracking to keep an object in your telescope's field of view as Earth rotates

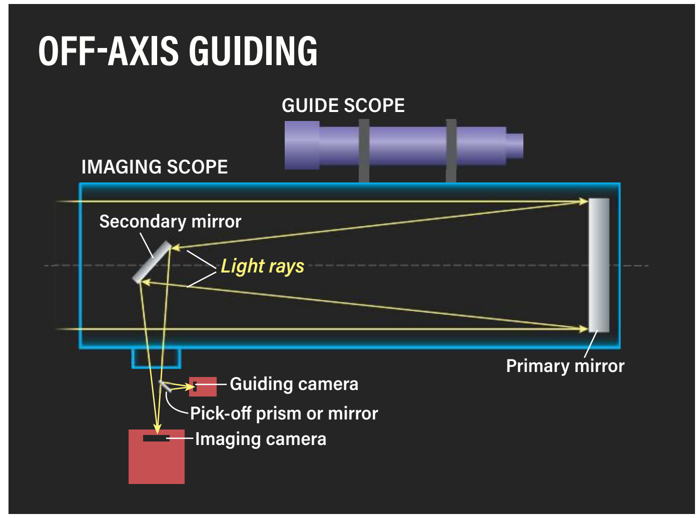


Autoguiding can take your astrophotography to the next level, as exemplified in this 6.5-hour exposure of the Trifid Nebula (M20). Here, the nebulosity stands out in all its glory among perfect, round stars. The author took this shot with a 10-inch f/3.8 Newtonian and Atik 16200 CCD. CHRIS SHUR

The difference between guided and unguided images is clear. At top is an unguided shot of Comet 12P/Pons-Brooks, with stars clearly trailed. At bottom is a second shot, with guiding turned on. Both are two-minute exposures taken April 13, 2024, from Payson, Arizona, with an 8-inch RASA scope and ASI071MC camera. CHRIS SCHUR




Autoguiding via a separate guide scope utilizes an external small refractor mounted piggyback on the main astroimaging instrument's cradle. The guiding camera is attached to the guide scope, while the imaging camera receives light only from the main scope. *ASTRONOMY*: ROEN KELLY, AFTER CHRIS SCHUR




In an astroimaging system using off-axis guiding, a small pick-off prism or mirror diverts light from a star outside the imaging scope's field of view into the guiding camera. *ASTRONOMY*: ROEN KELLY, AFTER CHRIS SCHUR

is the first step toward creating clear images, but it's not always enough, particularly as you increase the telescope's focal length. And while professional telescopes costing millions of dollars have exquisitely accurate drive systems with sub-arcsecond tracking, the commercially produced mounts available for amateurs vary greatly in this regard. The gears in amateur mounts can have periodic error accuracy ranging from a few arcseconds at best to several arcminutes or more in the worst cases. Although this tracking error is usually the primary reason to guide using a second camera trained on a star near your target when taking exposures longer than a few seconds, there are other, more significant reasons to consider guiding as well.

One is the subject's altitude above the horizon. Stars' movements in the field slow as they near the horizon due to atmospheric refraction. The closer you are to the horizon, the worse it gets. So tracking at a constant rate isn't enough. Additionally, wind may exert pressure on the telescope tube and change its tracking rate in an irregular way.

Another typical issue is declination drift due to poor polar alignment. Just a small offset from the pole will result in a constant north or south drift easily seen in exposures of five minutes or less — especially when shooting subjects near the celestial poles. Even the way you hang power and data cables on your instruments can have effects. If, say, the USB cables to the guide camera or primary camera are tugging during the exposure, it can cause a tracking offset that leads to strangely trailed star images.

Finally, without guiding on a target star near the subject, you can never get a perfect alignment on stacks of consecutive images if subsequent shots have drifted in any way from the first shot in a set.

## How guiding has evolved

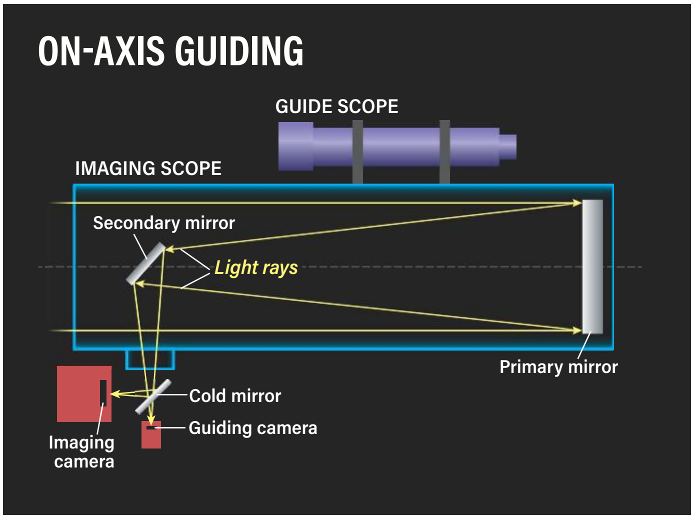
For most of the past century, guiding was accomplished via a separate piggyback guide scope — usually a long-focus refractor equipped with an illuminated high-power crosshair eyepiece. The imager would watch the guide star throughout the entire exposure and manually press a button on a hand box every few seconds to change the drive speed and keep the star centered if it drifted off target. This could get quite interesting (read: uncomfortable), depending on where the telescope was pointed and where the eyepiece was attached.

Thankfully, we don't have to go through that today! The advent of small, affordable CCDs — and now CMOS guiding cameras and software — has relieved us of that burden. Today's guiding cameras can make corrections every one to two seconds for hours on end without testing the limits of human concentration or the uncomfortable body contortion of manual guiding. The future of accurate autoguiding looks bright, with many manufacturers now including the required optics and camera built into the mount itself for a completely integrated system.

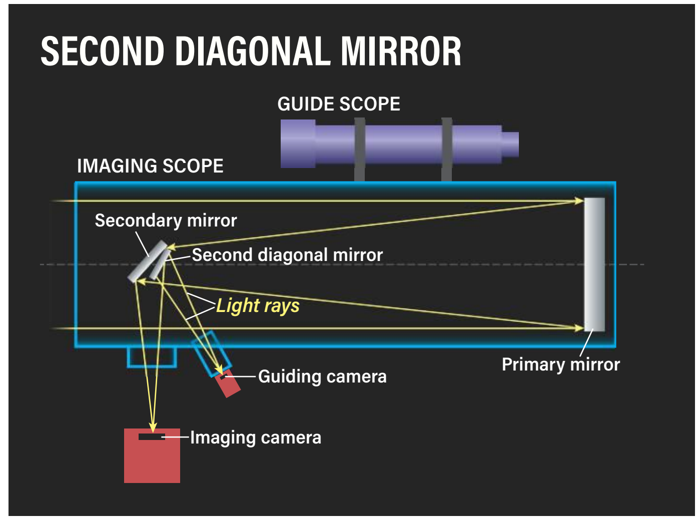
## Guiding methods

There are four ways you can set up a guiding system for your telescope, depending on its optical configuration and the mechanical design of the telescope cradle. The least expensive route is an off-axis guider installed directly between the camera and focuser, while the most expensive is a separate guide scope. The latter is the simplest to use but comes with a grab bag of problems to overcome. Your personal best option for guiding will involve consideration for your budget, mounting configuration, camera weight and balance, and the type of objects you intend to shoot.

**Separate guide scope.** This option uses a small refractor mounted piggyback on the cradle or directly on the tube of the main instrument. It must be adjustable so it can be centered on either the target or a nearby suitable guide star. Years of experience have dictated that the aperture and focal length of the guide scope should be no less than a quarter the aperture and half the focal length of the main imaging instrument. You can add a Barlow lens to the optical train to ensure shorter-focal-length guide scopes meet this requirement. Although not required, the ability to install




In an on-axis guiding configuration, a cold mirror deflects visible light from the target at a 90° angle into the imaging camera, while the infrared light passing through the mirror is used for guiding. *ASTRONOMY*: ROEN KELLY, AFTER CHRIS SCHUR




Mounting a small, adjustable flat mirror in the center of the main diagonal mirror allows you to capture a small annulus of light around the shadow of the secondary and divert it to the side of the telescope tube and into a second focuser for guiding. *ASTRONOMY*: ROEN KELLY, AFTER CHRIS SCHUR

a low-power eyepiece for guiding target centering is a big plus with such an arrangement.

**Off-axis guiding.** A second commonly used method is an off-axis guider, essentially a short tube installed between the camera and focuser drawtube, with an adjustable pick-off prism to intercept guide stars just outside the normal field of the imaging chip's short dimension. Any coma correctors or field flatteners must be installed in front of the pick-off prism to ensure the roundest possible guide stars. But to be honest, I find these devices difficult to use. While they're the best at capturing tracking and flexing errors during the exposure, finding a suitable guide star can be daunting in the limited field. If you go this route, also be aware there is a steep learning curve and you may encounter objects with no usable guide stars available.

**On-axis guiders.** Also known as ONAG guiders, this recent addition to guiding options can be perfect for bright comets, asteroids, or any targets near bright stars. These guiders are basically a 90° diagonal with an infrared (IR) mirror instead of the diagonal mirror. The main camera is mounted to see the visible light reflected in the "cold mirror," while the guiding camera is mounted on the back of the diagonal and views the IR image for guiding. Since most silicon sensors do well in the IR, these work well for fields containing cooler stars. Note, however, that mounting a heavy CCD or CMOS camera at a 90° angle can cause issues with balance. Additionally, the equipment needed is still quite expensive at this point, but may become cheaper in the future.

**Second diagonal mirror.** A few enterprising amateurs have found success by mounting a small, adjustable, square, flat mirror on the center of their main Newtonian diagonal mirror. The smaller mirror picks off a small annulus of light around the shadow of the secondary for guiding. This light is sent to a second focuser (where the guide scope is mounted) next to the primary focuser. While this method can work extremely well and will allow you to guide on either your subject or any sufficiently bright star in the field, it requires you to be skilled with tools and have the courage to modify your telescope.

## Selecting the right guide camera

When selecting a suitable guiding camera, there are a few important parameters to consider. While in the past autoguiding cameras were CCDs, today's cameras use CMOS technology. These sensors offer high sensitivity and low noise, with small pixel sizes and larger chip sizes for bigger fields.

Of key importance here is

## MY SUGGESTED WORKFLOW

Once you're set up and ready to go, a smooth workflow is essential to maximize your results at the telescope when imaging a deep-sky subject. Here is my suggested workflow:

1. Balance your telescope with a slight eastward lean. Worm drives track better when the motor is pulling the gear, rather than the gear pulling the motor.
2. Center the target in the main instrument. (Camera software often includes a crosshairs function for precise centering.)
3. Center a guide star in the guide scope field as close as possible to the center of the imaging target. This will minimize declination drift.
4. Insert the guiding camera with right ascension along the horizontal axis and focus it. PHD guiding uses a different algorithm for right ascension and declination, so this distinction is important for the best tracking.
5. Train the autoguider for this part of the sky, setting aggressiveness in declination to 50 percent. (Declination overshoot is the leading cause of guiding failures, so limiting its aggressiveness can keep it under control.)
6. Re-center the target in the main telescope if needed, then start autoguiding.
7. Focus the imaging camera, set up the shooting sequence, and expose all the subframes.
8. Upon completion of the sequence, stop guiding, move to the next target, and repeat as needed.

This superbly sharp shot of globular cluster M5 in Serpens comprises a one-hour exposure taken with a 10-inch f/3.8 Newtonian scope and Atik 16200 CCD. CHRIS SCHUR

pixel size. Most imaging cameras used today for deep-sky targets have pixels ranging in size from 2.5 to 12 micrometers on multi-megapixel chips. Your guiding camera must be able to see equal to or better than the resolution on the imaging camera sensor. To ensure this is the case, calculate the image scale per pixel for both and compare. The formula for calculating arcseconds per pixel is: (Pixel size [µm]/Focal length [mm]) x 206.3.

Let's look at an example. Say you have an 8-inch (200 mm) f/4 imaging Newtonian with an imaging camera with 6-µm pixels, and want to use a 3-inch (80 mm) f/6 guide scope with a guider camera with 3-µm pixels. Will this setup work?

The imaging camera has a scale of (6/800) x 206.3 = 1.5"/pixel. For the guiding camera, (3/480) x 206.3 = 1.3"/pixel. This is indeed close enough to ensure any movement on the imaging chip will be mirrored in the guiding chip. And you can add a 2–5x Barlow to achieve the correct effective focal length on the guide scope.

Guiding cameras must also have a guiding port. This usually is an RJ11 connector with six pins, called an ST4 port. This connects to your mount or hand controller with a standard RJ11 cable.

## Guiding software

Many advanced cooled cameras for imaging deep-sky objects come with an autoguiding function in their control software. These can simultaneously run the guiding camera and the imaging camera, offering the convenience of using the same software option for everything.

There are also standalone programs for autoguiding, such as PHD2, Metaguide, and Guide Dog. I personally prefer PHD2. Not only does it support the widest variety of cameras and is simple to use, it also offers multistar guiding to average the movements of multiple guide stars. This eliminates improper corrections from poor seeing, which can cause the guide star to jump all over the field. I feel this feature allows PHD2 to outperform other guiding software in terms of accuracy and smooth tracking.

## Analyzing your results

It's best to immediately check your results to ensure you're guiding correctly. When the first frame comes up on the computer screen at the end of the exposure, focus on the center of the image at 100-percent scale and examine the stars. If they are round and crisp, then congratulations on a fine job setting up your system!

If, however, the stars appear trailed in right ascension, this usually means either overaggressive tracking when trying to follow a star in poor seeing or flexure of the guide scope relative to the main instrument. Try a shorter exposure and see if anything changes. Poor guiding will make the stars trail the same amount even in shorter exposures. Conversely, if the issue gets progressively worse in longer exposures, then it is due to flexure.

Declination errors are usually remedied by changing the aggressiveness of the corrections to a lower value. Try an aggressiveness of 25 to 50 percent instead. Otherwise, too much backlash in declination gearing is usually the culprit. While some software allows for backlash compensation, it is best to eliminate the backlash, either by tightening the axis or shimming out the play in the telescope's mount.

The author poses with his astroimaging rig. CHRIS SCHUR

## A winning shot

While non-astronomy family and friends usually look only for rich color, a nice composition, and plenty of colorful stars in your images, your astronomy friends and other deep-sky imagers will take a far more critical look at your results. The first thing they will see is the quality of the star images. No amount of good composition or splashy colors will be able to compensate for poorly imaged stars. So, it's best to be patient and take the time to learn how to perfect your images. A well-guided image with sharp, round stars will go a long way toward producing a winning shot.

**Chris Schur** *is a retired Mechatronics engineer in Payson, Arizona, who uses his engineering knowledge to continually improve his astroimages.*

# Nature's eclipse reactions

Total solar eclipses trigger all kinds of behavior in the animal kingdom.

The five members of the animal kingdom we observed during the April 2024 solar eclipse from Bee Cave, Texas, are shown clockwise from top left: northern cardinal, American robin, mosquito, cloudless sulphur butterfly, and a Mexican free-tailed bat. Images showing totality and the mosquito were taken on eclipse day.

NORTHERN CARDINAL: DOUGLAS CHEWNING/AUDUBON PHOTOGRAPHY AWARDS. AMERICAN ROBIN: BRIAN KUSHNER/AUDUBON. MOSQUITO: DEBORAH CARTER. BUTTERFLY: PIMMIMEMOM/DREAMSTIME.COM. BAT: BRUCE D. TAUBERT/MINDEN PICTURES/BAT CONSERVATION INTERNATIONAL

Astronomers have long investigated the effects of totality on the animal kingdom. Results vary from eclipse to eclipse and location to location, leaving one to wonder just what specific aspects of the event can trigger behavioral responses. It's part of what makes totality one of the greatest natural wonders.

Before diving into the events of the April 8, 2024, total solar eclipse, let's look at some historical examples.

One of the earliest known records comes from the June 24, 1778, eclipse when Spanish naval officer and scientist Antonio de Ulloa observed that while sailing between the Azores and Portugal's Cape St. Vincent, the "fowls, birds, and other animals on board took their usual position for sleeping as if it had been night."

**Animals took their usual position for sleeping.**

During the July 8, 1842, eclipse at Pavia, Italy, British astronomer Francis Baily observed that the "great number of swallows flying about" before totality had vanished "towards the middle of the eclipse," only to return to full activity after third contact. So how did the animal kingdom react during the April 8, 2024 eclipse?

My wife, Deborah Carter, and I observed totality from Bee Cave, Texas, about 15 miles (24 kilometers) northwest of Austin. We set up next to a wildlife habitat which served as a stage to record the effects of totality on non-human life forms.

The Sun sat at an altitude of about 70° at the onset of totality, which lasted a little more than three minutes in Bee Cave. We observed the partial phase in the interstices between broken bands of altocumulus clouds, but a significant hole opened up at second contact, allowing a full view of the main event. Clouds covered the Sun shortly after third contact, followed by rain.

As expected, numerous insects went about their business prior to first contact. An abundance of butterflies flitted around the Texas wildflowers underfoot, a nearby cardinal whistled incessantly, and the swallows darted. The air was filled with the sound of distant bird calls. The temperature reached a high of 80 degrees Fahrenheit (27 degrees Celsius) and the winds were very erratic throughout most of the initial partial phases.

When the Sun was about 40 percent devoured, a mild chill filled the air and the wind gusts became stronger. At first, this change appeared to have no effect on the birds or insects. But only about five minutes later, all low-flying butterflies had vanished from view — with the exception of one straggler, which dove into the grass and did not return. Some high-flying butterflies still made occasional stops among the trees. A hawk soared overhead.

When the Sun was about 70 percent eclipsed, an appreciable darkening occurred. The receding crescent of the Sun turned the grasses yellow, and the light looked dull and flat, as if filtered through smoke. In the forest, leaves took on an eerie waxy sheen that seemed to glow against the darkened tree limbs.

At about 75 percent eclipsed, the cardinal had stopped singing. An American robin, usually vocal during twilight, now became the most dominant-sounding bird. We saw our last high-flying butterfly, and Deborah encountered the first mosquitoes; they became prolific when the Sun was about 95 percent eclipsed.

Three minutes before second contact, two low-flying bats came out of the woods and glided past us.

After a brief chorus of cheers from distant humans at the onset of totality, the wind and all insect and bird activity ceased. As the sky plunged into a silvery twilight, a sudden silence filled the air. It wasn't broken until crickets began serenading the approach of third contact. Five minutes after the Sun returned, the crickets hushed and distant bird songs resumed. Other insects did not return to flight until about 10 minutes after third contact. Butterflies did not resume their field duties until about 40 minutes after third contact — when the flight of birds, and life itself, seemed to also return to normal.

If you had a chance to record how the animal kingdom reacted during the April 8 eclipse, send your observations to sjomeara31@gmail.com.

**BY STEPHEN JAMES O'MEARA**
*Stephen is a globe-trotting observer who is always looking for the next great celestial event.*

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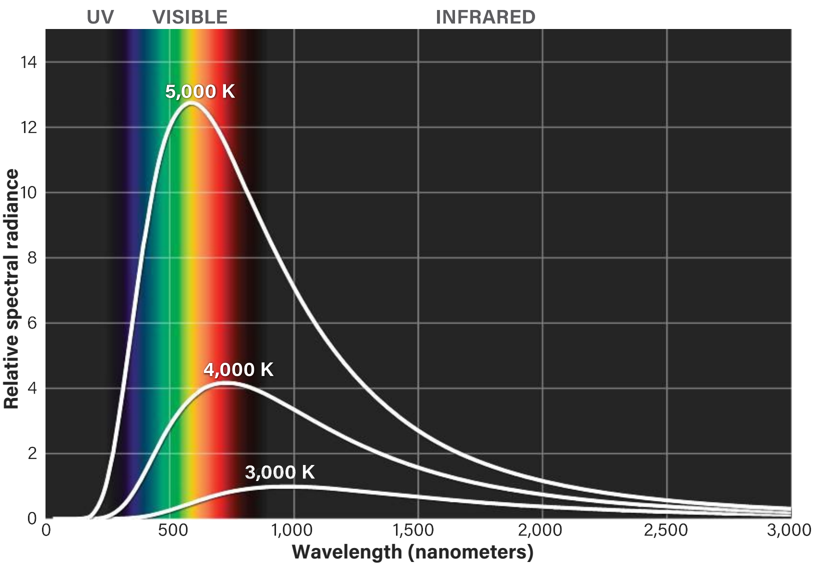
# A rainbow of stars

If you're looking for color in the cosmos, try targeting some double stars.




Stars, like incandescent bulbs, produce different spectra depending on their temperature. The color we perceive an object to be depends on the balance of light across the part of the spectrum to which our eyes are sensitive. *ASTRONOMY*: ROEN KELLY, AFTER DARTH KULE/WIKIMEDIA COMMONS

UPPER RIGHT: Albireo (Beta [β] Cygni) is a classic example of a double star with contrasting colors. MASSIMO DI FUSCO

**BY MOLLY WAKELING**
*Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.*

When we think of color in the night sky, we often think of beautiful images of galaxies and nebulae. Unfortunately, most of the time, their faint, diffuse light shows no color to our human eyes. Stars, on the other hand, have more concentrated light, and there we can see color — even with the naked eye!

So why do stars appear to have color, and in a variety of hues at that? The short answer is that the temperature of a hot object determines the shape and position of the emitted spectrum. In general, cooler objects peak at redder wavelengths, and hotter objects peak at bluer wavelengths. Think of the flame on a propane stove, which is blue toward the hotter bottom and orange toward the cooler top. The Sun, with a surface temperature of 5,700 kelvins (9,800 degrees Fahrenheit [5,400 degrees Celsius]), peaks in the green portion of the visible spectrum but appears white because the intensity of the red and blue light is nearly as high as the green. Red supergiant Betelgeuse, with a surface temperature of 3,700 kelvins (6,200 F [3,400 C]), peaks in the red and appears orange to our eyes.

For stars, there is a relationship between the color, temperature, size, and chemical composition. You may have heard the Sun called a type G2V star, or that the members of the Pleiades (M45) are hot B-type stars. These are both examples of spectral types. There are six traditional designations for stars: O, B, A, F, G, K, and M.

Type O stars, which are the hottest and bluest, are also extremely luminous; some of the most massive stars are O-type. At the other extreme, M-type stars are by far the most common — they account for 76 percent of the main-sequence stars in our neighborhood. Most M-type stars are red dwarfs, but there are a few notable exceptions. One is the extreme star VY Canis Majoris, a red hypergiant that is the one of the largest and most luminous stars known in the entire Milky Way Galaxy.

Each spectral type is split into 10 subdivisions, which are denoted by adding a numeral. Within each letter class, 0 is hottest and 9 is coolest.

A Roman numeral can also be added to indicate the luminosity class of the star, with I for supergiants, II for bright giants, III for regular giants, IV for subgiants, V for main-sequence stars, VI (or sd) for subdwarfs, and VII (or D) for white dwarfs. This distinguishes a red giant from a red dwarf with the same effective temperature.

You can see star colors in action by checking out the double star Albireo (Beta [β] Cygni), located at the head of Cygnus the Swan. A small telescope or mounted 10x50 binoculars can resolve the pair, with one glowing orange (Beta Cygni A) and one blazing blue (Beta Cygni B). The A star is itself a double star, although not resolvable by amateur instruments. Beta Cygni Aa is a K-type star, with a surface temperature of 4,400 K and a mass of 5.2 solar masses. Beta Cygni B is a B-type star of temperature 13,200 K and is 3.7 solar masses. You can catch Albireo just about all night this month.

**You can catch Albireo just about all night this month.**

Another beautiful color-contrasting pair is the double star Eta (η) Cassiopeiae, located between Navi and Shedar, the two bottom points of the Cassiopeia W. You will need a telescope for this one, but a refractor will do — 64x is enough for a nice view. Eta Cas is slightly more challenging with its four-magnitude difference in brightness between the two stars. Some people see the pair as yellow and red, while some see gold and purple. The brighter of the two is a G0V main-sequence star, very similar to our Sun. Its partner is a K7V main-sequence star. This binary — which lies only 19.4 light-years away — is also visible all night this month.

How many different star colors have you seen? Go out and observe tonight!

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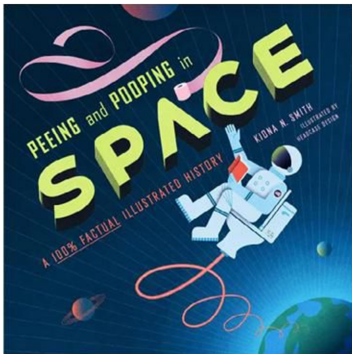


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NGC 253 in Sculptor is just one of thousands of objects cataloged in *The New General Catalogue of Nebulae and Clusters of Stars.* ESO

# The NGC catalog

**Q** | THE DESIGNATION M STANDS FOR MESSIER OBJECTS. I UNDERSTAND THE HISTORY BEHIND HOW THESE WERE IDENTIFIED AND CATALOGED. BUT WHAT ARE NGC OBJECTS? WHERE DID NGC COME FROM AND HOW IS IT APPLIED?

***Dean Treadway***
*Jesup, Georgia*

**A** | Anyone who has developed an interest in stargazing has certainly heard of the Messier and NGC catalogs. These publications list thousands of outstanding nonstellar objects, and both have a rich history.

Inspired by the six-tailed comet of 1744, Charles Messier made a career of hunting comets. Messier's frustration with finding "fuzzy" bodies that weren't comets resulted in his famous list of 103 objects, published in 1781, later revised by other astronomers to 110 objects. His list still provides challenges for any observer.

Five years later, in 1786, English astronomer William Herschel published his *Catalogue of Nebulae and Clusters of Stars*. With revisions, his publication eventually held 3,500 nebulae, clusters, and galaxies. William's son, Sir John Herschel, also produced a catalog of nonstellar objects. These catalogs often overlapped and were not always consistent in their listings.

Astronomer John Louis Emil Dreyer left his native Denmark in 1874 to work with Irish astronomer William Parsons, Earl of Rosse. Dreyer eventually moved to the directorship of the Armagh Observatory in Ireland, where he pursued many astronomical projects. There was a growing need to organize the astronomical catalogs compiled over the last century. Dreyer submitted a proposal to the Royal Astronomical Society to create a supplement for these early catalogs. However, the society encouraged Dreyer to compile a new and original list. This would become *The New General Catalogue of Nebulae and Clusters of Stars*, or NGC.

Dreyer found sorting through the thousands of objects listed in previous catalogs to be a daunting task. He even attempted to visually verify at least some of the objects with his own telescope. It soon became apparent that this was not practical. The nebulae, star clusters, galaxies, and more listed in past catalogs had been observed with telescopes ranging in size from Messier's 4-inch refractor to the 72-inch reflector of Lord Rosse. Verifying every object listed in previous catalogs would need to be accomplished by many other observers, who could then make the necessary corrections.

The first edition of the NGC, published in 1888, listed 7,840 objects and contained errors copied from earlier sources. However, Dreyer was meticulous in citing the references he used so other astronomers could verify them. Later editions of the NGC have been revised, corrected, and supplemented with an additional 5,386 objects in the so-called *Index Catalogues* (IC).

After more than a century, *The New General Catalogue of Nebulae and Clusters of Stars* is still an indispensable guide to nebulae, star clusters, and galaxies for professional and amateur astronomers alike.

***Raymond Shubinski***
*Contributing Editor*

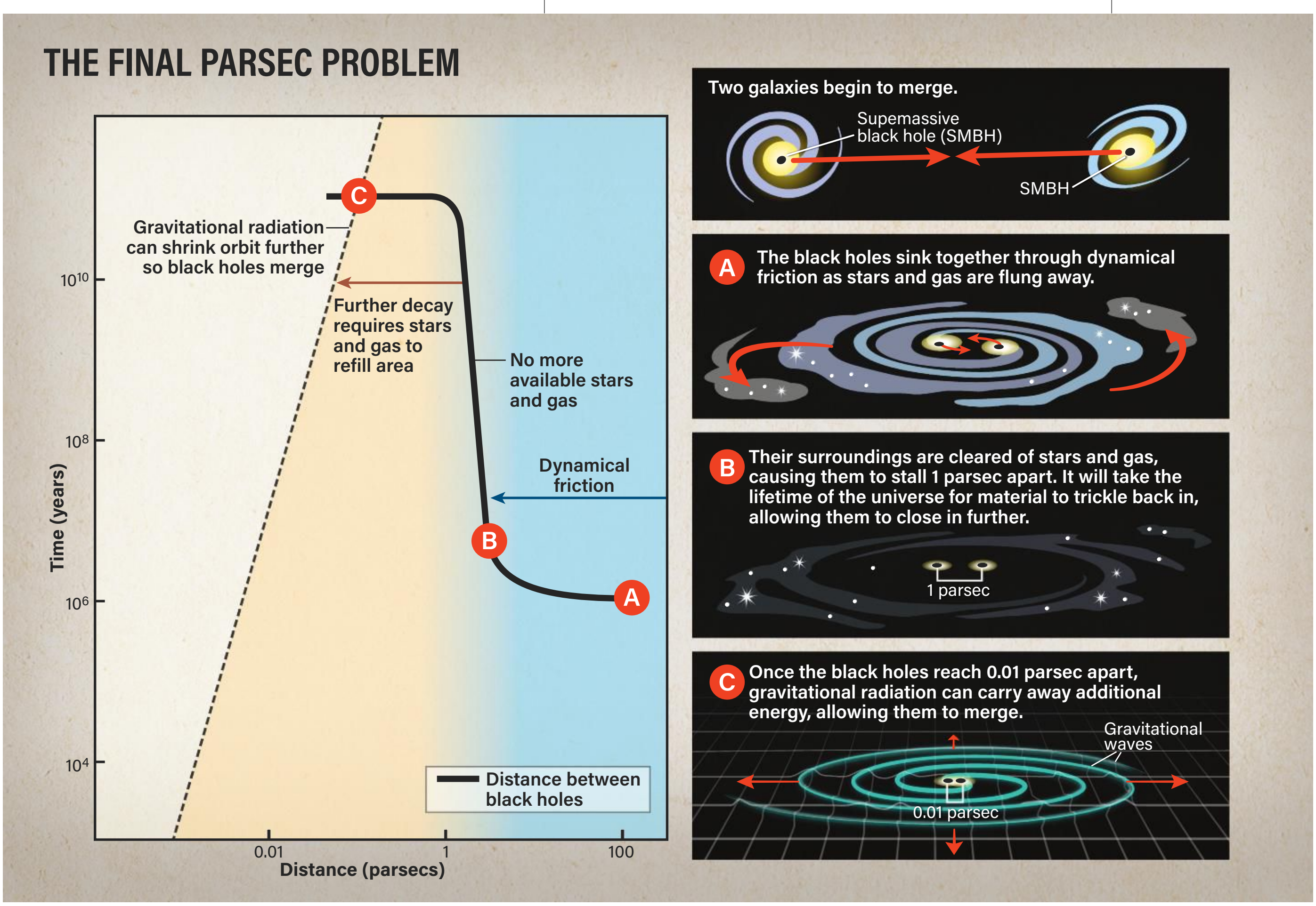
**Q** “THE GREAT HUM” IN THE OCTOBER 2023 ISSUE STATES THAT ASTRONOMERS WEREN’T SURE THAT SUPERMASSIVE BLACK HOLES IN BINARY SYSTEMS COULD CLOSE IN ON EACH OTHER. I WOULD ASSUME THAT OBJECTS WITH SUCH MASSIVE GRAVITY WOULD ABSOLUTELY ATTRACT EACH OTHER OVER TIME AND EVENTUALLY MERGE. WHAT AM I MISSING?

***Bill Ziegler***
*West Chicago, Illinois*

**WE UNDERSTAND HOW TO GET SUPERMASSIVE BLACK HOLES 1 PARSEC APART, BUT NO CLOSER.**

**A** All massive galaxies are believed to host supermassive black holes millions or billions of times the mass of the Sun. When galaxies merge — which we know they do, and frequently — it seems a foregone conclusion that their supermassive black holes (SMBHs) should also merge. After all, we have seen smaller stellar-mass black holes merge. But the physics involved in the way SMBHs ultimately approach each other before merging gets a little tricky. This conundrum is often called the final parsec problem, and it’s plagued astrophysicists since the 1980s.

Let’s start with two merging galaxies. Each has an SMBH. As the galaxies entwine, they eventually form a single galaxy made up of the combined material — including stars, gas, and black holes — of the two progenitors. As things settle, the two SMBHs, once in the middle of their respective galaxies, begin to work their way toward the center of the final galaxy as well. They do so through a process called dynamical friction, also




This simplified figure shows the progress of two black holes as they approach each other in the center of a galaxy, moving from right to left on the graph. At first, dynamical friction causes them to close in quickly, reaching a separation of 1 pc in the order of a million years. By then, the area has been cleared of gas and dust, stalling the process for some 10 billion years or more — roughly the age of the universe! Only once the black holes reach a separation of 0.01 pc can the effects of gravitational radiation carry away enough energy for the black holes to finally merge. *ASTRONOMY*: ROEN KELLY, AFTER BEGELMAN, BLANDFORD & REES (1980) called gravitational drag. As the black holes encounter nearby stars and gas, sometimes instead of falling into the SMBH, the star or gas cloud instead gets a gravitational boost. Essentially, they are slingshot away from the SMBH, just like a spacecraft that uses planetary gravitational assists to move through the solar system. Giving a star or gas some energy robs the SMBH of a tiny bit of its own, reducing its momentum.

Eventually, dynamical friction brings both SMBHs to the galactic center and they begin to orbit each other (point A in the diagram on page 51). They continue to lose momentum through dynamical friction for several billion years, until they close to a distance about 1 parsec (3.26 light-years) apart.

Then the process stalls out, bringing us to the "final parsec" part of the problem. To reach this point, the black holes will have cleared the area of stars and gas, leaving nothing for further interactions (point B). It would take the black holes some 10 billion additional years, essentially the age of the universe, for enough stars and gas to trickle back into the area, refill it, and create enough drag though interactions to allow the black holes to cross the final parsec and merge.

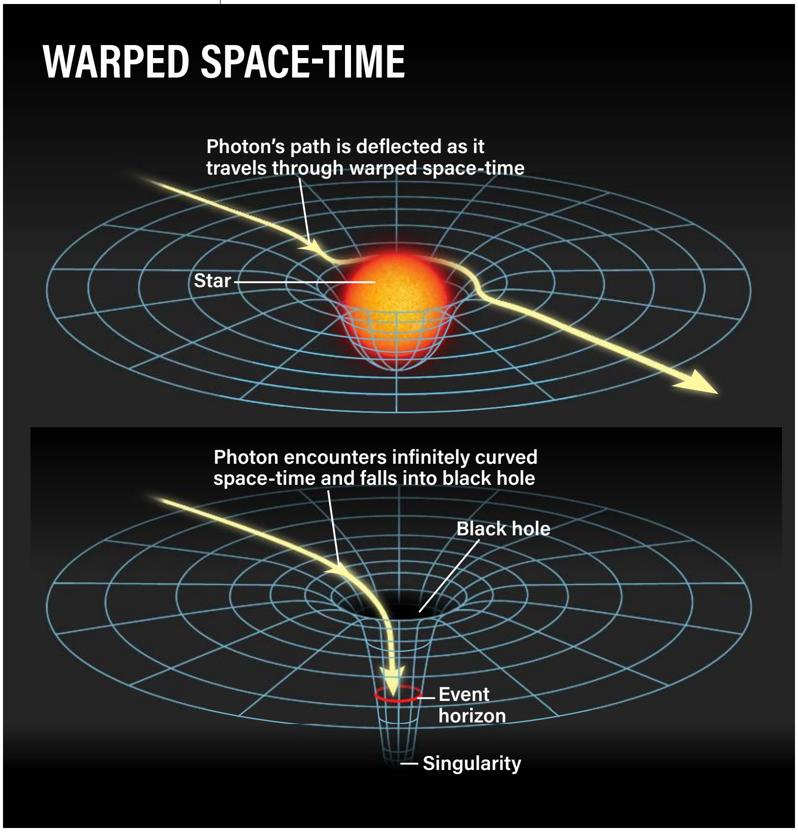
**IF EARTH HAD NO AIR, THE MOON WOULD DISAPPEAR DURING A LUNAR ECLIPSE'S TOTAL PHASE.**

What about gravitational waves? These ripples in space-time carry energy away from orbiting objects so that they can merge. But for gravitational waves to carry away enough energy for SMBHs to merge, those SMBHs must be at most 0.01 pc apart. So, you see the problem — we understand how to get SMBHs 1 pc apart, but no closer.

In June 2023, the NANOGrav team of radio astronomers announced they had detected a background hum of low-frequency gravitational waves of the kind we think would be generated by merging SMBHs. This suggests that there *is* a way to bring SMBHs close enough to lose energy through gravitational waves and merge (point C). Astronomers have several ideas about how the universe might overcome the final parsec problem, notably by throwing a third SMBH into the mix (which then gets kicked out of the system, depleting the two remaining SMBHs of significant energy). Or perhaps the calculations behind the approach of SMBHs are oversimplified and other factors need to be considered.

The recently detected background hum cannot yet be separated into its components well enough to finally say for sure whether we're seeing merging SMBHs. But astronomers strongly suspect this is the case and now have a great jumping-off point for finding that final piece of solid evidence that will show us the irrefutable merger of a pair of SMBHs.

***Alison Klesman***
*Senior Editor*




Massive objects warp the fabric of space-time (shown here as a grid) through which photons travel. If the warping is significant enough, such as around a black hole, the photon's straight path through curved space-time will carry it into the black hole, from which it cannot escape. *ASTRONOMY*: ROEN KELLY, AFTER NOWSCIENCENEWS

## Q | HOW CAN A BLACK HOLE PULL LIGHT INTO ITSELF IF A PHOTON IS MASSLESS?

***Dennis Murphy***
*Fort Bragg, California*

**A** | Photons are indeed massless, but they still travel through our universe. You can picture the fabric of the cosmos as a sort of grid — one that is four-dimensional and incorporates not only the three dimensions of space, but also the fourth dimension of time (hence, why we call it space-time).

For this purpose, though, let's throw out time and picture the universe simply as a three-dimensional grid in all directions. Objects with mass distort this grid in the same way that placing a bowling ball on a mattress will cause the mattress to dip. The more mass an object has, the more it bends the grid around itself in all three dimensions. So, instead of imagining gravity as a pulling force, imagine it as a distortion in the grid, or terrain, of the universe. Thus, every particle that moves through the universe — regardless of whether the particle itself has mass — is affected by the distortions in space-time caused by massive objects.

Illustrations representing the effects of mass on space-time in this way are called embedding diagrams; keep in mind that they are a bit limited and don't show exactly what's going on in the right number of dimensions, but they are still a good way to grasp the concept of how mass bends space-time!

Using this analogy, you can picture a black hole not as a bowling ball distorting the mattress or grid, but as a funnel. Near the opening of the funnel, there is a point where space-time curves so much that, after passing this point, nothing in the universe has enough energy or speed to climb back up out of the funnel and escape — not even light. That boundary is the black hole's event horizon.

Let's get back to our photon. Picture it moving through the universe. Photons move straight through space, but if that space itself is curved, then the photon will follow that curve as it travels. In the case of a planet or star or galaxy, if a photon passes close to the region of space-time that is distorted, then light will appear to curve *around* that object — a phenomenon that causes gravitational lensing.

But what if the space-time that a photon skims too near is *infinitely* curved downward into a funnel? Then its path will curve into the funnel — i.e., the black hole. So, photons aren't pulled into black holes so much as their formerly straight paths simply travel through regions of space-time that are so curved that the photon falls into the gravitational well of the black hole. Once past the event horizon, it's unable to escape.

***Alison Klesman***
*Senior Editor*

**Q** | WHILE WATCHING A TOTAL LUNAR ECLIPSE, I CAN STILL FAINTLY DISCERN THE MOON'S DISK, EVEN DURING THE UMBRAL PORTION. HOW IS THIS POSSIBLE, GIVEN THAT NO SIGNIFICANT SOURCE OF LIGHT REFLECTS FROM THE MOON AT THAT TIME?

***Justin Farr***
*Dallas, Texas*

**A** | The most noticeable feature of any total lunar eclipse is its color, which is due to conditions on Earth. As the Moon passes through Earth's shadow, less and less sunlight falls on its surface, causing it to darken. But during the eclipse's total phase, the Moon seldom disappears; rather, it takes on one of a variety of hues.

The reason for this is Earth's atmosphere. If Earth had no air, the Moon would disappear during totality. Of course, our planet does have an atmosphere, so some of the sunlight that passes through it scatters into Earth's shadow during a lunar eclipse. By the time the light leaves our atmosphere on its way to the Moon, most of the blue light has scattered through our sky because that color does so more easily than red light. The light that falls upon an eclipsed Moon, therefore, has the same reddish color that we see during sunsets here on Earth.

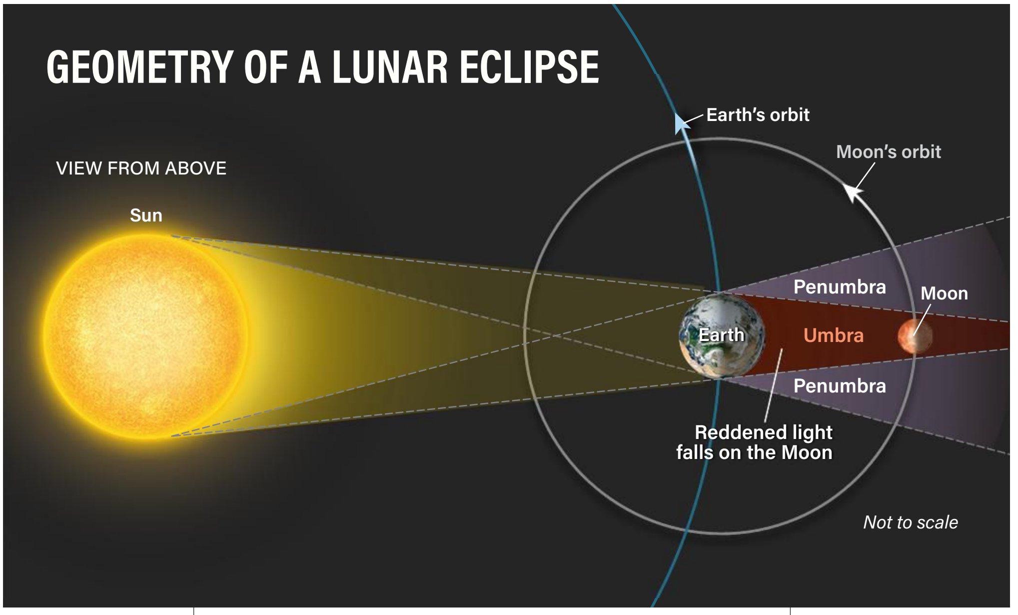
This is a common effect, but it doesn't always occur and thus not every eclipse looks red. Sometimes our atmosphere is "clean," with fewer particles of smoke or dust floating through it. Other times it's "dirty" — consider the 1991 volcanic eruption of Mount Pinatubo in the Philippines. Total eclipses of the Moon following this event were dark, with Earth's satellite nearly disappearing from view.

During totality, the Moon may appear orange, brown, golden, yellow, or any number of combinations of these colors as well as all possible shades of red.

Often, variations in brightness even occur across the Moon's disk during totality. One reason is that rarely does the Moon pass directly through the center of Earth's shadow during a lunar eclipse; the Moon may pass through either the northern or the southern edge of the shadow. In either instance, at mideclipse, one of the Moon's edges should appear a bit brighter because it lies farthest from the shadow's center.

Large cloud formations on Earth also can account for differences in brightness. Cloud effects appear as dark splotches across the face of the eclipsed Moon.

***Michael E. Bakich***
*Associate Editor*




During a total lunar eclipse, the Moon moves through Earth's shadow. The passage makes our satellite appears reddish but rarely causes it to disappear completely from view. The color results from sunlight interacting with Earth's atmosphere. *ASTRONOMY*: ROEN KELLY

## SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro @astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

**1. BOK BOK BOK**
IC 2948 is a reflection and emission nebula in Centaurus associated with the open cluster IC 2944, though the region is more popularly known as the Running Chicken Nebula. This cropped view highlights Bok globules at top center — dense clouds of gas that serve as stellar nurseries. The image represents 70 hours of data with a 17-inch scope. ▪ ***Nicholas Clarke***

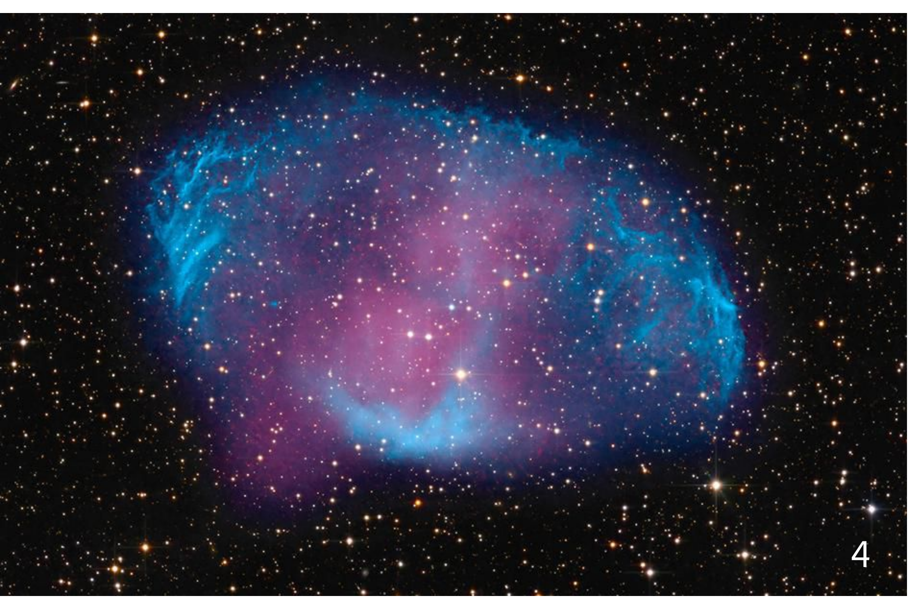
**2. GALACTIC UNRAVELING**
NGC 3169 (left) and NGC 3166 (right) are a pair of galaxies in Sextans whose gravitational interactions are destroying their spiral structure, resulting in distinct tidal tails. Roughly 17 hours of LRGB exposure for this image were taken on a 1-meter scope in the Atacama Desert; the final image represents a "superstack" of the individual processing efforts of the 15 team members, weighted according to a vote among them. ▪ ***Team ShaRA***


3

**3. THE WAY OVER KOTLI**
The Milky Way and the Rho Ophiuchi cloud complex (at right) float over the town of Kotli in northern India. The imager used a Nikon D5600 and 35mm lens at f/3.2 and captured 25 sky frames of 120 seconds each at ISO 1600. The foreground was captured at blue hour with three 8-second frames at f/10 and ISO 400.
*• Samit Saha*

**4. ANCIENT PLANETARY**
Planetary nebulae are ephemeral objects created as a dying star lets go of its outer layers, typically glowing for 20,000 years or so. But the Methuselah Nebula (MWP1), 4,500 light-years away in Cygnus, appears to be 150,000 years old, based on the material's speed and extent. This image was taken with a 20-inch scope at f/7.7 over 15.8 hours in H$\alpha$/OIII/RGB filters.
*• Eric Coles/Bob Fera*

**5. THE KOI AND THE HERON**
The interacting spirals of NGC 5394/5 lie 160 million light-years away in Canes Venatici and are collectively known as Arp 84, or the Heron Galaxy. The feathered creature appears to be spearing a fish in the form of a background edge-on galaxy. This HaLRGB image was taken with a 24-inch scope at f/4.5 and 4.5 hours of exposure. *• Kfir Simon*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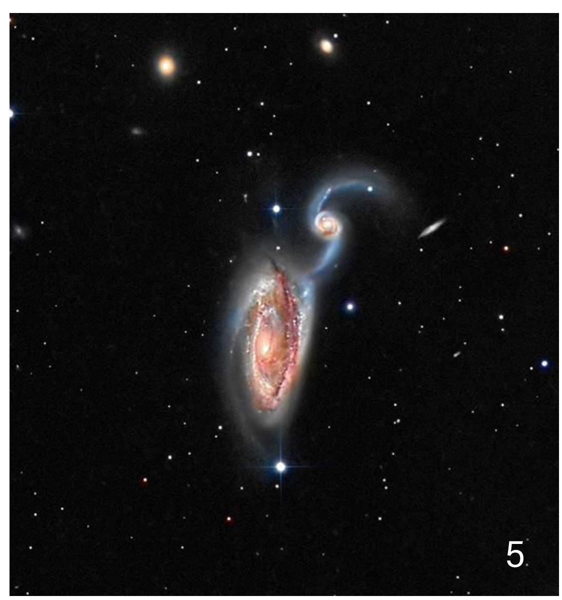
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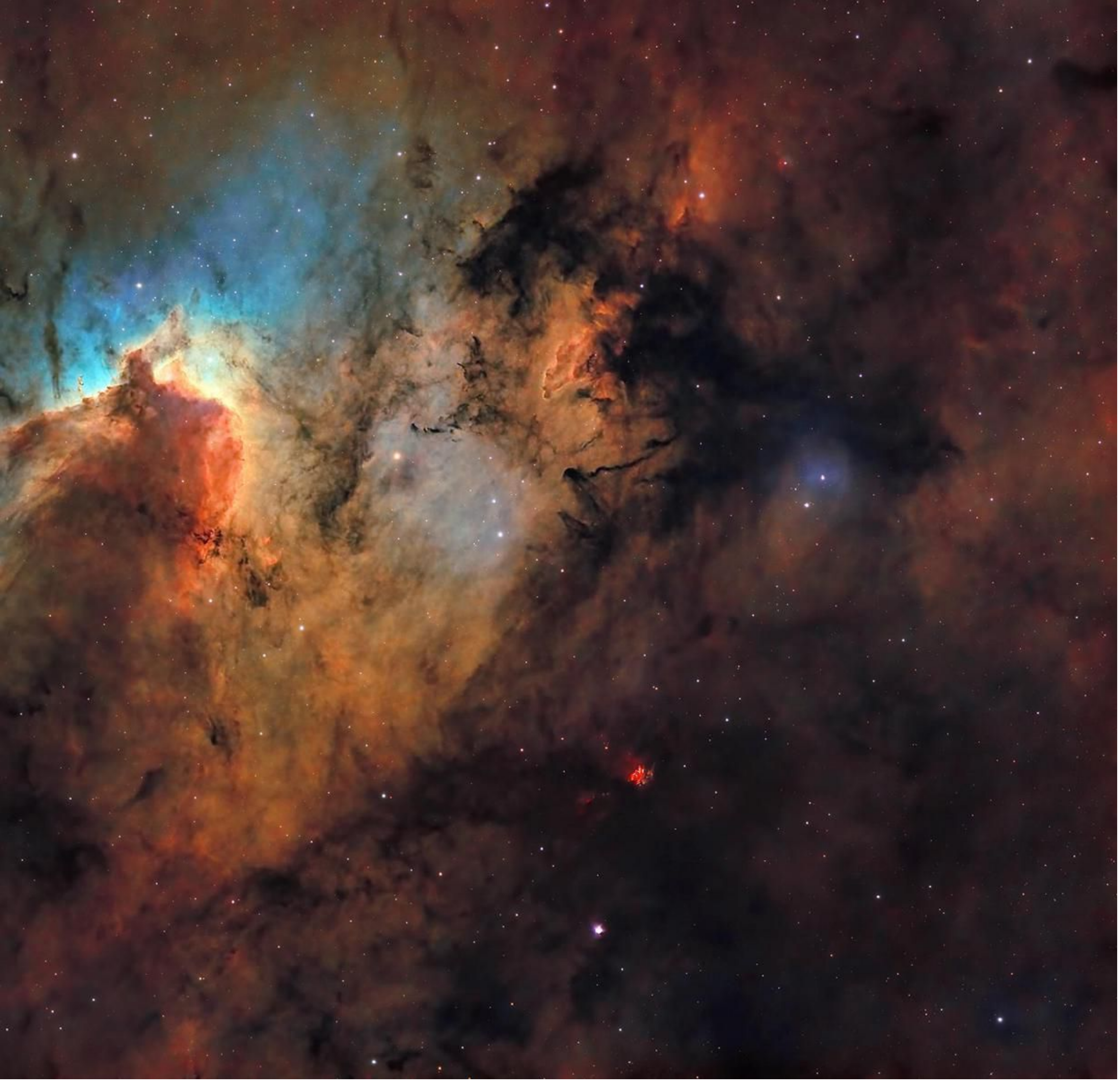
**6. JELLYFISHING**
The Jellyfish Nebula (IC 443) in Gemini, roughly 5,000 light-years distant, was formed as debris from a supernova some 30,000 years ago plowed into surrounding molecular clouds. This SHO image represents nearly 24 hours of exposure with an 8-inch scope. • ***Simon Todd***

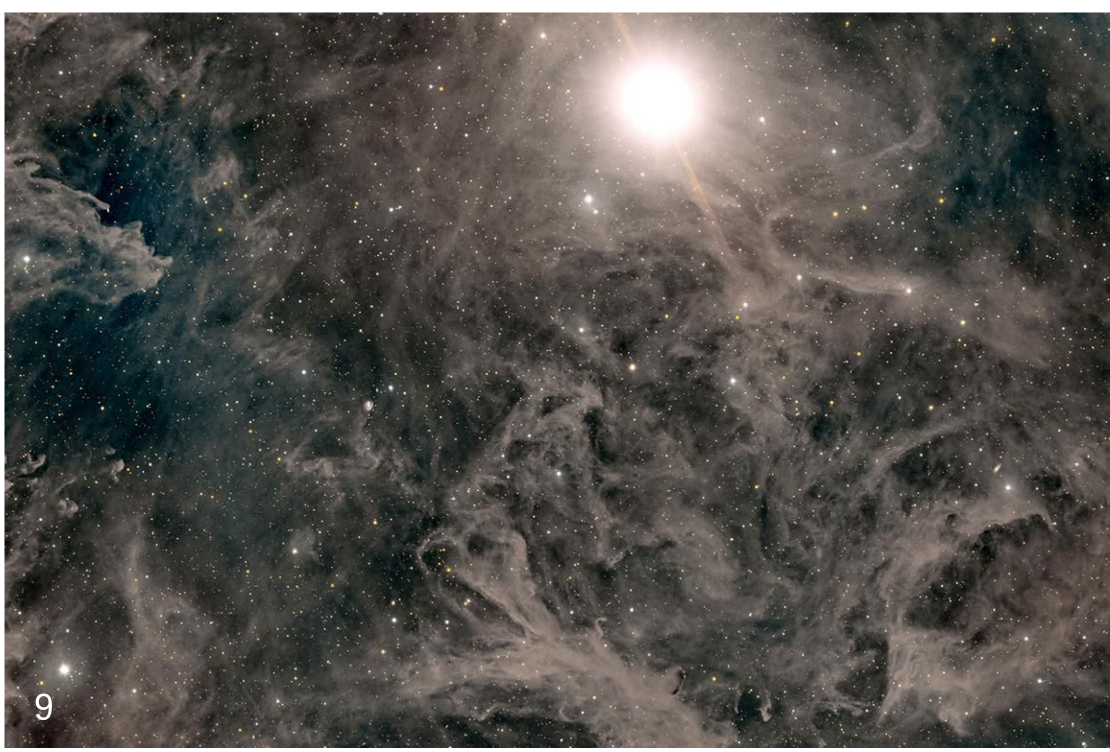
**7. CAVE PAINTINGS**
The Cave Nebula (Sharpless 2–155) in Cepheus features emission, reflection, and dark nebulae. This image was taken over 29 hours with a 4.5-inch refractor in SHO filters. In processing, the imager blended a Hubble-palette rendition with a dynamic Foraxx palette, which uses a nonlinear combination of channels. • ***Steve Leonard***

**8. A TEMPORARY DISCONNECT**
The pronounced kink in the blue tail of Comet 12P/Pons-Brooks in this image taken May 4 (about two weeks after perihelion) is the mark of a disconnection event — when a passing solar storm of plasma rips the ion tail away from a comet's nucleus. • ***Gerald Rhemann/ Michael Jäger/Lukas Demetz***



**9. HIGH CLOUD LAYER**
Mandel-Wilson 1 (MW1) is not a traditional deep-sky object — rather, it is composed of extremely faint, wispy gas that lies outside the plane of our galaxy. Though it appears to surround Polaris, it is much more distant, lit not by a single star but the overall glow of the Milky Way Galaxy. Astrophotographers often refer to this type of "object" as an integrated flux nebula, and the clouds that make up such objects are called galactic cirrus. The imager used an 11-inch f/2.2 Celestron RASA astrograph to take 12.75 hours of data in RGB filters. • ***Josh Jones***

**SEND YOUR IMAGES TO:**
**readergallery@ astronomy.com.**
Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



## GUM UP THE WORKS

In *The Empire Strikes Back*, the *Millennium Falcon* barely escapes the clutches of a giant space slug hiding in what appears to be an asteroid cave. Reality mimics fiction in this scene from the constellation Puppis. The "mouth" of the cometary globule CG 4 (just left of center) seems to reach for the edge-on spiral galaxy ESO 257–19, which bears more than a passing resemblance to the iconic spaceship. Despite their name, cometary globules have nothing to do with comets. With dusty heads and tenuous tails, these gas clouds look the part but dwarf their solar system namesakes. CG 4's head spans 1.5 light-years and its tail stretches 8 light-years. It lies some 1,300 light-years from Earth on the outskirts of the Gum Nebula, the remnant of a supernova. In contrast, ESO 257–19 resides more than 100 million light-years away. CTIO/NOIRLAB/DOE/NSF/AURA

# November 2024
# An evening spectacle

The two inner planets form a beautiful pair in the western evening sky this month. **Venus** outshines **Mercury** by a factor of 30 or so — magnitude –4.1 to magnitude –0.3 — and stands significantly higher in the sky.

Venus begins November in Ophiuchus the Serpent-bearer and on the 9th crosses into Sagittarius the Archer, where it remains the rest of the month. A telescope reveals slow changes to the planet's appearance. On November 1, Venus measures 14" across and is 77 percent lit. By month's end, its disk spans 17" and the Sun illuminates 68 percent of its Earth-facing hemisphere.

Venus' companion, Mercury, puts on a less spectacular but still impressive show. The Sun's smallest planet reaches greatest elongation November 16, when it lies 23° east of the Sun and stands nearly 10° high in the west-southwest an hour after sunset. Six days earlier, Mercury passes 2° north (upper right) of 1st-magnitude Antares, Scorpius the Scorpion's brightest star.

The best time to view Mercury through a telescope comes about a week before month's end when the planet shows a relatively large and crescent-shaped disk. On November 24, it appears 8" across and 39 percent lit. Mercury disappears in the twilight at the end of the month as it approaches inferior conjunction in early December.

**Saturn** stands more than 60° high in the northwest as evening twilight ends. Shining at magnitude 0.8, it stands out from the relatively faint stars of its host constellation, Aquarius the Water-bearer. It remains nearly stationary relative to this starry backdrop.

The gas giant is a remarkable sight when viewed through a telescope. Any size instrument reveals the planet's 18"-diameter disk surrounded by a beautiful ring system that spans 41" and tilts 5° to our line of sight. The 8th-magnitude moon Titan also shows up through any scope, while a 10-centimeter instrument brings in a trio of 10th-magnitude moons: Tethys, Dione, and Rhea.

Much later in the evening we see **Jupiter** poking above the eastern horizon. The giant planet remains trapped between the two horns of Taurus the Bull, roughly 10° northeast (below) 1st-magnitude Aldebaran. Jupiter shines brilliantly at magnitude –2.8, making it the brightest point of light in the sky once Venus sets.

The Sun's largest planet is near its peak in late November, with opposition coming at the end of December's first week. Jupiter's northern declination means it doesn't climb particularly high in our sky, though wonderful telescopic views still await observers during moments of good seeing. Watch for plenty of atmospheric detail on its 47"-diameter disk as well as the constantly changing positions of the planet's four bright Galilean moons.

You still have to wait until after midnight to glimpse **Mars**, though the wait isn't as long as it has been these past several months. The Red Planet continues its eastward motion across Cancer the Crab, ending November just 2° northwest (lower left) of the famous Beehive star cluster (M44).

Mars will reach opposition in mid-January, so its appearance now changes quite rapidly. It brightens from magnitude 0.0 to magnitude –0.5 during November while its angular diameter increases from 9.2" to 11.5". During steady moments, a telescope should reveal several dark surface markings as well as the north polar cap.

## The starry sky

This month Saturn points the way to the often overlooked constellation Aquarius. The Water-bearer, which lies in the northwest once darkness falls, possesses no conspicuous stars. The brightest, Beta (β) Aquarii, shines at magnitude 2.89. Alpha (α) Aqr glows at magnitude 2.94, making Aquarius one of several constellations in which the Alpha star is not the brightest.

Many of Aquarius' stars have proper names approved by the International Astronomical Union (IAU), whose IAU Working Group on Star Names began formally listing names in 2016. This constellation contains several intriguing ones.

Alpha and Beta are called Sadalmelik and Sadalsuud, respectively. Sadalmelik comes from an Arabic phrase meaning "luck of the king." Sadalsuud derives from another Arabic phrase that translates to "luckiest of the lucky," apparently because it rose with the Sun at the end of winter.

The idea of luck continues with magnitude 3.8 Gamma (γ) Aqr, whose name, Sadachbia, relates to its rising in morning twilight as spring began and the weather improved.

The name Skat for magnitude 3.3 Delta (δ) Aqr often causes confusion because centuries ago some astronomers, most notably the great Danish scientist Tycho Brahe, called this star Scheat. To add to the puzzle, Skat also once referred to Beta Pegasi, which now has the official name Scheat. The origin of Skat remains uncertain. One hypothesis claims it arose from the name Al Sak, meaning "shin bone."

One star in Aquarius whose name appeals to me — simply because it sounds lovely to my ear — is Ancha (Theta [θ] Aqr). This magnitude 4.2 sun's name means "hip."

Several other stars in Aquarius have proper names. Magnitude 3.8 Epsilon (ε) goes by Albali, magnitude 4.7 Xi (ξ) is Bunda, and magnitude 5.0 Kappa (κ) is Situla. The Water-bearer even has a trio of stars with proper names that fall well below naked-eye visibility. We'll save those for another time.

# STAR DOME

## HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

11 P.M. November 1
10 P.M. November 15
9 P.M. November 30

Planets are shown at midmonth


## MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

## STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


# NOVEMBER 2024

| SUN. | MON. | TUES. | WED. | THURS. | 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 |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

**Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.**

## CALENDAR OF EVENTS

**1** New Moon occurs at 12h47m UT

**3** The Moon passes 2° south of Mercury, 8h UT

**4** The Moon passes 0.08° south of Antares, 1h UT

**5** The Moon passes 3° south of Venus, 0h UT

**9** First Quarter Moon occurs at 5h55m UT

**10** Mercury passes 2° north of Antares, 4h UT

**11** The Moon passes 0.09° north of Saturn, 2h UT

**12** The Moon passes 0.6° north of Neptune, 2h UT

**14** The Moon is at perigee (360,109 kilometers from Earth), 11h16m UT

**15** Full Moon occurs at 21h29m UT

**16** The Moon passes 4° north of Uranus, 1h UT

Saturn is stationary, 6h UT

Mercury is at greatest eastern elongation (23°), 8h UT

**17** Uranus is at opposition, 3h UT

Leonid meteor shower peaks

The Moon passes 6° north of Jupiter, 15h UT

**20** The Moon passes 2° north of Mars, 21h UT

**23** Last Quarter Moon occurs at 1h28m UT

**26** Mercury is stationary, 4h UT

The Moon is at apogee (405,314 kilometers from Earth), 11h56m UT

**27** The Moon passes 0.4° north of Spica, 12h UT