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# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



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SEPTEMBER 2018

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& TELESCOPE

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ESA's Venus Express orbiter took this ultra-violet view of Venus.

ESA / MPS / DLR / IDA / M. PÉREZ-AYÚCAR & C. WILSON

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# Returning to Venus



**AMERICAN PLANETARY SCIENTISTS** who specialize in Venus are a disheartened bunch, and understandably so: NASA hasn't dispatched a dedicated mission to our sister planet in almost three decades. These scientists don't begrudge spacecraft the agency has sent during that time to Mars, Saturn, Pluto, and other destinations. They'd be the first to say that those explorations have made fantastic discoveries and conducted stupefying science. They just want a piece of the pie.

To me, and I'm hardly alone in this, the chief reason why NASA should return to Venus can be encapsulated in one word: exoplanets. The number of worlds in other solar systems that we've identified now stands in the thousands, thanks to the Kepler space telescope. And the newly launched Transiting Exoplanet Survey Satellite (TESS) is expected to find hundreds more (*S&T*: March 2018, p. 22).

While the Holy Grail of exoplanet studies is to locate Earth-like worlds, many of the rocky bodies around other stars are more likely to be akin to Venus than to our beloved Gaea. The transit method that both Kepler and TESS rely on is biased toward detecting planets that are close to their host stars rather than farther away. As such, we may have more Earth-size planets to study that are interior to the vaunted *habitable zone* than those that lie more comfortably within it, as we do.

What those discouraged Venusian experts keep harping on is: How are we to understand all these Venus analogs if we don't have a good grasp of Venus itself? As astrobiologist (and *S&T* columnist) David Grinspoon says in our cover story on page 14, "We have no hope of making sense of those [exo-Venus] observations without getting a handle on the Venus-Earth dichotomy."

Many basic questions about our twin remain unanswered: Why did Venus evolve into a lifeless hell instead of the living heaven that is Mother Earth? Billions of years ago, Venus might have had oceans; today its surface is hot enough to melt lead. Where did the water go? Did the planet ever have plate tectonism? Perhaps most of interest in terms of exoplanet research, was it ever habitable?

To attempt to answer such questions, and to be able to correctly interpret data we gather about extra-solar Venuses, it's imperative that we return to our toxic twin and further investigate it — above, on, and below its surface.

Fortunately, the European and Japanese space agencies have kept Venus studies alive with their recent (and highly successful) Venus Express and Akatsuki missions. And Europe, Russia, and India are researching future sorties. Does NASA really want to be left behind in the on-site examination of our solar system's natural exoplanet laboratory? Not just planetary scientists, but exoplanet astronomers, hang on the answer.



*Peter*  
Editor in Chief

## SKY & TELESCOPE

The Essential Guide to Astronomy

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

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## Solace in the Sky

Thank you, Kyle Jeter, for writing the Focal Point about holding your Astronomy Night nine days after the school shooting in Parkland, Florida (S&T: July 2018, p. 84). I seldom get tears in my eyes while reading S&T, but I did while reading your essay. We cannot see faces at astronomy events, but the voices we overhear are probing our place in the universe. I imagine holding such an event in a community struck by such horrific violence was a perfect gift of solace for all who attended.

Tom Kellogg • San Francisco, California

▲ Students, parents, and teachers at Marjory Stoneman Douglas High School had this view of the Moon on their Astronomy Night on February 23, 2018.

## Constant Pressure

In his article about dark energy (S&T: May 2018, p. 14), Marcus Woo notes, “When applying his theory of general relativity to cosmology, [Albert] Einstein realized his equations implied the cosmos doesn’t stay still. Presumably, due to the attractive pull of matter’s gravity, it was shrinking. He deemed that preposterous. So he introduced a term, later dubbed the *cosmological constant*, which represented an antigravity force that countered the contraction.”

But the story as I’ve always heard

it is that the constant was introduced in order to “prevent” the universe from expanding, which is why Hubble’s discovery made Einstein say it had been his biggest mistake to insert this ad hoc device in his equations.

Joel Marks  
Milford, Connecticut

“**Camille Carlisle replies:** *Einstein’s equations implied that the universe wasn’t static, so it could have been expanding or shrinking. He interpreted the result as a shrinking universe due to the attractive pull of matter’s gravity, so he added a sort of outward “pressure” or antigravity, which he called lambda, to counteract gravity and keep everything balanced. That’s why, when he learned of cosmic expansion, Einstein could forgo the need for lambda and describe the expansion with the original equations — and why, when the antigravity effect of dark energy was discovered, lambda went back in.*

## Home-Grown Globulars

In “Nearby Relic of Ancient Universe” (S&T: July 2018, p. 11), Camille Carlisle cites a study of the galaxy NGC 1277, which is “largely ungrown since the universe’s early years.” The study’s assumption is that “if NGC 1277 were really a relic, all its globular clusters would be rich in heavy elements.”

I thought the prevailing wisdom these days is that early galaxies should be deficient in heavy elements because they haven’t been synthesized yet by supernovas. Could you clarify, please?

Paul Trent  
Yelm, Washington

“**Camille Carlisle replies:** *The globular clusters would be relatively rich in heavy elements because they’ve been around long enough to pollute themselves as their stars age. Conversely, any globulars with more pristine compositions would have been nabbed from smaller satellite galaxies that NGC 1277 accreted.*

So NGC 1277’s lack of pristine globulars indicates the galaxy hasn’t done much accreting — its globulars are all home-grown, as it were. Here’s a recent press release that offers more details, if you’re

curious: [hubblesite.org/news\\_release/news/2018-17](http://hubblesite.org/news_release/news/2018-17). At the bottom of that you’ll find a link to the team’s paper, too.

## A Fourth Neutrino?

I read with interest the article “The Little Galaxies That Can” (S&T: Apr. 2018, p. 22) and was intrigued by a higher primordial helium abundance (25.5) pointing to a fourth neutrino type. Would this be the sought-for sterile neutrino, or would it be an active type lying beyond the tau?

Robert Stivers  
Edmonds, Washington

“**Camille Carlisle replies:** *If the primordial helium abundance is higher than predicted and indeed is that way because there’s an additional neutrino family, it would be a sterile neutrino. It amazes me that a single percentage point on helium’s abundance could make a difference between three and four neutrinos!*

## Space Junkie

“Litter in Orbit” (S&T: July 2018, p. 34) brought back memories. My father and I had the privilege of observing one of the first pieces of “space junk” in October 1957. A few days after the launch of Sputnik 1 by the Soviets, the New York *Daily News* printed an article noting that the booster rocket that carried Sputnik 1 would be crossing the southern sky of New York City soon after 7:00 p.m.

Dad and I went to our backyard in Queens and prepared for a glimpse of the rocket booster. It was dusk, and the sky was clear. Around 7:15 p.m. Dad suddenly said, “Look!” and I clearly saw the booster tumbling end over end from west to east across the southern sky.

Arthur J. Erdman  
Passaic, New Jersey

## Retrograde Notion

Did you ever notice how astronomers name things backward? For example, when I think about coordinates for the night sky, I understand that celestial longitudes increase toward my left as I face south. Yet we don’t call these longitudes “left ascension” but rather “right ascension.” Similarly, “declina-



tion” sounds like something declining downhill from the equator, but what it measures is an increasing angle, so it arguably could be called “inclination.”

In timekeeping, “Julian Days” don’t start at midnight in Greenwich, England, but rather at local noon there. They count Julian nights, not days. And “magnitude” doesn’t measure brightness but rather its opposite: faintness.

Just saying.

**Mike Lampton**  
Berkeley, California

## Speaking of Misnomers . . .

The sidebar to the article on Messier 27 (S&T: July 2018, p. 68) says, “[P]lanetary nebula’ isn’t the only archaic and misleading name still in common use, so it seems destined to remain part of astronomy’s vocabulary.” I wondered if I could think of more, and it didn’t take long. “H II region” is the most obvious, and here’s how it came to be.

Early spectroscopists observed that

many elements (iron, for example) showed two distinct spectra, according to whether the spectrum was excited in an arc or in a much more energetic spark. They used Fe I to denote iron’s “first” or “arc” spectrum, and Fe II for the “second” or “spark” spectrum. Only later was it understood that the first spectrum arose from the neutral atom (Fe), while the second spectrum arose from ionized iron (Fe<sup>+</sup>).

Hydrogen has only one electron and thus only one spectrum, H I. The strongest line of this spectrum is hydrogen alpha (H $\alpha$ ), which causes the red glow that is characteristic of an “H II” region. Ionized hydrogen is just a proton and thus has no line spectrum, so there is really no such thing as H II.

Yet in describing emission nebulae, an H II region has come to mean one where hydrogen is largely ionized, while

an H I region is one where the hydrogen is largely neutral. An H II region would — but probably never will — be better called an “H<sup>+</sup> region.” In such an ionized region, protons (H<sup>+</sup>) and electrons occasionally combine to form neutral but excited H atoms — and it’s these atoms that then radiate the H I spectrum.

**Jeremy B. Tatum**  
Victoria, British Columbia

## FOR THE RECORD

• In “The Dark Energy Enigma” (S&T: May 2018, p.14), the distance to faraway supernovae published in 1998 was not based on theories of how stars explode (as stated) but rather estimated using the shapes of the supernova light curves at different wavelengths, based on a calibrated shape-distance relationship.

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

1943

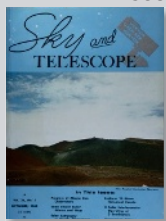


### September 1943

**Parallax Pioneer** “With the death on July 10th of Dr. Frank Schlesinger, director emeritus of the Yale University Observatory, we have lost one of the great astronomers in the field of astrometry. . . . When Frank Schlesinger began his investigations, scarcely 100 parallaxes (or distances) were known to a fair degree of accuracy. Now, mainly as a consequence of his standardization of the methods, the number has grown to a few thousand.”

*The tally of good star distances hardly changed over the next 50 years. The floodgates finally opened with the Hipparcos spacecraft’s survey in the 1990s, and they’re widening more with today’s Gaia mission.*

1968



### September 1968

**Quasar Conundrum** “The quasar 3C-287 has been identified on photographs as an 18th-magnitude blue starlike object, with a much

fainter red companion 3.3 seconds of arc away. Last December, Thomas A. Matthews (University of Maryland) reported . . . that these two components were linked by a nebulous bridge, which became much brighter in 1966. . . .

“This change, and even the existence of the bridge, have now been denied by J. Kristian and P. V. Peach, Mount Wilson and Palomar Observatories. . . . None of four 200-inch plates taken in 1964, 1967, and 1968 shows any trace of nebulosity. . . .

“The issue has far-reaching implications. Proof that a quasar can undergo observable structural changes would have meant that it is a small object inside our own galaxy, rather than at the enormous cosmic distance corresponding to its spectral red shift.”

### September 1993

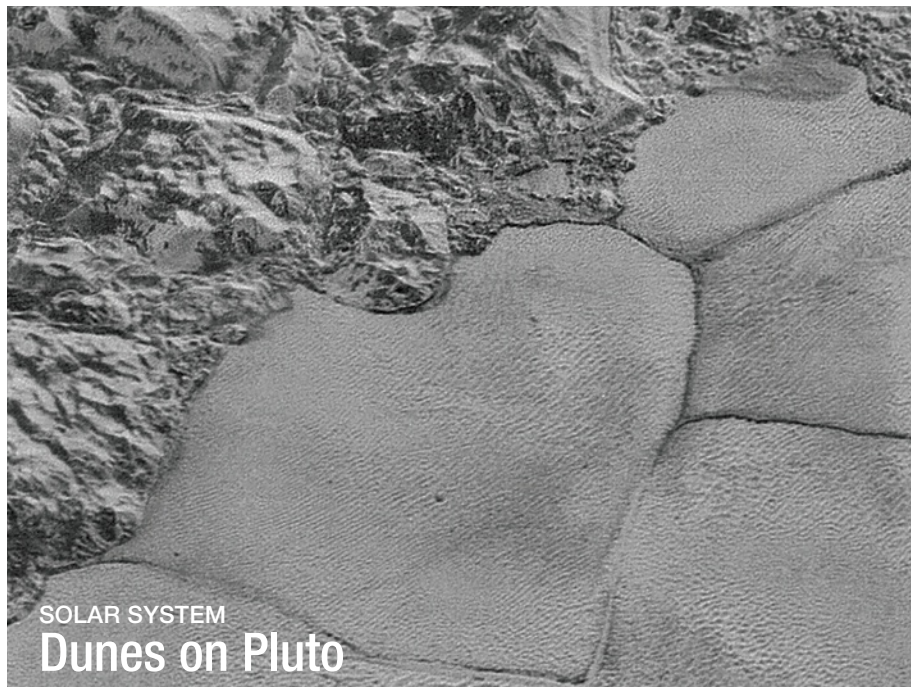
**Alternate Universe** “With the enormous successes of Big Bang cosmology and inflationary-universe theory, the ‘standard

model’ of the universe goes almost unquestioned by cosmologists these days. In this picture . . . the Big Bang happened around 10 or 15 billion years ago, and, very early in the Big Bang, inflation gave the cosmos precisely the right density to balance it forever between rapid expansion and recollapse. . . .

“Or maybe not. As an exercise, cosmologist Edward Harrison (University of Massachusetts, Amherst) tried to devise a radically different universe [and] succeeded surprisingly well. In Harrison’s most extreme model . . . the expansion is very slow [and] the density of the universe today is about 10 times greater than needed to halt the expansion. . . . Harrison’s universe is 35 billion years old. . . . The universe will cease expanding in another 22 billion years, then begin recollapsing toward a Big Crunch 79 billion years in the future.”

*Harrison’s cooked-up model passed all the major observational tests — without the need to invoke unknown types of dark matter.*





## SOLAR SYSTEM Dunes on Pluto

▲ New Horizons imaged the mountain range on the edge of the Sputnik Planitia ice plain. Dune formations are clearly visible in the bottom half of the picture.

**USING DATA SENT BACK** from NASA's New Horizons spacecraft after its 2015 flyby of Pluto, planetary scientists think they've found evidence of wind-built ripples of methane ice on the world's surface. The results appear in the June 1st *Science*.

Matt Telfer (University of Plymouth, UK) and colleagues discovered a wide swath of parallel ripples on the western edge of Sputnik Planitia, the vast plain of molecular nitrogen-rich ice at Pluto's equator. This edge abuts the Al-Idrisi Montes, a mountain range that reaches up to 5 km (3 mi). The series of ripples runs largely parallel to the mountain-plain boundary. From there, it extends some 75 km before fading out. This pattern is just what you'd expect if the ridges are dunes formed by wind coming off the mountains and sweeping across Sputnik Planitia.

But winds are gentle on Pluto, reaching 10 m/s (20 mph) at the gustiest. Such breezes could carry grains through the air once aloft, but it's hard for them to pick grains up off the ground.

The team thinks Sputnik Planitia is to blame. Its molecular nitrogen ice sublimates in daily, intense bouts that could loft nearby grains. Methane mixed in with the nitrogen may exacerbate the gasification: Although the methane doesn't sublime, it warms in sunlight and would transfer that heat to the surrounding nitrogen — which would then in turn launch the methane grains. Once in the air, the grains would be caught by the wind and do a hopping dance across the surface, called *saltation*, kicking up more grains and building undulating dunes.

How long the dunes remain once they're in place, or if they're undergoing erosion, is unclear. But given the time it takes Sputnik Planitia's convecting cells of ice to turn over, the features can be no older than 500,000 years.

■ CAMILLE M. CARLISLE

● Learn more about the dunes and the origin of Sputnik Planitia's nitrogen-rich ice at <https://is.gd/plutodunes>. Also, see Cosmic Relief on page 12.

## SOLAR SYSTEM

### Methane and Other Organics on Mars

**IN THE JUNE 8TH *SCIENCE***, team members from NASA's Curiosity rover mission reported the presence of several organic compounds in ancient mudstones on Mars, as well as the conclusive detection of a seasonal methane cycle. (Organics are molecules that contain carbon and hydrogen.) Neither of these results means we've found Martian life, but they do make the question of whether it ever existed a more reasonable one to ask.

The studies used Curiosity's Sample Analysis at Mars, a suite of instruments in the rover's body. For the mudstone study, Jennifer Eigenbrode (NASA Goddard) and colleagues heated pulverized rock to nearly 900°C (1,600°F), catching the gases released as the rock molecules underwent chemical reactions or broke down. The rover then analyzed these gases to determine their molecular masses and components.

Based on these data, the researchers determined that the mudstones contained organic compounds containing carbon, hydrogen, and sulfur. However, the compounds don't show the diversity

## COSMOLOGY

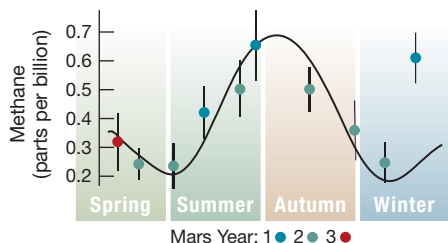
### Early Star Formation Presents New Cosmic Mystery

**NEW OBSERVATIONS SUGGEST** that stars began forming just 250 million years after the Big Bang — a record-breaker that will likely open a new line of cosmological inquiry.

Reporting in the May 17th *Nature*, Takuya Hashimoto (Osaka Sangyo University, Japan) and colleagues used the Atacama Large Millimeter/submillimeter Array to detect doubly ionized oxygen in a galaxy that existed just 550 million years after the Big Bang (at a redshift of 9.1).

Because only hydrogen, helium, and a little lithium emerged from the Big Bang, it wasn't until the first generation of stars exploded and breathed carbon,





▲ Methane cycle on Mars

of molecules or the structural patterns usually created biologically.

The sulfur might have protected the organics in these samples from degradation by acting as a “sacrificial element,” Eigenbrode says, serving as a chemical victim in Mars’s oxidizing environment in place of the carbon.

A separate paper by Christopher Webster (NASA Jet Propulsion Laboratory) and colleagues details the Martian methane cycle. Curiosity has detected methane before, including a startling spike back in 2013 (*S&T*: Apr. 2015, p. 14), but the new result reveals a clear seasonal trend, with a peak in the northern hemisphere’s late summer.

The researchers think the gas comes from the subsurface, perhaps via rock fissures; surface temperature may govern its release.

■ CAMILLE M. CARLISLE

## SOLAR SYSTEM

### Apollo Astronauts Warmed the Moon

**A NEW FIND HAS SOLVED** an old mystery: What slightly warmed the Moon in the 1970s?

During the Apollo 15 and 17 missions in 1971 and 1972, astronauts placed Heat Flow Experiment (HFE) monitors a few meters into the lunar surface to measure the temperature of soil undisturbed by the month-long day/night cycle. Lunar scientists planned to use the data to measure the heat flow from the Moon’s core, characterizing geological activity.

To their surprise, investigators saw the temperature increase gradually at both the Apollo 15 and Apollo 17 sites, by 1° to 2°C (2° to 4°F). The warming continued until the sensors fell silent in 1977.

A study published in the May issue of the *Journal of Geophysical Research: Planets* reveals the cause of this heating: the astronauts themselves. As the astronauts traveled, they disturbed the smooth surface of the Moon. The rumpled surface better absorbed heat from the sunlight.

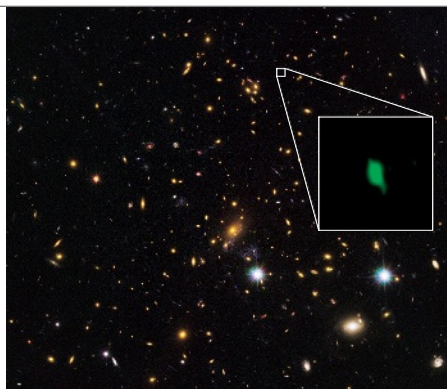
The study wouldn’t have been possible without some detective work. NASA had recorded data from 1971 to 1974, storing it on open-reel magnetic tapes, but data collected in later years had gone missing. After some digging, researchers recovered a set of 440 archival tapes at the Washington National Records Center. With additional legwork, they also discovered hundreds of weekly logs with temperature readings that filled in the gaps in the remaining years, confirming that warming continued through 1977.

Key evidence also came from the Lunar Reconnaissance Orbiter’s images of the Apollo landing sites, which showed that the places where the astronauts had traveled appeared darker, showing that they absorb more solar heat than the surrounding regolith. The finding may affect future Moon exploration.

■ DAVID DICKINSON



▲ This image of Apollo 15’s ALSEP setup shows the HFE power box in the foreground. Cords to the detectors snake off to the lower right. The foreground shadow is that of astronaut David Scott.



▲ The galaxy cluster MACS J1149.5+2223 (background) magnifies the young galaxy MACS 1149-JD1 (inset), in which ALMA detected oxygen (green).

oxygen, and other heavy elements into the cosmos that the universe’s inventory of elements increased. The detection of oxygen 550 million years after the Big Bang suggests that a generation of stars had already formed and died.

The results are in line with a tentative result from the EDGES experiment (*S&T*: June 2018, p. 8), which found a signal from stars forming just 180 million years after the Big Bang. However, the EDGES result still awaits confirmation from other groups performing similar experiments.

Hashimoto and colleagues used data from the Hubble and Spitzer Space Telescopes to gauge the galaxy’s star-formation history. The observations indicate that starbirth kicked off strong, tapered off, then restarted. That’s different from the slow start and exponential growth that simulations of high-mass galaxies in the early universe predict.

“It may mean that we don’t really understand the first generation of galaxies sufficiently well,” says coauthor Erik Zackrisson (Uppsala Univer-

sity, Sweden). “There might be some ingredient that is missing from the simulations.” That missing ingredient could come in the form of powerful supernovae or a ravenous supermassive black hole, either of which could have unleashed powerful winds and suppressed further star formation.

Rychard Bouwens (Leiden University, The Netherlands), who was not involved in the study, argues that the paper’s conclusions are reliable but uncertain, only because the team is peering so far back into the universe’s history. “It’s always this way when you’re at the cutting edge,” he says. “It might be providing us with important clues to what happened at very early times in the universe, but we can’t be sure until we observe more objects.”

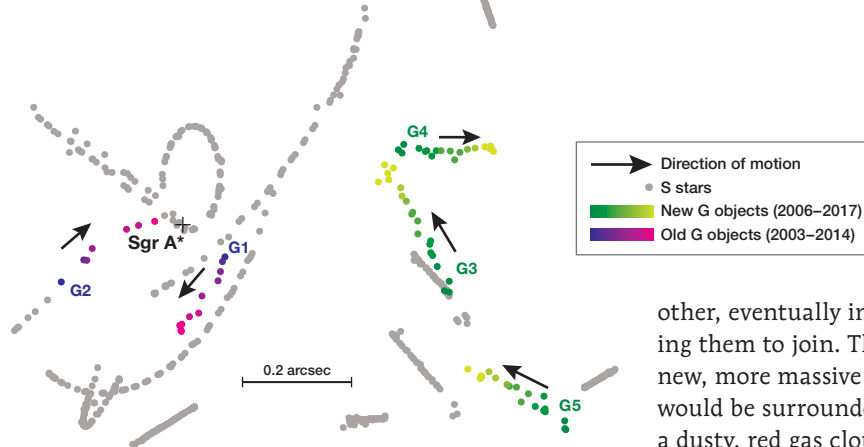
■ SHANNON HALL

## MILKY WAY

## More Mystery Objects in the Galactic Center

**ANNA CIURLO** (University of California, Los Angeles), Randy Campbell (W. M. Keck Observatory), and their colleagues announced the discovery of three red, dusty objects near our galaxy's supermassive black hole, Sgr A\*, at the American Astronomical Society meeting in Denver. The objects are bright in hydrogen emission and compact — unlike disrupted gas clouds.

This isn't the first time that astronomers have detected such objects near the black hole. Two others, called G1 and G2, follow slingshot paths around Sgr A\*. Observers across the world monitored the G2 object as it plunged near the black hole, but although its shroud was disrupted, the object itself survived the close pass (*S&T*: Jan. 2015, p. 16). Many astronomers suspect a star hides inside the shroud, holding the object together.



▲ Preliminary data analysis shows the motion of G3, G4, and G5 from 2006 through 2017 (green to yellow). The black arrows show which direction each object is moving. Observations of G1 and G2 are shown in blue and magenta.

Now, as part of a reanalysis of 12 years of Keck data, Ciurlo, Campbell, and their colleagues have found three more G objects: G3, G4, and G5.

The team thinks these objects might be something extraordinary: new stars made when two stars have merged. If a binary system were orbiting the supermassive black hole, the black hole would stretch the stars' orbits around each

other, eventually inducing them to join. The new, more massive star would be surrounded by a dusty, red gas cloud that looks similar to the

G objects. The cloud would then dissipate in about a million years, leaving behind a young, massive star like those seen near Sgr A\* (see page 22).

But there could be a wee snag in this explanation. The team doesn't have enough data yet to conclusively nail down the new objects' orbits, but preliminary data show G3's orbit to be roughly circular, which means the black hole would have had a harder time forcing the two stars to combine. That raises the question of whether all the G objects really have the same origin.

■ CAMILLE M. CARLISLE



## STAR FORMATION

## Too Many Massive Stars in Early Universe

**A NEW METHOD OF MEASURING** star formation in four galaxies in the early universe finds that they're producing more massive stars than expected.

Astronomers have long thought that the same basic processes ought to shape star formation no matter where it happens. However, the nearby star-forming region 30 Doradus (*S&T*: May 2018, p. 9) recently challenged that assumption and now, in the June 14th *Nature*, new work on early galaxies appears to confirm that the stars that form depend on their environment.

◀ Artist's concept of a starburst galaxy (upper right) hidden behind a veil of dust (lower left). ALMA observations peered through the veil to measure interstellar carbon monoxide.

The galaxies, whose light took more than 10 billion years to travel to Earth, are bursting with stars. But they're also dusty, which makes them immune to measurements requiring ultraviolet, visible, or infrared light. So Zhi-Yu Zhang (University of Edinburgh, UK) and colleagues trained the Atacama Millimeter/submillimeter Array on these galaxies, searching for carbon monoxide emission, a signal tied to a galaxy's history of star formation.

The scientists measured two forms of carbon monoxide:  $^{13}\text{CO}$  and  $^{18}\text{O}$ . Stars of all masses release  $^{13}\text{C}$ , whereas only more massive stars produce  $^{18}\text{O}$ . Since massive stars live brief lives, the relative abundance of  $^{13}\text{CO}$  to  $^{18}\text{O}$  serves as a fossil record, showing that too many massive stars formed relative to low-mass stars in these four galaxies.

If the measurements hold up, then it might change our understanding of

starbirth. For example, the galaxies we call "starbursts" might not be making more stars compared to other galaxies, as astronomers assume; rather they might be pouring more resources into making massive stars, resulting in a fewer total stars. This could throw off our understanding of cosmic star formation, which astronomers currently think peaked when the universe was roughly a third its current age.

However, the carbon monoxide signature measures the interstellar medium rather than the stars themselves, so it's gauging the galaxy's entire history of star formation. While galaxies in the early universe have a pretty short history, there's still time for confounding effects to complicate the measurements, points out Kevin Covey (Western Washington University).

Zhang's team may not have convinced all their colleagues, but they're only getting started: Zhang says more systematic surveys, including of nearby galaxies, are in the works.

■ MONICA YOUNG



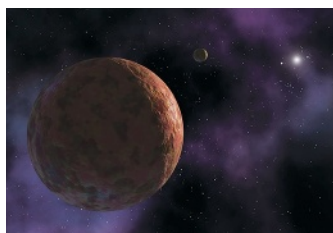
## SOLAR SYSTEM No Planet X in the Kuiper Belt?

### NEW RESEARCH

**PRESENTED** at the American Astronomical Society meeting in Denver suggests that interactions between small objects in the outer solar system — rather than a hypothetical “Planet X” — could be the reason some of these far-flung objects follow odd trajectories.

These *detached objects* are members of the larger family of trans-Neptunian objects (TNOs), bodies that orbit beyond Neptune’s orbit. But unlike most TNOs, detached objects orbit far beyond Neptune’s gravitational influence. Sedna, discovered in 2003, is one of the most famous (and distant) examples. Yet even though these bodies move beyond the gravitational effect of the inner eight planets, their trajectories share similarities that seem to point to a common but unknown influence, dubbed Planet X (*S&T*: Oct. 2017, p. 16).

But a group led by Ann-Marie Madigan and Jacob Fleisig (both at University of Colorado, Boulder) have found an alternative cause: the combined gravitational pull of the whole TNO family.



▲ Artist’s concept of Sedna, the largest known trans-Neptunian object, whose orbit is “detached” from Neptune’s gravitational influence.

The team’s simulations show that the orbits of smaller bodies revolve more quickly around the Sun than those of larger bodies, catching up like the minute hand of a clock catches up to the hour hand. When that happens, the larger body feels the combined gravity of the small TNOs piling up behind it, ultimately pushing it out to a more distant and more circular orbit.

“This could be a really big deal,” says Hal Levison (Southwest Research Institute), though he’s reserving judgment until he sees the published paper (currently in preparation).

One of Planet X’s main proponents, astronomer Mike Brown (Caltech), agrees that the new work could explain how the orbits become detached from Neptune’s gravitational influence, but he doesn’t think it rules out the existence of Planet X. Other characteristics, such as how the orbits line up with one another and their tilt with respect to the planets’ orbital plane, remain unexplained. Nevertheless, findings like this may put a bit more pressure on those looking for Planet X.

■ JAVIER BARBUZANO

## IN BRIEF

### Globular Clusters Get a Face-lift

Globular clusters hold the key to understanding our galaxy’s earliest years. For a long time, globular clusters were thought to be among the earliest objects to form in our galaxy — a beautiful (and typical) example is Messier 4, whose age researchers had pegged at roughly 13 billion years old. Now, a new study by Elizabeth Stanway (University of Warwick, UK) and JJ Eldridge (University of Auckland, New Zealand) has given these ancient beauties a face-lift. Previous studies had often compared the collective colors of stars in a globular cluster to models of stellar populations with known ages and compositions. Stanway and

Eldridge instead compared colors to a new computational model called Binary Population and Spectral Synthesis, which takes paired stars into account. They found they were able to reproduce globular clusters’ colors using far younger stars. Stanway and Eldridge find that globular clusters previously found to be between 10 billion and 14 billion years old are more likely to be between 5 billion and 8 billion years old. The results, which appear in the *Monthly Notices of the Royal Astronomical Society*, could affect astronomers’ understanding of galaxy evolution.

■ MONICA YOUNG

### Curiosity Rover Is Drilling Again

After an 18-month hiatus, NASA’s Curiosity resumed drilling and sampling rocks in May using a new technique known as *percussive*

## Dust Storm on Mars; Opportunity Hunkers Down

Just as the Red Planet began to inch into the evening sky in late May, ahead of its closest opposition since 2003, a swath of bright orange dust clouds covered the dark albedo feature Mare Acidaliu. Within days, NASA’s Mars Reconnaissance Orbiter watched the dust move south and expand to cover almost half the planet by June 11th. In addition to obscuring albedo features normally visible from Earth, the thick dust blocked the solar panels of the 14-year-old Opportunity rover, preventing its batteries from charging. While NASA engineers received a transmission from Opportunity on June 10th, the rover has since fallen silent, indicating that it has entered low-power mode. In this mode, only the mission clock runs, periodically waking the computer to check power levels. The concern is whether the batteries can outlast the storm. Curiosity, which roves in the opposite hemisphere, has also seen an increase in dust, but that won’t affect its radioactive power supply. As of June 21st, amateur images have shown previously obscured features, so the storm may now be subsiding. See the storm’s progress at <https://is.gd/duststorm>.

■ BOB KING

▲ The dust storm on Mars as seen on June 16, 2018.



drilling, which allows Curiosity to keep its drill feed permanently extended. Curiosity had obtained 15 samples on Mars before issues began cropping up with the balky drill feed in October 2016, which led to a temporary suspension of drilling operations. Engineers worked on the solution for more than a year, testing the new method in March. On May 20th the rover successfully drilled a hole 2 inches (50 millimeters) deep into a rock named Duluth, which is located near Vera Rubin Ridge in Gale Crater. While this first attempt experienced difficulty delivering the drilled sample into the rover for processing, a second attempt on May 31st successfully transferred the rock powder to the rover’s mineralogy lab.

■ DAVID DICKINSON

# Variations on a Theme

*Nature loves to riff on existing motifs, even in the most unearthly of environments.*

## THE MOST INTERESTING WORLDS

are those that are most varied and vibrant. Consider Earth. Lying between its churning interior and solar-driven atmosphere, its surface is constantly reworked, producing infinite diversity and beauty. Maybe I'm biased, but that winning combination of vigorous internal and atmospheric activity makes for the best planetary exteriors.

Fortunately, we keep finding more places where the fertile interface between geology and meteorology cooks up marvels. Such features are often a beguiling mix of the familiar and the exotic, with recognizable forms assembled from available materials that are malleable in the extreme (to us) conditions found on other worlds. On Titan, for example, a *hydrological cycle* creates recognizable fractal rivers and lakeshores, but the working fluid is methane, not water.

Pluto, as revealed to us by the New Horizons encounter of 2015, sports precipitous water-ice mountains capped with methane snow, ringing a vast nitrogen glacier called Sputnik Planitia. Upon seeing that massive smooth plain, clear and fresh and free of craters, we were consumed by the mystery of its self-erasing surface. What is happening below to drive that sea of solid nitrogen to turn itself over? It may simply be that the radioactive decay of the rocky interior generates enough heat to churn the soft nitrogen ice.

There's no new physics here — simply common materials found in such otherworldly scales and conditions that our pre-encounter imaginations were not quite up to the task. This is why we explore rather than simply stay home

and construct models.

Yet it's not just internally driven activity that gives Pluto its dazzling variety and complexity. Our favorite Kuiper Belt orb, we find, is another place where many of the grandest enigmas and most exquisite features arise from the interaction between surface and atmosphere.

The wonderful discovery of dunes on the western flanks of Sputnik (see page 8) confirms this. Among the discoverers is Jani Radebaugh, a planetary geologist at Brigham Young University, who was instrumental in gathering the international, multi-disciplinary team that produced the June 1st *Science* paper that made the case for Plutonian dunes.

I admit I was skeptical when I first heard about potential dunes on Pluto. I assumed its wispy atmosphere, 100,000 times thinner than Earth's at the surface, would be far too rarefied to blow around material in the way needed to fashion dunes.

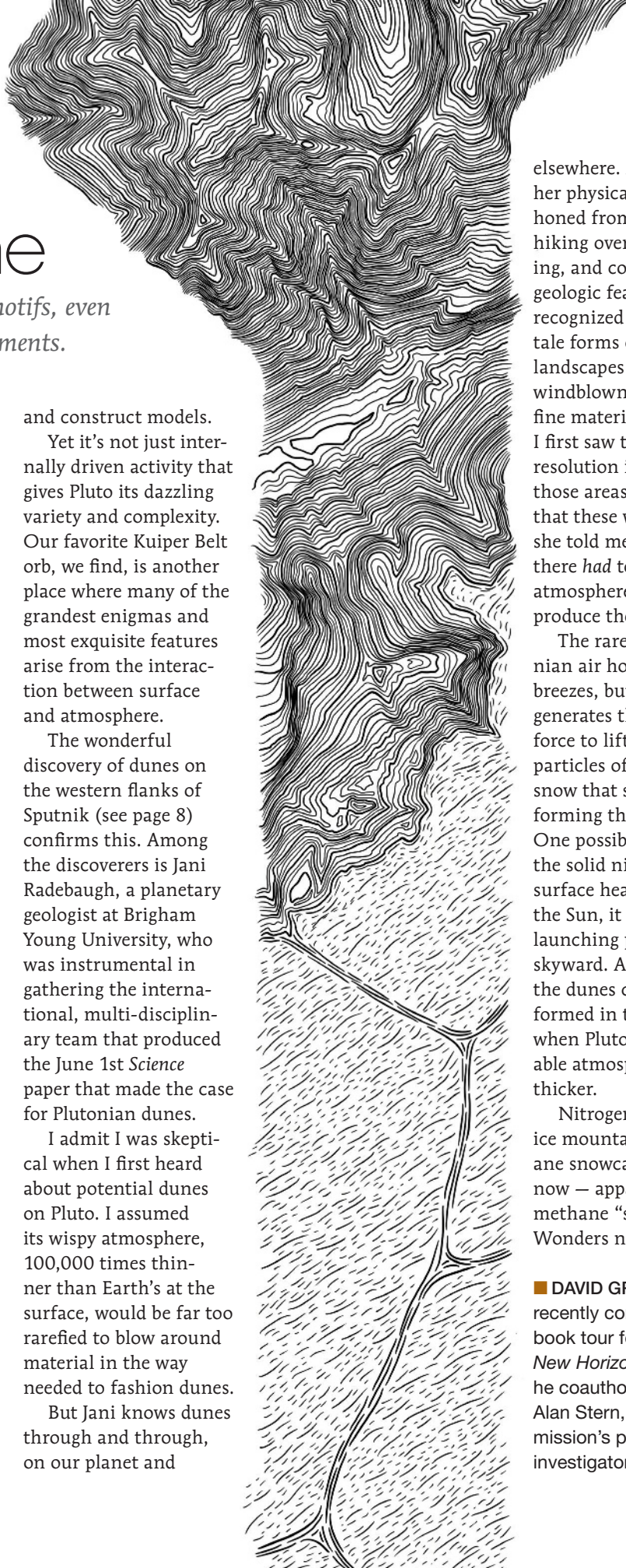
But Jani knows dunes through and through, on our planet and

elsewhere. Applying her physical intuition, honed from years of hiking over, measuring, and comparing geologic features, she recognized the tell-tale forms of surface landscapes formed by windblown deposits of fine materials. "When I first saw the high-resolution images of those areas, I realized that these were dunes," she told me. "I knew there *had* to be an atmosphere that could produce them."

The rare Plutonian air hosts strong breezes, but what generates the initial force to lift the small particles of methane snow that seem to be forming these drifts? One possibility: As the solid nitrogen surface heats up in the Sun, it vaporizes, launching particles skyward. Alternatively, the dunes could have formed in the past when Pluto's changeable atmosphere was thicker.

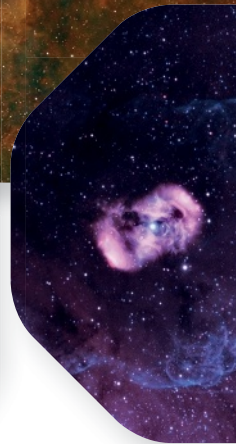
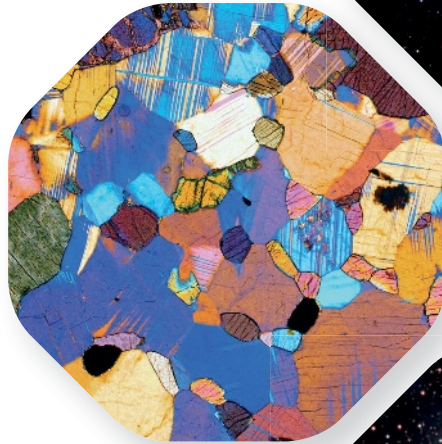
Nitrogen glaciers, ice mountains, methane snowcaps, and now — apparently — methane "sand" dunes. Wonders never cease.

■ **DAVID GRINSPOON** recently completed a book tour for *Chasing New Horizons*, which he coauthored with Alan Stern, the Pluto mission's principal investigator.





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# DESTINATION: Venus?

Our **toxic twin** might be a scientific treasure-trove, but infrequent visits are hindering studies, causing many planetary scientists to grow frustrated.

It was a little after 3 a.m. when Ellen Stofan jumped into her car and raced toward the Jet Propulsion Laboratory. She had just learned that the first radar image of Venus had arrived from the Magellan spacecraft, and she literally could not wait to see it.

Stofan, the mission's deputy project scientist at the time, was one of the first people to peer beneath the clouds using Magellan and inspect our sister planet in unprecedented detail. And that first black-and-white image in August 1990 did not disappoint. It revealed a vast volcanic plain scarred by a giant impact crater. Unlike the Moon, Mars, and Mercury, Venus appeared to have been geologically active in the recent past.

But it was only a hint of what was to come. By the end of its four-year mapping effort, the spacecraft revealed 98% of the planet's surface at a higher resolution than ever before. "We uncovered this amazing, confusing planet," Stofan says.

The most confusing — and compelling — aspect, Stofan says, was that so many images looked like the first. Not only is Venus covered in lava flows, but it also lacks a lot of craters (which build up over time), suggesting that the planet resurfaced much of itself only a few hundred million years ago. And although scientists aren't sure what can cause such a startling global change, they do think the answer might help explain how the planet's runaway greenhouse began — a twist of fate that caused the once-habitable world to turn into a toxic one. Needless to say, Stofan and her colleagues were eager to send more missions to the world in search of an answer.

But while the European and Japanese space agencies have both mounted successful orbital missions to Venus, NASA has not returned there. And the geologic questions that Magellan raised remain a mystery today — nearly 30 years later.

▲ **CLOUDTOPS** Bright and dark bands caused by an unknown chemical absorber mark this ultraviolet view of Venus from the European Venus Express orbiter. The patterns are about 70 km above the surface.

It's a tragedy to many U.S. planetary scientists, some of whom are now up in arms over NASA's shift away from Venus exploration. In the years since Magellan, planning teams have proposed more than 25 new Venus missions. Every single one has been shot down. The latest saga ended in December when Venus researchers received a double dose of bad news: Yet another two mission proposals were rejected.

"We jump-started our understanding of Venus with Magellan, and then it was just like we got cut off at the knees," Stofan says.

Yet not only does Venus likely hold the key to understanding open questions about Earth, but it also can address habitability in general — an issue that's crucial now that astronomers have discovered thousands of exoplanets, many of which likely resemble Venus. For that reason, Venus scientists are trudging onward, hopeful that the tides will soon turn and that NASA will one day return to the evening star.

## Volcanic World

There's no doubt that Venus is Earth's deadly sibling. The two planets are near-twins in size, density, gravity, and, likely, chemical makeup. Although today Venus doesn't reside in our Sun's life-favoring "Goldilocks zone," it, along with Mars, might have been habitable billions of years ago. (Yes, some astronomers argue that Venus once hosted global oceans and moderate temperatures.) But despite these similarities, something caused the two planets to wander down two very different evolutionary paths.





◀ **PANCAKE DOMES** These seven circular hills in Alpha Regio, on average 25 km wide and 750 m high, appear to be thick lava flows that welled up onto level ground, which allowed them to flow out in an even pattern.

▲ **VENUSIAN TICK** This bizarre volcanic construct is a tick, a caldera surrounded by radiating ridges and valleys. Lava flows breaching the rim created the “head.” Ticks sometimes appear near the deformed terrain regions called *tesserae*, but it’s unclear if they’re related.

Earth, as we know, transformed into a paradise fit for life, while Venus morphed into a hellscape. It boasts clouds of sulfuric acid and an atmosphere that slams down on the surface with 90 times the pressure found in Earth’s atmosphere. That surface averages a blistering 460°C (860°F) — hot enough to melt lead. Smooth, gently rolling plains cover about 70% of its surface — the result of past volcanic flows, some of which travel for thousands of kilometers before fanning outward. Recent research even suggests that volcanism continues today. Needless to say: Venus is hot, stifling, and dynamic.

Magellan and its predecessors also revealed terrain studied with mountains, plains, high plateaus, canyons, and ridges. The planet even boasts highlands akin to Earth’s continents. The two largest are the sprawling Aphrodite Terra along the equator, nearly as large as Europe and Asia combined, and Ishtar Terra in the northern hemisphere, roughly the size of Antarctica. Those two highlands stand a few kilometers above the plains, roughly similar to the rise of Earth’s continents above its seafloor, and they’re marred by more than 1,000 large volcanoes and 100 mountains — the tallest of which tower above the landscape at a height greater than that of Mount Everest in the Himalayas.

But that range of peaks, Maxwell Montes, built up in a different way than the Himalayas, which were created when two tectonic plates — those large slabs of rock that divide Earth’s crust and jostle about — rammed into each other. In fact, Venus does not appear to host plate tectonics at all. That much can be seen from the distribution of volcanoes, which do not

create long chains along the boundaries of tectonic plates like they do on Earth, but dot the surface haphazardly. It’s a mystery whose answer might explain Venus’s young landscape, its stifling atmosphere, and even phenomena on our own world.

## Shedding Light on Earth

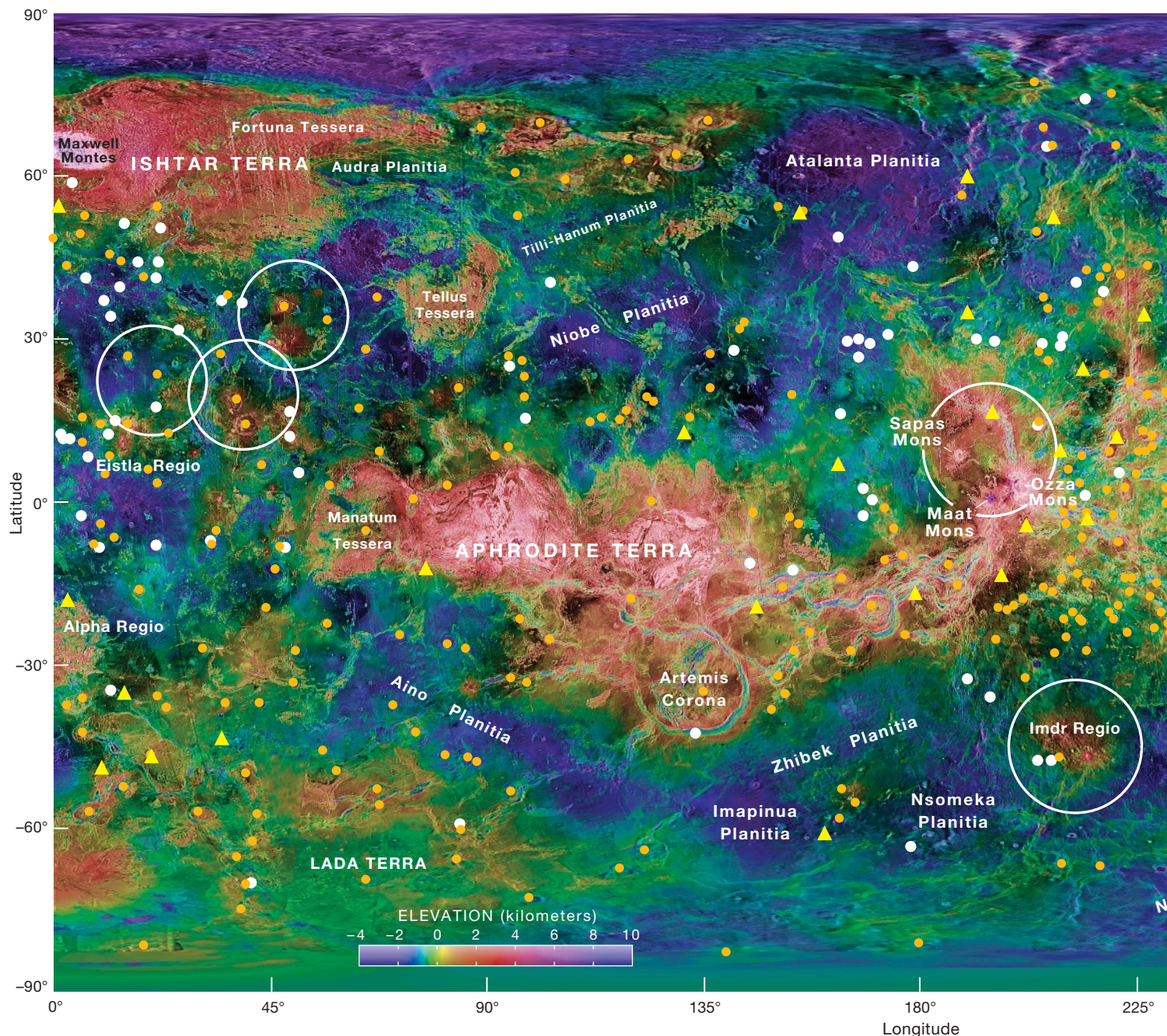
On Earth, jostling crustal plates help regulate our planet’s temperature over tens to hundreds of millions of years as carbon dioxide shifts between the atmosphere and Earth’s mantle. So it could be that Venus once had plate tectonics, but over time those plates became thicker and harder to break apart or subduct. As a result, there was no way to pull carbon dioxide out of the atmosphere and into the mantle, forcing the planet down a path that led to extreme temperatures and atmospheric pressures.

### ► MAGELLAN TEAM

Members of the Magellan team pore over images from the orbiting spacecraft. The map being studied is assembled from the long strips of data from Magellan’s pole-to-pole passes. From left to right: Nick Stacy, Ellen Stofan, Barry Parsons (rear), and Don Campbell.







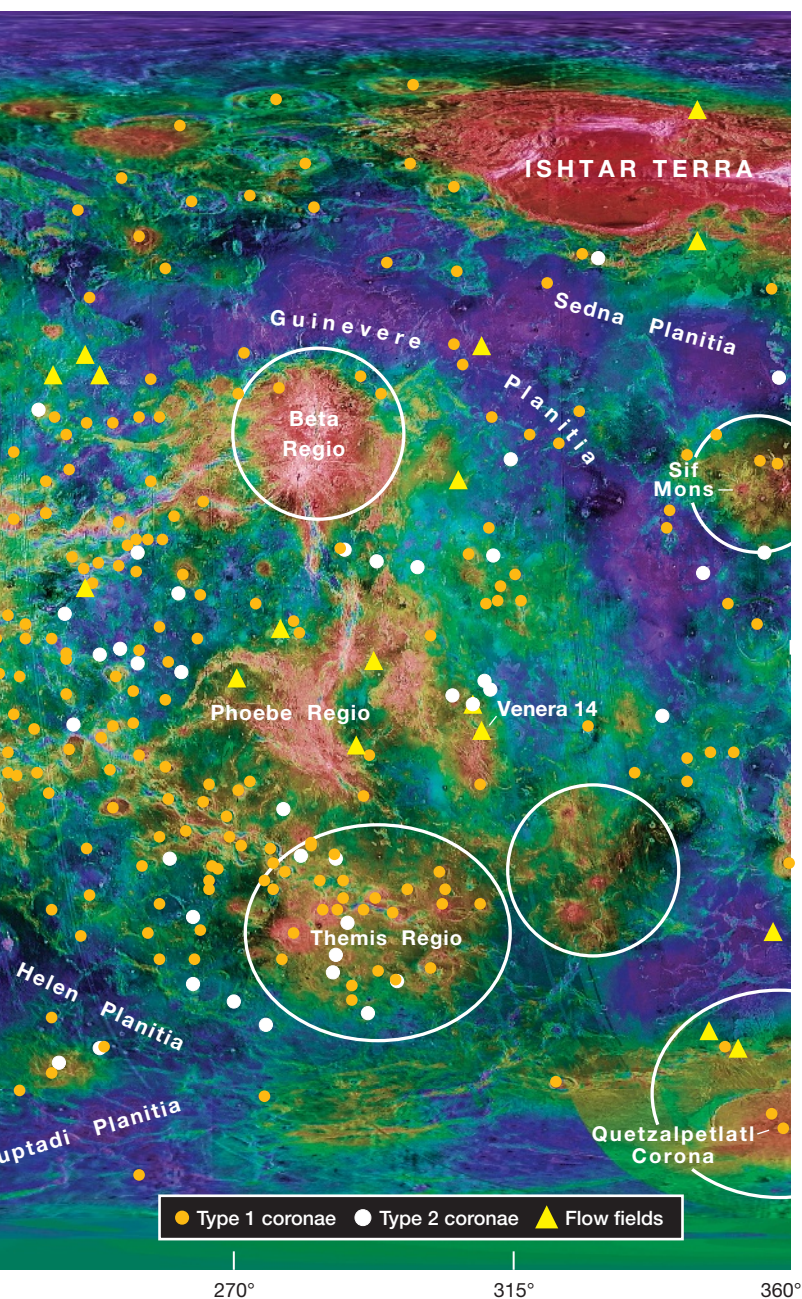
Or it might be that Venus never had plate tectonics in the traditional sense. Instead, as the crust piles up with lava, it thickens and grows more massive, pushing the crust beneath it back down into Venus's interior. That process would also create compressional crumpling that, together with the lava flows, would wipe away craters, thus explaining why the surface looks so young.

Some scientists argue that a similar process could have provided the initial force that kick-started plate tectonics on Earth. That's important because plate tectonics just might be a crucial ingredient for sustaining life (given that it keeps our planet's temperature in check), and yet scientists can't yet pin down just how and when it began here.

As such, Venus harbors secrets that might bear on our pale blue dot. Take its stifling atmosphere as a second example. It's a department store of climate puzzles, says David Grinspoon (Planetary Science Institute), including the circulation of the atmosphere, the balance of radiation, the function of clouds, and the role of trace greenhouse gases. Although scientists have a fairly good understanding of how those processes work on Earth, seeing them in an altered way on a new world will help them better understand the underlying physics and thus improve their models for Earth overall.

Grinspoon even argues that Venus might reveal hidden fine-tunings that could help climate scientists better forecast our own future in a warming world and better understand

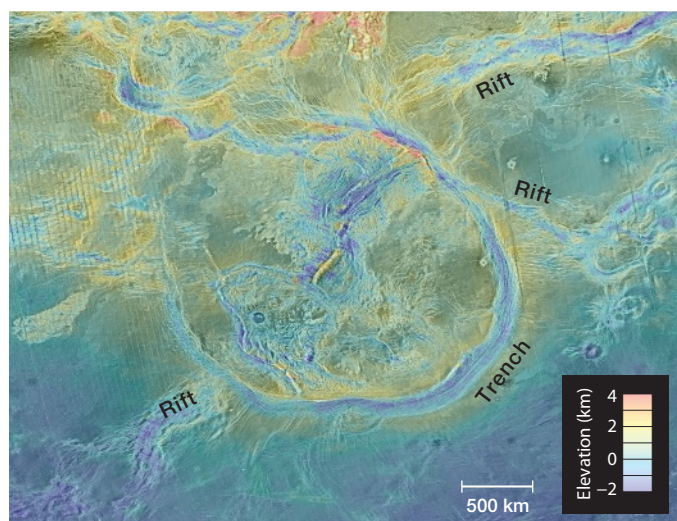




the role we play in those changes. “It’s not just an academic question,” Grinspoon says. “Understanding how climate works on Earth-like planets is now a matter of survival.”

If scientists could pinpoint the factors that tipped Venus away from becoming a habitable world and toward a noxious one, then they would also be able to pinpoint the factors that kept Earth on the other course. “We want to know when in the 4.5 billion years of the history of the solar system, the destiny of the two planets was written — and when did it diverge,” says Thomas Widemann (Paris Observatory).

Only then can we understand what truly makes a world habitable. Or as Lori Glaze (NASA Goddard) says: “If we don’t understand that, we don’t know what makes Earth *Earth*.”



◀ **VOLCANISM** Venus has widespread signs of recent (perhaps active) volcanic activity. Expansive lava flows cover its surface, and giant hotspots (circled) are the surface manifestations of upwelling mantle plumes. These can span more than 1,000 km and likely underlie the roughly 500 circular features called coronae. (Type 1 coronae have concentric rings of cracks.) Representative features and those mentioned in the article are labeled.

▲ **ARTEMIS CORONA** This image combines radar (gray) and topographic (color scale) views of Artemis Corona, a 2,600-km-wide hotspot in Venus’s southern hemisphere. Scientists think coronae form when a large molten plume wells up from the mantle, fracturing the crust above it and exuding onto the surface. The weight from the spreading lava bends the underlying crust, forcing it to subduct back into the mantle. This process would explain the rifts radiating out from the corona and its encircling trench and buckled terrain. In Artemis’s case, there also appear to be several smaller corona-like features inside the large one.

At the end of the day, our toxic twin — which is eerily similar to our planet in some regards and yet worlds apart in others — could easily help explain our changing climate, the initiation of plate tectonics, and what made our world habitable. “Venus is uniquely positioned and equipped to give us answers in a way that no other planet that we can explore can,” Grinspoon says. “And yet we’ve been completely neglecting it. It’s criminal.”

## A Planet Left in the Dust

With so much to learn from our neighboring planet, many planetary geologists find it inconceivable that NASA hasn’t sent a dedicated mission there since the 1990s. And it’s not like Venus was a one-hit wonder back then. When scientists first started to explore the solar system, they set their eyes on Venus. Not only was it the target of our first successful encounter beyond Earth, but it also was frequently visited throughout the 1960s and ’70s.

But after Magellan, no new probe embraced its skies for more than 10 years, until European and Japanese orbiters launched in 2005 and 2010, respectively. So, James Green, NASA’s new Chief Scientist, argues that there are more Venus missions happening than disgruntled researchers let on. “You don’t have to lead the mission to do Venus science,” he says.



**Venus** was the first target for planetary exploration in the Space Age. Nearly twice as many spacecraft visited it as went to Mars in the 1960s — and four times as many in the 1980s. But after Magellan's mission ended in 1994, interest waned.

- - Failed mission
- Successful mission  
(includes partially)

[B] = balloon  
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[L] = lander  
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## DID YOU KNOW?

All Venusian landers so far have incorporated **spherical structures**, because that shape best withstands collapse under the tremendous atmospheric pressure. In fact, the pressure is similar to what you'd experience nearly 1 km beneath the ocean's surface on Earth.

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Mission	Agency	Year	Status
Marsnik 1	USSR	1960	Failed
Marsnik 2	USSR	1960	Failed
Sputnik 22	USSR	1962	Failed
Mars 1	USSR	1962	Failed
Sputnik 24	USSR	1962	Failed
Mariner 3	NASA	1964	Failed
Mariner 4	NASA	1964	Successful
Zond 2	USSR	1964	Failed
Venera 1964A	USSR	1964	Failed
Venera 1964B	USSR	1964	Failed
Cosmos 27	USSR	1964	Failed
Zond 1	USSR	1964	Failed
Venera 2	USSR	1965	Failed
Venera 3	USSR	1965	Failed
Cosmos 96	USSR	1965	Failed
Venera 1965A	USSR	1965	Failed
Venera 4	USSR	1967	Successful
Mariner 5	NASA	1967	Successful
Cosmos 167	USSR	1967	Successful
Mariner 6	NASA	1969	Successful
Mariner 7	NASA	1969	Successful
Mars 1969A	USSR	1969	Failed
Mars 1969B	USSR	1969	Failed
Venera 5	USSR	1969	Successful
Venera 6	USSR	1969	Successful
Venera 7	USSR	1970	Successful
Cosmos 359	USSR	1970	Successful
Mariner 8	NASA	1971	Failed
Cosmos 419	USSR	1971	Failed
Mars 2	USSR	1971	Failed
Mars 3	USSR	1971	Failed
Mariner 9	NASA	1971	Successful
Venera 8	USSR	1972	Successful
Cosmos 482	USSR	1972	Successful
Mars 4	USSR	1973	Failed
Mars 5	USSR	1973	Failed
Mars 6	USSR	1973	Failed
Mars 7	USSR	1973	Failed
Viking 1	NASA	1975	Successful
Viking 2	NASA	1975	Successful
Venera 9	USSR	1975	Successful
Venera 10	USSR	1975	Successful
Pioneer Venus 1	NASA	1978	Successful
Pioneer Venus 2	NASA	1978	Successful
Venera 11	USSR	1978	Successful
Venera 12	USSR	1978	Successful
Venera 13	USSR	1981	Successful
Venera 14	USSR	1981	Successful
Venera 15	USSR	1983	Successful
Venera 16	USSR	1983	Successful
Vega 1	USSR	1984	Successful
Vega 2	USSR	1984	Successful
Phobos 1	USSR	1988	Failed
Phobos 2	USSR	1988	Failed
Magellan	NASA	1989	Successful
Galileo	NASA	1989	Successful
Mars Observer	NASA	1992	Failed
Mars Global Surveyor	NASA	1996	Successful
Mars 96	Roscosmos	1996	Failed
Mars Pathfinder and Sojourner	NASA	1996	Successful
Cassini	NASA	1997	Successful
Nozomi	JAXA	1998	Failed
Mars Climate Orbiter	NASA	1998	Failed
Mars Polar Lander/Deep Space 2	NASA	1999	Failed
Mars Odyssey	NASA	2001	Successful
Mars Express/Beagle 2	ESA	2003	Failed
Mars Exploration Rover Spirit	NASA	2003	Successful
Mars Exploration Rover Opportunity	NASA	2003	Successful
Mars Reconnaissance Orbiter	NASA	2005	Successful
Venus Express	ESA	2005	Successful
Phoenix Mars	NASA	2007	Successful
Akatsuki	JAXA	2010	Successful
Phobos-Grunt/Yinghuo-1	Roscosmos and CNSA	2011	Failed
Curiosity	NASA	2011	Successful
Mars Orbiter Mission/Mangalyaan	ISRO	2013	Successful
MAVEN	NASA	2013	Successful
ExoMars Trace Gas Orbiter/Schiaparelli	ESA and Roscosmos	2016	Successful



But while NASA's planetary-science community is thankful that its international partners have picked up the baton, many say it is not enough. They want to send orbiters that will map the world in closer detail. They want to send balloons that will fly into those acidic clouds to test for stable isotopes and noble gases, which bear the fingerprints of Venus's origin and evolution. And they want to drop probes onto its surface, landing on some fresh lava flows or the *teserae* — regions of crumpled terrain with unknown origins



▲ **IN ULTRAVIOLET** This two-image composite from Akatsuki data shows clouds and hazes (65 to 75 km altitude). Colors track changes in sulfur dioxide and an unknown UV absorber.

— in order to better assess the past habitability of our sister planet.

With such lofty goals, scientists have written one mission proposal after the next, only to watch NASA reject them time and time again. “It’s like Lucy holding the football for Charlie Brown,” says Darby Dyar (Mount Holyoke College). “We run and we run and we try to kick the damn ball and it gets pulled out from under us.”

That isn’t to say that Venus scientists don’t recognize the merit of other missions. “I look at the missions that have been selected

over the last couple of rounds, and they’re all outstanding,” Glaze says. “They have great science ideas. They’re all going to produce compelling discoveries.” But she admits she’s also a bit frustrated. “I do feel that it’s time for Venus to play a role in this whole planetary evolution story.”

Others are more dismal. Without a dedicated mission, some argue, the group of Venus scientists will shrink. And that will mean that there are even fewer scientists who will advocate for new missions. It will also mean that NASA might soon find itself devoid of anyone who has actually sent a probe to Venus. There is simply so much to gain from a Venus mission and so much to lose without one.

## The Martian Allure

So what’s behind NASA’s long hiatus? The one to ask is Thomas Zurbuchen, NASA’s Associate Administrator for the Science Mission Directorate. He’s guided by a once-per-decade survey of planetary scientists that ranks funding priorities and future exploration candidates — and which, notably, ranked placing a spacecraft on Venus’s surface below a Mars sample-return effort and a mission to the subsurface-ocean-bearing Europa. But ultimately, he’s the person who chooses the interplanetary missions that fly and those that won’t. And he does so based on three criteria: “The science is excellent, the technology is ready to go, and sometimes you need a little bit of luck, too,” he says. Not that it’s an easy decision. “It’s one of the hardest things you’ll ever do,” he adds.

Zurbuchen has profound empathy for those who don’t see their projects accepted. “Every time I lost a proposal I took it personally — deeply personally,” he says. “I think that’s what

we’re seeing. It’s just researchers who really care about what they do, and they bring passion to the table every day.”

Green agrees. Several years ago, NASA rejected his own mission proposal, causing his sunny demeanor to take a downward swing. “I was depressed for six months,” he says. “That’s what happens in this field. It’s not easy.”

But most Venus researchers argue there are deeper issues at work. Although every planetary scientist has a pet theory — which together shed more light on human nature than on our sister planet — all agree that the dogged search for extra-terrestrial life helped shift NASA’s gaze away from Venus and toward Mars. In fact, Magellan’s discovery just might be what sealed Venus’s exploratory fate: Once NASA managers realized that Venus’s young lava flows likely covered any evidence of past life or liquid water, they left the toxic world behind and turned their focus toward the Red Planet.

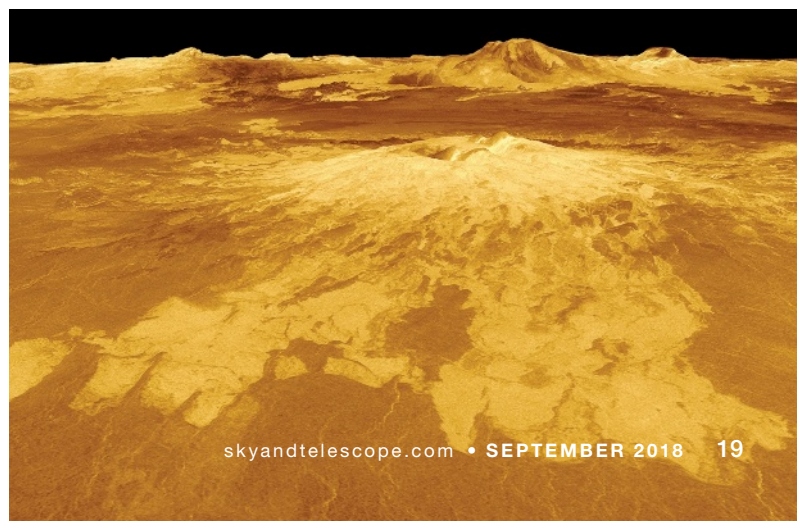
“Mars has this glitter to it,” says Mark Marley (NASA Ames). That much could be seen in 1996 when scientists announced the discovery of what looked like bacteria fossilized within the Allan Hills 84001 meteorite — a rock that

**“It’s quite possible that Venus is actually the end-state of all terrestrial planets.” —Stephen Kane**

blasted off Mars and landed on Earth. Although scientists now almost universally dismiss a biologic origin for the meteorite’s microscopic structures, the excitement it helped feed persisted. Exploring Mars’s dusty red surface could help scientists answer one of the greatest questions they have ever asked: Is there life beyond Earth? The temptation was impossible to resist.

And it remains impossible to resist. Even as NASA pushes outward to other bodies in the solar system (and beyond), the

▼ **VENUS IN 3D** Colored based on images from the Soviet Venera 13 and 14 landers, this simulated perspective of Magellan data looks down on Sapas Mons, an equatorial shield volcano on the western edge of Atla Regio. The volcano is 1.5 km tall. Lava flows extend for hundreds of kilometers across the foreground plains, and Maat Mons lies on the horizon. The vertical scale in this perspective is exaggerated by a factor of 10.

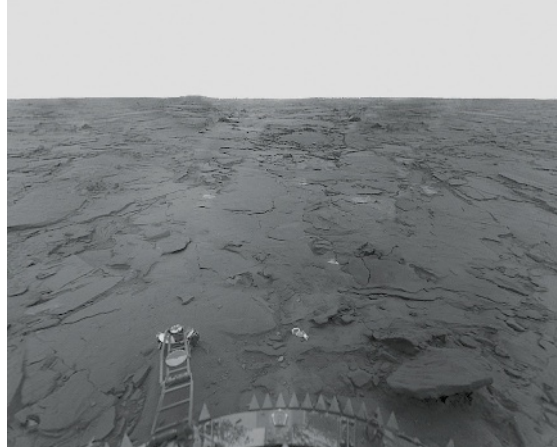
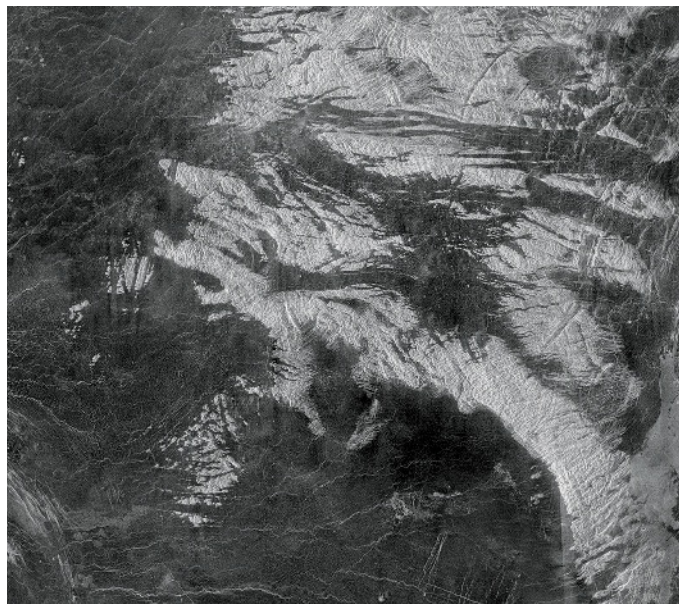


search for life is still a high priority. Take the two mission proposals that were accepted last December for the final assessment round. Instead of exploring lifeless Venus, Zurbuchen opted for studying a flying rotorcraft that would investigate the geology and prebiotic chemistry on Saturn's largest moon, Titan — which is thought to be a great place for testing ideas on how life arose on Earth — and a craft to return samples from the nucleus of Comet 67P/Churyumov-Gerasimenko (*S&T*: May 2017, p. 14), whose primordial cousins might have delivered the essential building blocks of life to Earth. There's no doubt that NASA has stayed true to its mantra.

Additionally, many Venusian critics argue that the current technology favors visits to Mars over infernal Venus. The Red Planet won't melt lead, so rovers and landers placed there have lifespans measured not in hours but in years. Grinspoon thinks that could be a factor in the slew of Venus mission rejections. "I believe there's a psychological bias that we're not going to select a mission that essentially takes an hour's worth of science data — no matter how important that data is, no matter how vital the questions are that could be addressed," he says. The other missions will seem like they give a bigger bang for one's buck.

To be clear, no one is saying that NASA should stop going to Mars. "One thing you'll never hear me do is put down the cause of Mars exploration," Grinspoon adds. "It's just fantastic what we've learned."

▼ **TESSERA TERRAIN** Radar-bright and roughly textured, Fortuna Tessera and other tesserae have strange cracks and wrinkle-ridge folds. Lava plains infiltrating the tessera's cracks indicate the fractured terrain is older. Scientists aren't sure how tessera terrain formed.



◀ **GROUND TRUTH** Donald Mitchell remapped and combined a spherically projected Venera 14 panorama to create this more intuitive view of the Venusian surface. The spacecraft landed just south of the equator, near the border of Phoebe Regio and Navka Planitia.

But it doesn't have to be an either-or endeavor. Many Venus researchers say that there are fundamental questions about our neighboring planet that could be answered with the technology available today — even if those missions might not survive for long. "To say that we can't get to the surface of Venus is just hogwash," Dyar says.

Finally, many planetary scientists argue that Mars has a romantic appeal that Venus will never possess (despite the fact that it's named after the Roman goddess of love and beauty). Not only is Mars a world that might host evidence of past life, but it also might host humans in the future, as we settle on the Red Planet or use it as a stepping stone as we venture outward beyond Earth. The same cannot be said of Venus.

### All Hope Is Not Lost

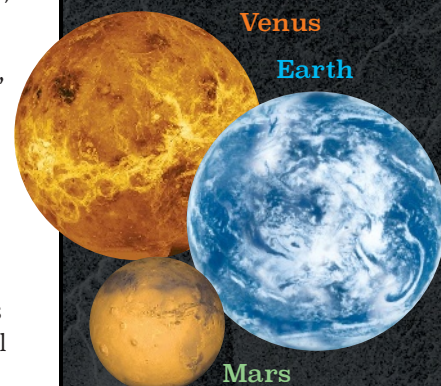
But the tides might be turning. Despite the shrinking constituency of Venus scientists, a counter-trend seems to be building within the ballooning field of exoplanet astronomy.

There, researchers have uncovered thousands of planets around other stars, dozens of which are Earth-size and in their star's habitable zone. But because most observations often only reveal a planet's size and distance from its host star — and Venus and Earth are essentially twins in these respects — there is no way to determine whether these planets are true Earth analogs or if they're more akin to our hellish sister.

As such, many argue that we must better understand Venus if we wish to better interpret exoplanets. "If we really are interested in studying Earth-size planets, then we need to go to the exoplanet laboratory right next door, which is Venus," says exoplanet astronomer Stephen Kane (University of California, Riverside).

To boot, there might simply be far more Venus analogs than Earths. "It's quite possible that Venus is actually the end-state of all terrestrial planets," Kane

**THREE WORLDS** Although Venus and Earth have similar sizes, Mars is more akin to our planet in terms of temperature, day length, and axial tilt. Mars and Venus both have carbon dioxide-dominated atmospheres — but Venus has a lot more CO<sub>2</sub>.





says. “You can go from a habitable environment to a runaway greenhouse. But you can’t go from a runaway greenhouse back to a habitable environment. It’s a one-way street.”

But scientists won’t know the exact ratio of Venus-like to Earth-like worlds until they uncover Venus’s evolutionary path. “We have no hope of making sense of those observations without getting a handle on the Venus-Earth dichotomy,” Grinspoon says. Nor will scientists know if there are other key characteristics that might hint at a planet’s current status, allowing them to pour their precious resources into worlds that are more likely to harbor life.

“The exoplanet community is having a very slow and gradual realization that we can’t do this on our own — we need the planetary-science community,” says Kane. And that has caused some Venus proponents to regain hope. “I think that constituency is already starting to gather, it may help come to the rescue of the small-but-determined Venus community,” Grinspoon says. “I’m still cautiously — perhaps foolishly — hopeful that NASA will come around.”

And he is not alone. “I think it’s inevitable that we’ll go back there eventually,” Kane says. “But I certainly do hope that people will see the immense importance of it so that it can be sooner rather than later.”

Until that time comes, U.S. scientists will keep kicking at Lucy’s ball by writing one mission proposal after the next. And there is some cause for optimism: NASA recently selected a mission concept called Venus In Situ Composition Investigations (VICI) for further technology development. Meanwhile, the European Space Agency, Russia, and India are all researching future missions to send to our sister planet.

“Look at the history of Magellan — that didn’t get handed to us at all,” says James Head (Brown University), who fought

## Venus on Earth

NASA’s Glenn Extreme Environments Rig (GEER) enables researchers to simulate various planetary conditions in a chamber a little smaller than a refrigerator. Last year, they exposed various mineral, rock, and glass samples to Venusian conditions for 80 days to see what reactions would take place. Researchers have also exposed different kinds of high-temperature electronics, some of which survived, says NASA’s Jim Green. That success might open the door to small, long-lived landers.

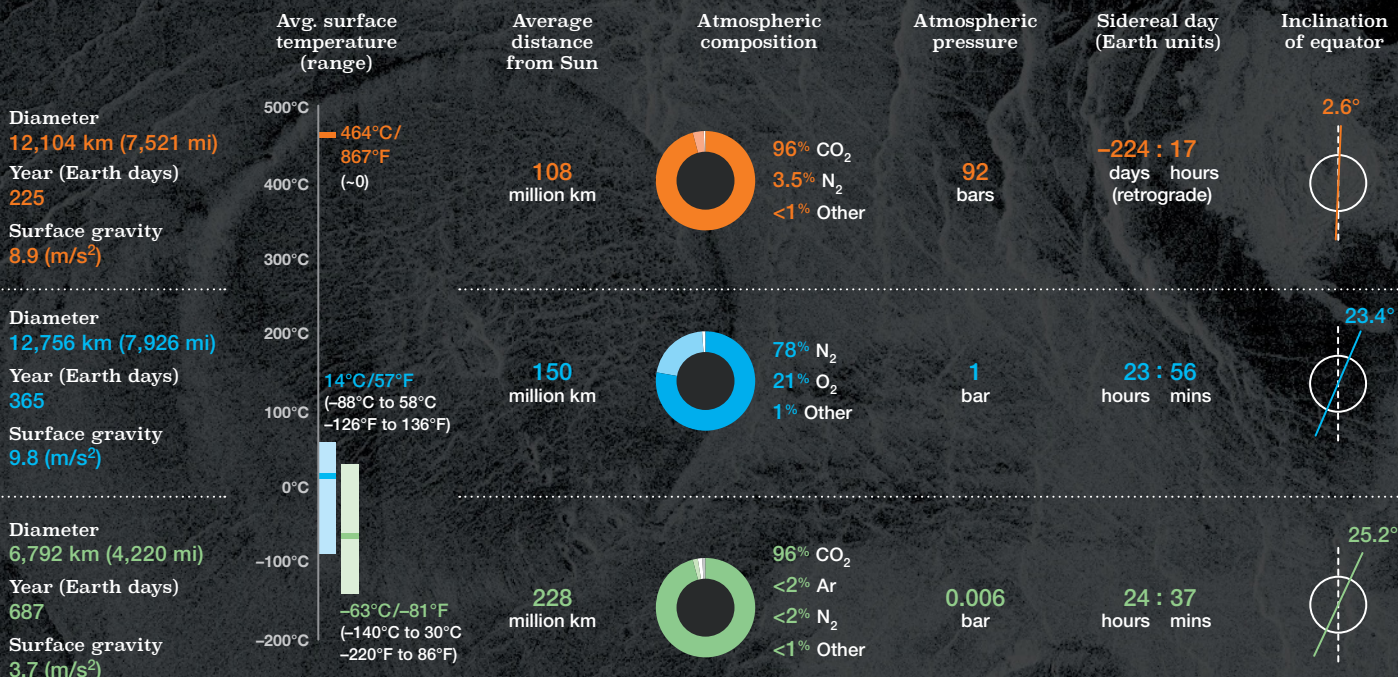


▲ **TO HELL AND BACK**  
NASA Glenn engineer Kyle Phillips removes samples from GEER after they were exposed to Venus surface conditions for 80 days.

hard to include the orbiter in Jimmy Carter’s campaign and later in President Reagan’s budget. “It was a long, hard slog to get that mission funded. We just have to keep fighting because it’s the right thing to do.”

■ Freelance science journalist SHANNON HALL was watching Venus’s dark shadow dance across the surface of the Sun six years ago when her niece was born. So, when she later taught her niece the names of the planets, Venus was first on the list.

Dive into historic exploration images of Venus’s surface: <https://is.gd/venusgallery>.





# Near the Pit

A bumfuzzling troupe of young stars crowds around the Milky Way's central black hole. How did they get there, and what can they tell us about gravity?





**UNFRIENDLY TERRITORY** The black hole's gravity is strong enough to warp spacetime into a 4D well, twisted by its spin. Distances are logarithmic, but the grid is not in order to make clearer where spacetime is flat or warped.

NICOLLE R. FULLER / SAYO-ART LLC



**B**lack holes are not known for being particularly chummy with stars. It's not just that they can rip individual stars into pieces and eat them. The great leviathans of the cosmos, supermassive black holes, have such incredible gravitational fields that their wrenching tidal forces shred clouds that would otherwise collapse and give birth to new suns, sterilizing would-be stellar nurseries.

So astronomers were amazed to discover that roughly 200 young, massive stars huddle around the Milky Way's central black hole, Sagittarius A\*. The youngest are only a few million years old. They're not keeping their distance, either: One comes within two-thousandths of a light-year of the black hole, or four times Neptune's distance from the Sun.

These stars should not exist. For them to be born here, their natal clouds would have had to be almost as dense as a star in order to overcome the black hole's shearing effects, says Reinhard Genzel (Max Planck Institute for Extraterrestrial Physics, Germany). "It seems absolutely preposterous."

But if black holes are known for anything, it's for making the preposterous real. Not only do the stars around Sgr A\* give us a glimpse into a fantastical world where stars and black holes coexist, but one of these stars is also providing astronomers with a long-awaited test of general relativity. As the star swung through its closest approach to the black hole

this past May, it entered gravitational territory we've never been able to explore before. These perplexing stars thus have a lot to teach us not only about how stars and black holes make peace, but about gravity itself.

## Close Quarters

The galactic center is a crowded place. Within four light-years of Sgr A\* snuggle more than a million stars. Average distances between them range from a few hundred astronomical units (in the innermost sanctum) to a few thousand a.u. — roughly a hundredth the distance between us and the nearest star system, Alpha Centauri.

These stars split into several populations, forming what essentially looks like a ball surrounded by a disk surrounded by a bigger ball. It's a familiar picture for astronomers. "The galactic center looks just like a solar system," says Andrea Ghez (University of California, Los Angeles), comparing the region to our planar system of planets and the vast sphere of icy bodies around it, called the Oort Cloud. "The physics is really just scaled-up solar system physics."

The central ball in the galactic center, called the S cluster, is a cloud of some three dozen massive, bluish-white B-type stars. Each star follows an elongated loop around the black hole. The cluster cuddles close to Sgr A\*, the stars not straying more than 0.13 light-year away, or about 8,000 a.u. That's roughly where the outer comet reservoir begins in our solar system. Imagine having 30-something beefy stars scuttling around the solar system.

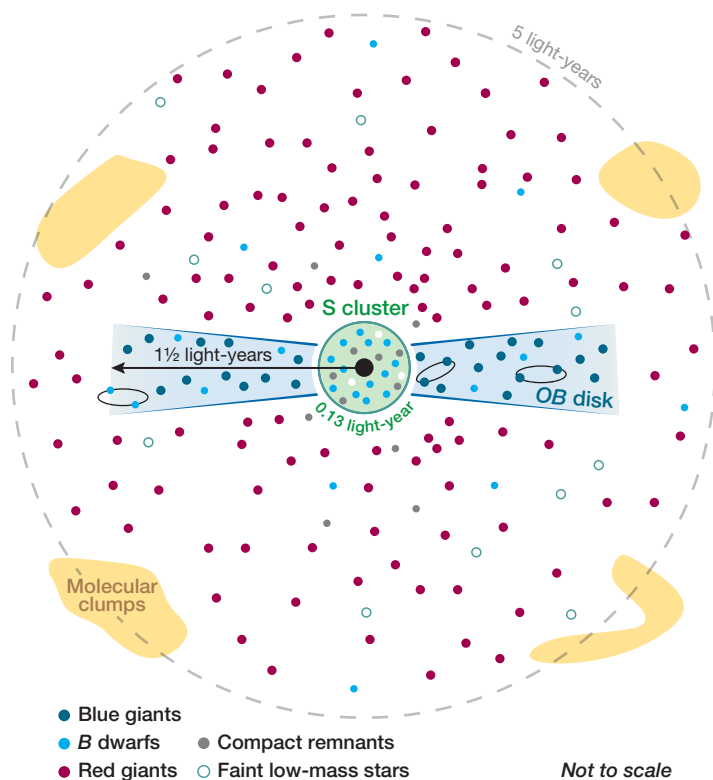
Just beyond the S stars lies a disk of about 120 O- and B-type stars, the youngest, hottest, and most massive main-sequence stars. This disk extends out to 1½ light-years and rotates clockwise around the black hole. Around it are more OB stars, some of which may inhabit a looser, counterclockwise-moving disk. Both the S stars and those in the OB disk live fast, furious lives; now several million years old, they've already burned through a fair fraction of their fuel.

Surrounding these big, bright orbs is a large cloud of red giants. These older stars, roughly 100 million to a billion years old, have passed through the main sequence of stellar life and entered retirement. The red giants extend out about 5 light-years from the black hole.

The puzzle is, none of this looks anything like what astronomers predicted they would see in the mid-20th century. "Let's be very precise: The expectation was *no* young stars," Genzel says. The black hole's gravity should have prevented starbirth; the only stellar neighbors ought to have been a dense crowd of old, red stars. "That there are 200 O stars in the central region and all of them more or less the same age — that seemed outrageous, *ja?*"

## Captive Audience

If they weren't born there, any stars near the black hole would presumably have migrated to the spot over billions of years, driven into the heart of the galaxy by gravitational interactions. But massive stars like those in the S cluster and OB disk



▲ **GALACTIC CENTER** Within 5 light-years of Sgr A\* lie several stellar populations, split into structures and shown here as a cutaway. The older stars are randomly distributed, whereas the young ones preferentially appear in either the warped, rotating disk of OB stars or in the S cluster inside the disk. Stars are color-coded by type, but the dots are representative of detections or inferences, not exact counts and coordinates.

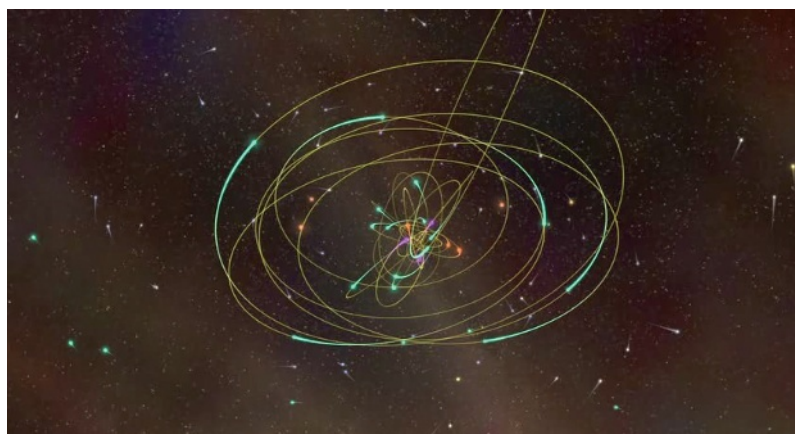
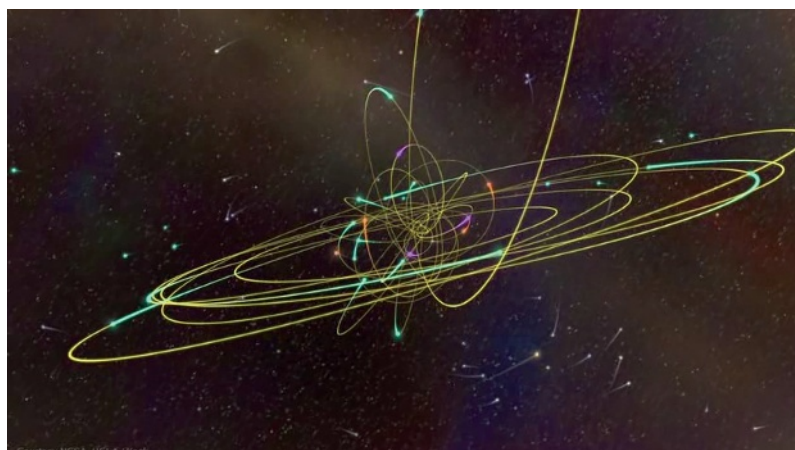


► **THE CENTRAL PARSEC** These stills from a 3D visualization show the stars within a parsec ( $3\frac{1}{4}$  light-years) of Sgr A\*, based on the UCLA team's observations from 1995 through 2012. Visible are the two populations of young, massive stars: the inner tangle of S stars and the OB disk outside it. Watch the movie at <https://is.gd/uclagalacticcenter>.

don't live long — maybe 100 million years or so. That's not enough time for them to sink to the center.

Could astronomers be wrong and these stars did form here? Not the S stars. In order for a cloud to collapse into a star, the gravitational attraction of the front side of the cloud to its back side must be stronger than either side's attraction to the black hole. In the light-year around Sgr A\*, it's essentially impossible to achieve those conditions. "For a gas cloud to form a new star requires such an enormously high density, it's almost stellar density," Genzel says. None of the gas seen in the region is anywhere near that dense.

One alternative is that the S stars we see are the survivors of binary systems torn apart by the black hole. Imagine a pair of stars happily orbiting around each other, far away from Sgr A\*, Genzel explains. Take that pair and shoot it at the black hole. As the binary approaches the black hole, it falls deeper into the wide pit the black hole creates around itself in spacetime. Much like a ball speeds up as it rolls down a hill, the binary gains energy, its stars whipping faster and faster around each other until finally they can't hold onto each other anymore. The pair splits. One star gets stuck near the black hole, orbiting it at a distance proportional to its original dis-



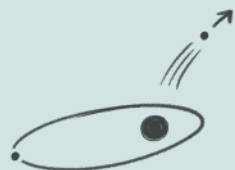
**HILLS MECHANISM** If a binary star system were to shoot by our galaxy's supermassive black hole, the black hole could tear the binary apart, keeping one star in orbit around itself and sending the other shooting away at an extreme velocity. This encounter, called the Hills mechanism, might explain how the S stars came to huddle around Sgr A\*.



- 1 Start with a stable binary star system, ignorant of the black hole.



- 2 An interaction (say, with a giant molecular cloud) deflects the binary toward the black hole. The binary shoots toward the black hole on a nearly straight-in path.

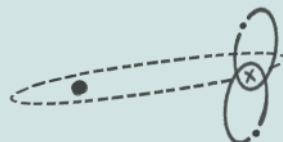


- 3 The black hole kicks one star out of the binary and takes its place. The switcheroo boosts the gravitational energy holding the new "binary system" together. The result is to widen the separation approximately 1,000x and also to eject the deposited star at 100s to 1,000s km/s.

**ECCENTRIC KOZAI-LIDOV EFFECT** In this three-body interaction, the black hole plays gravitational havoc on a binary star system that's orbiting it — the two stars' orbits around each other elongate and flip every which way. The elongation can bring the two stars dangerously close, ultimately causing them to merge and create a new, young-looking star.



- 1 Binary stars start out in an elongated orbit around the black hole.



- 2 The black hole's influence elongates the stars' orbits around each other, and the orbits flip around a lot with respect to the circuit around the black hole.



- 3 The two stars merge!



- 4 New, young-looking star orbits the black hole.



tance from its companion. The other is ejected at enormous speed — not only out of the galactic center but out of the Milky Way entirely.

Astronomers have found more than a dozen stars that might be these slingshotted suns. At hundreds of thousands of light-years from the galactic center, they don't have an obvious connection to the black hole. But like those in the S cluster they're B stars, and many are flying fast enough through space that our galaxy can't hold onto them. In fact, using Gaia data, Warren Brown (Smithsonian Astrophysical Observatory) and others recently determined that seven of the more than three dozen *hypervelocity stars* they studied are moving so fast that the only reasonable explanation is that they've been ejected from the galactic center by the supermassive black hole. The team suspects another nine stars might be members of same club.

Recent calculations by Smadar Naoz (University of California, Los Angeles) and colleagues suggest a different kind of binary-black hole encounter might be at work in the S cluster's creation. When three bodies interact, the gravitational influences become complicated. For two stars in a binary that's already orbiting the supermassive black hole, the black hole's influence will make the stars' orbits around each other elongate with time. This change moves their closest approach to each other even closer, potentially close enough that they merge — either by colliding or by getting stuck in a different orbit such that, when one or both stars ages and swells, the stars kiss and combine.

When stars merge, they reset their clocks. "It's like a total face-lift," she says. "They rejuvenate themselves."

Astronomers have seen at least one likely stellar merger unfold elsewhere in the galaxy, the star V1309 Scorpii. They've also detected mysteriously youthful stars known as *blue stragglers* in the ancient stellar balls called globular clusters, where starbirth died out eons ago. In some cases these blue stragglers are likely merger products.

#### peribothron, *n.*

An orbit's closest approach to a black hole. From the prefix *peri-* for closest and the Greek *bothros*, translations for which include "a hole or pit in the ground" and "cesspool."

Furthermore, binaries are common. A star of the Sun's mass has about a 50/50 chance of being born as a binary, and the chances are higher for massive stars like those in the galactic center. "So if you think that stars form the same way near the black hole — which of course is a big IF — then it's quite possible that the massive stars would form as binary stars," Ghez says. "And those binaries, when they're close to the black hole, can merge."

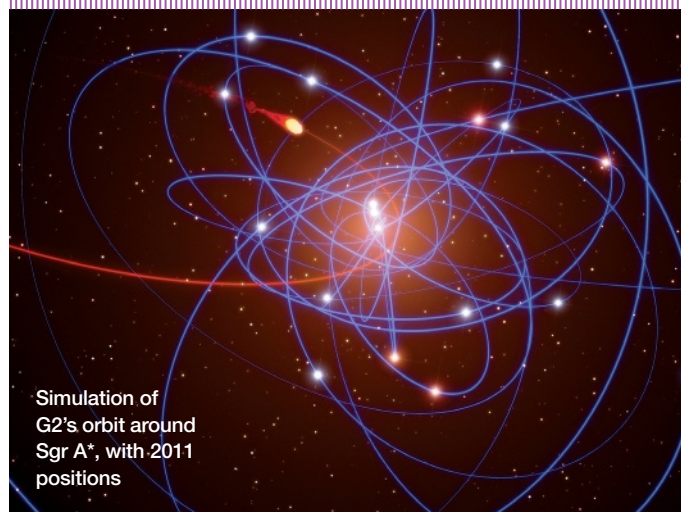
Naoz's student Alexander Stephan (University of California, Los Angeles), along with Naoz, Ghez, and their colleagues, decided to see how common mergers might be in the galactic center. Simulating more than a thousand binaries in the innermost 0.3 light-year, the team found that 13% of the binaries merged after a few million years. For those stars specifically in the S cluster region, the rate was even higher: About 40% had fused in the same time period.

This three-body merging process, called the *eccentric Kozai-Lidov* (EKL) mechanism, might explain why there are far more fledgling stars around Sgr A\* than expected. "If it's correct, [then] young stars in the S cluster actually belong to a way older population, as old as a billion years or so," Naoz says. The team is now looking at specific S stars to see if it can spot signs that indicate they're merger products.

### A Major Event

The disk of massive stars outside the S cluster is a different kettle of fish. The stars orbit too far from the black hole to be survivors of split-up binaries. Furthermore, out beyond one-third light-year, other things besides the black hole influence stars' motions.

Astronomers increasingly suspect that, despite the odds, these stars actually did form in place. If a big enough cloud of dense gas fell into the galactic center, the black hole's gravity would stretch the cloud into a long streamer and wrap the gas around itself like a pool noodle. As the gas came back around



## The Mysterious G Objects

The three-body interaction that Naoz and others are exploring might explain more than just the youthful S stars. The mechanism might also have created some strange sources near the black hole, called the G objects. These are red, dusty thingamajigs that might be stars ensconced in gas. The most famous is G2, which swung around Sgr A\* in 2013 and 2014, coming within 130 a.u. of it. Members of the UCLA group and their collaborators recently discovered three more, for a total of five.

Genzel, whose team discovered G2 in 2012, pleads agnosticism about these objects' nature. But Ghez is more willing to speculate. When two stars first merge, she says, the result is a red, dusty cocoon. This state lasts roughly a million years. It also happens to be a



► **FERMI BUBBLES** Spanning some 50,000 light-years from end to end, the Fermi bubbles were formed by one or more energetic events in our galaxy's core. The pink regions are based on gamma-ray data, the purple edges on X-ray observations. The bubbles are to scale.

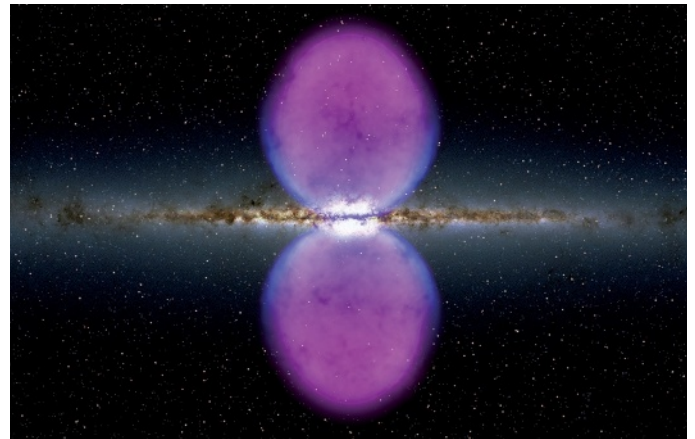
the bend, one end of the noodle would collide with the other. Collision begets shocks and compression in gas, which lead to little knots that collapse into stars.

Several simulations indicate that, with this method, star formation is plausible at the disk's location. Furthermore, this scenario might actually favor the birth of massive stars like those in the disk. When large amounts of gas pour onto a black hole, the stuff nearest the black hole forms a tutu around it and heats up due to internal friction. Work presented by Chris Frazer (University of North Carolina, Chapel Hill) at the American Astronomical Society meeting this past January suggests that the blazing glow from this accretion disk heats gas at much greater distances from the black hole. The radiation reaches all the way to where the OB disk lies, hundreds of times farther out than the accretion disk. Because gas generally needs to be cold in order to condense into stars, the radiation could affect star formation, warming things up enough that protostellar clumps would have to pack on more gas before they collapsed.

"The most startling point about this entire story — which we are all still dazzled about — is how robust this star-formation process actually is," Frazer says. "Even extreme radiation feedback doesn't appear to disrupt star formation."

The key to the OB disk's origin might be its age. Of the O stars, about half have already converted into Wolf-Rayet (WR) stars. WR stars are extremely hot, massive stars that spew out hefty winds of material. They're a short-lived stage of evolution for the largest stars, providing an accurate clock for when the disk's stars were born, Naoz says. Their presence indicates that the stars are about 5 to 6 million years old.

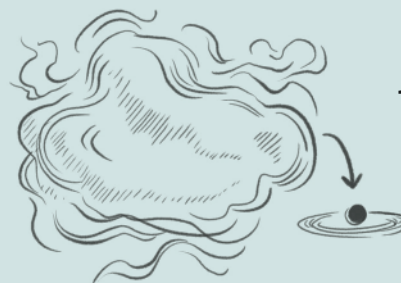
Another major event is thought to have happened in the galactic center around that time: the creation of the Fermi



bubbles (S&T: Apr. 2014, p. 26). Two gargantuan lobes that extend roughly 25,000 light-years above and below the Milky Way's disk, the Fermi bubbles were likely blown out by an energetic event, either an outburst from the black hole or a slew of star birth and death in its neighborhood.

"It's fascinating that the disk of stars is a comparable age," Ghez said during a recent talk at MIT. If a big gas cloud fell onto Sgr A\*, it would be natural for the cloud both to "wake up" the black hole by feeding it and to fragment into new stars. "I'm pretty convinced."

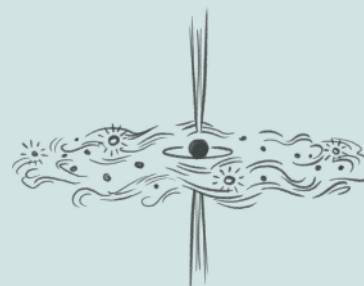
**ONE WAY TO MAKE THE OB DISK** Unlike the S cluster, the disk of OB stars likely formed in place, perhaps from a giant cloud of gas that accreted onto the black hole.



**1** Massive gas cloud falls onto black hole.



**2** Cloud forms gigantic disk around black hole.



**3** Disk feeds black hole, perhaps turning on jets, and forms a disk of stars.

good descriptor for G1 through G5 — and for many other objects in the galactic center. If the eccentric Kozai-Lidov (EKL) mechanism is forcing binary stars to merge, some of them would look exactly like the G objects, until they settled down to be S stars. Furthermore, binaries on bizarre, beeline-like routes like the ones G1 and G2 follow around Sgr A\* are the most susceptible to the EKL mechanism.

However, preliminary data suggest G3's orbit is fairly circular, which wouldn't favor a quick EKL-spurred merger. It could be that some G objects formed different ways. Furthermore, the EKL effect wouldn't explain how stars wind up on these strange orbits in the first place, a puzzle that remains bothersome.



Even if the OB disk isn't related to the current Fermi bubbles, its stars might produce a very similar structure in the future. Because the disk stars live such brief, brilliant existences, "quite a number of them are expected to explode more or less tomorrow," Genzel says. (By tomorrow, he means in the next few thousand years.) When they do, they'll throw out a lot of gas. "That could lead to a phenomenon like the Fermi bubbles."

### Close Encounters of the Stellar Kind

The brightest member of the S cluster is poised to reveal a lot about gravity in the galactic center. The star, called S2 by the Max Planck team and S02 by the UCLA team, is a 7-million-year-old B-type star that weighs about as much as a dozen Suns combined. It finishes its racetrack course around Sgr A\* every 16 years. During its closest approach it comes closer to the black hole than any other star yet detected: about 120 a.u. The latest pass was in May 2018.

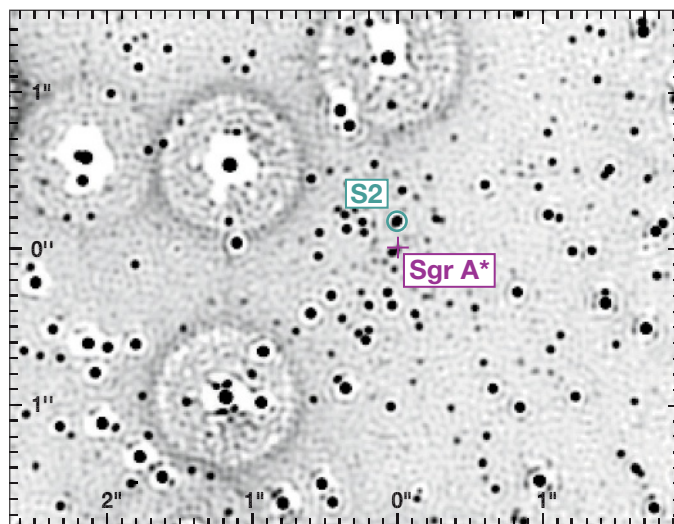
Ghez and Genzel each lead teams that have been watching S2 and its fellow S stars for more than two decades — Ghez with the W. M. Keck Observatory on Mauna Kea in Hawai'i, Genzel with the Very Large Telescope on Cerro Paranal in Chile. These stars scout out the gravity landscape around a supermassive black hole in a way that's never been probed before, Ghez explains.

"You're in unexplored turf," she says. "We know that ultimately we don't have the complete theory of gravity, so any of these tests [that] push the frontier . . . forward is very important. So everyone is extremely excited."

S2's flyby enables two tests of our current theory of gravity, general relativity. The first is *gravitational redshift*. As S2 bears down on the black hole, it dives further into the broad, deep well the black hole creates in spacetime. Its photons have to climb out of the well in order to reach us. This climb robs them of energy, shifting them to longer, redder wavelengths, manifesting as a dramatic swing of several thousand km/s in the star's velocity along our line of sight.

This shift happens in Newtonian gravity, too. But relativity adds something extra. The outer reaches of the

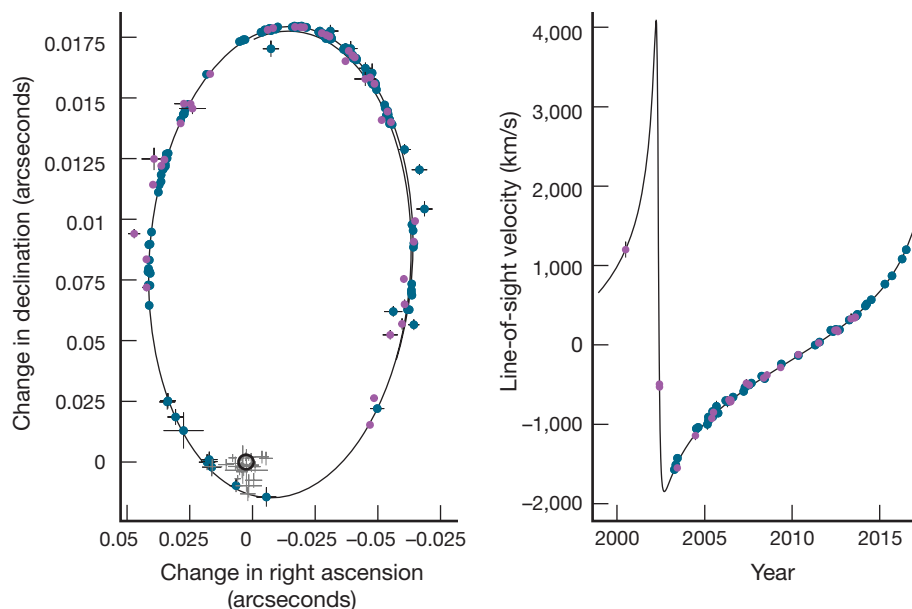
► **S2'S ORBIT** *Left:* Observations by the UCLA (purple) and Max Planck (blue) teams of S2's position over two decades trace out the star's orbit in the plane of the sky. The black circle marks Sgr A\*; gray crosshatches mark recorded flares. (No relativistic precession appears yet in these data; instead, the drawn orbit doesn't close due to motion with respect to the reference frame.) *Right:* When S2 completed its closest approach in 2002, two "turning points" appeared in a plot of its radial velocity: As the star swung around, its velocity along our line of sight quickly changed from a hasty retreat (positive values) to a headlong approach (negative values). The black line is the same orbit as on the left.



► **CROWDED** Adaptive optics reveals dozens of stars near Sgr A\* — including stellar interlopers that aren't physically near the black hole but invade the field of view. As stars move, they can overlap other ones from our perspective, as S2 does in this image. The region of sky shown spans roughly 4 arcseconds, about the size of Uranus in the sky. The light at the position of Sgr A\* could be from its gas or from an unrecognized star.

well look basically as they would in Newtonian physics, but farther in, relativity creates a distorted pit. When it enters this distorted region, S2's light loses more energy in its escape than it would otherwise, causing an additional redshift of about 250 km/s.

The redshift only shows up in the star's light right before and after its pass, appearing as two "turning points" in a plot of the star's radial velocity. One of these turning points happened at the beginning of May; the second should come at the end of September. At its peak the radial velocity will be changing by 100 km/s *per night*, Ghez says, due to both classical and relativistic effects. Both teams should have the





data they need to see the relativistic shift definitively by the end of 2018.

The second test S2 permits is that of *peribothron shift*, the movement of the star's closest point to the black hole. In general relativity, there are no closed orbits. Just as Mercury precesses around the Sun, drawing out cosmic Spirograph stencil patterns, so too do the S stars spiral around Sgr A\*. In S2's case, the precession is about 12 arc-minutes per orbit.

"Now *don't* think of the precession in this case as a sort of continuous motion of the orbit," Genzel warns. General relativity only matters close to the black hole, and S2 follows a very elongated orbit that has it spending most of its time beyond this region. "But when you are within half a year to a year of the peri, then that's when the 12-arcminute precession happens, almost all of it."

This measurement is immensely challenging. Images of the galactic center look like a polka-dot fabric. "Essentially everything is filled with stars," he says.

"And in this field of thousands of stars, *everything* is moving," Ghez says. Not only moving — orbiting. That adds multiple directions of motion to the problem, and because there's no clear coordinate system, it's all a big mess. Even with adaptive optics to combat the turbulence from Earth's atmosphere, astronomers are working at the limits of what 8- and 10-meter telescopes can do.

The German group is tackling this problem with a new interferometry instrument called Gravity. The instrument enables them to combine the four 8.2-meter telescopes of the Very Large Telescope in Chile into a single superscope, with an equivalent diameter of a whopping 130 meters. At near-infrared wavelengths, that boosts resolution by more than a factor of 10, enabling them to clearly see the star's motion from night to night.

The instrument has taken a decade and more than \$10 million to build, requiring all of the different telescopes' components to be aligned to about 5 nanometers. "That's something that does not come free, I can tell you that," Genzel laughs. But the payoff is worth it: They could see S2 moving night by night as it approached the black hole.

Gravity came online just in time for the researchers to watch the year or so leading up to S2's pass. They'll need a total of three

## Implications for LIGO?

Research into how the S stars formed might also help astronomers understand the origin of some of the black holes found with gravitational waves. The Milky Way's center contains the galaxy's most intense concentration of stars, and the same holds true for other galaxies. Since extremely massive stars turn into black holes when they die, astronomers expect a cadre of little black holes in galactic cores — and recent work by Charles Hailey (Columbia University) and colleagues suggests they're right: The team uncovered a dozen objects that might be black holes paired up with stars in the Milky Way's center, very close to where the *OB* disk lies (*S&T*: July 2018, p. 10).

Such small black holes could fall victim to the same eccentric Kozai-Lidov effect that might have created some of the S stars. Calculations by Naoz's student Bao-Minh Hoang (University of California, Los Angeles) and colleagues show that, if a pair of star-scale black holes loops around a galaxy's central supermassive one, the big black hole's gravity could force the binary members to merge. The process might create a fair number of the events gravitational-wave observations uncover.

years, with the peribothron in the middle, in order to triangulate the precession.

## Up Close and Personal

The S stars bring us within about 100 a.u. of Sgr A\*, some 1,000 times the radius of the event horizon. To get closer to the black hole, astronomers need to find more stars. Right now, they can see old, swollen red giants that are the Sun's mass or larger, but they can't see main-sequence stars that are much less than 10 solar masses, Ghez says. They know more stars are hiding beyond these detection limits.

A recent study by Idel Waisberg (Max Planck Institute for Extraterrestrial Physics, Germany), Genzel, and colleagues suggests that observers would need to find a star that approaches 10 times closer to Sgr A\* than S2 does in order to probe the way the black hole drags spacetime around as it spins. Given the odds of such a star existing (not high), they estimate that finding it would take several years of searching.

So to come closer, astronomers are placing their hopes in the Event Horizon Telescope, a worldwide network of radio telescopes that work together to create the equivalent of a planet-size dish (*S&T*: Feb. 2012, p. 20). In April 2017 the EHT integrated ALMA into its array and stared at Sgr A\* over several days, peering through the gas and dust hiding the black hole. The team is still working on the observations — it took the better part of a year to retrieve the data from the South Pole — but the image captured might show hints of the black hole's silhouette on the surrounding gas, delineated by a ring of light.

As astronomers dive deeper into the galactic center, they're finding connections to areas of study they never expected, not only to binary stars but also to how some of the stellar-mass black holes caught merging by gravitational-wave detectors might have formed (see sidebar). Coupled with the EHT and gravitational waves, the S stars are carrying us into a new regime of astrophysics, Ghez says. "We're in the era of gravity."

■ Much like the stars in this article, Science Editor CAMILLE M. CARLISLE is caught by the inexorable gravity of black holes. Find more adventures in her new blog, The Black Hole Files: <https://is.gd/bhfiles>.



## The Case Opens: A Strange But Uninteresting Star

Our story begins in the late 1800s. Invented in 1839, photography had advanced enough later in the century to become a new and exciting tool in astronomy. Like anyone with a new tool, astronomers wanted to explore what possibilities it offered.

With photography, astronomers could, for the first time, capture exactly what was visible through the telescope, rather than document their observations through writing or drawing. They could record stars to much fainter magnitudes than the eye could see and then take their time examining the results in the comfort of an office, even during daylight hours. Photography was also invaluable for building up a comprehensive and permanent reference for future study. It allowed for complete and accurate sky surveys, and yielded studies that could cover years or even decades.

Several observatories, including Harvard College Observatory in the United States and Sonneberg Observatory in Germany, performed all-sky surveys, beginning in 1885 and 1926, respectively, that led to important discoveries concerning stellar spectra and classification. These observa-

**But the most amazing thing was the spectrum — astronomers were amazed and aghast to find that it was completely featureless.**

tions were recorded in black-and-white on glass plates that could be fairly large, typically measuring 8 by 10 inches or even up to 14 by 17 inches, and sometimes contained tens of thousands of stars.

Photographic plates were particularly useful in the study of variable stars — comparing two or more plates of the same region at different times would render any variable object readily visible. Using this method, astronomers at both observatories started to find thousands of variable objects.

And so it was that the first part of our detective story starts. In 1929 German astronomer Cuno Hoffmeister at Sonneberg Observatory identified what he thought was a variable star in the small constellation of Lacerta, the Lizard. Following the standard naming convention for variable stars, it was designated BL Lacertae, or BL Lac for short.

Studies showed that BL Lac fluctuated on relatively short timescales between magnitudes 13 and 16 but with no discernible pattern, making it challenging to come up with a hypothesis to explain the variability.

In 1957 the great tome on variable stars *Geschichte und Literatur der Lichtwechsels des veränderlichen Sterne* was pub-

# The END



# ICMA

## that is BL Lacertae

Astronomers continue to fine-tune this long-standing cosmic detective story.



lished, compiling everything then known on these objects. Several entire pages were devoted to stars such as Mira and Algol, but only a few sentences mentioned BL Lac.

It seemed like this star would fade to obscurity; the case went cold for decades.

### Case Reopened

In the 1960s the burgeoning field of radio astronomy opened up a whole new “eye” on the sky, reaching the point where all-sky surveys could be carried out to some degree of positional accuracy. Radio astronomers began revealing a slew of interesting new objects, such as quasars — objects first thought to be radio stars but in 1963 discovered to be at cosmological distances (see *S&T*: Sept. 2013, p. 24). Then in 1968 astronomers discovered a strange point-like source. Its radio spectrum was relatively flat, with emission just as bright at low frequencies as at high ones. Moreover, the radio waves were polarized — when the vibrations of an electromagnetic wave are restricted, even partially, in one direction, so that there's less random orientation — indicating the presence of magnetic fields. Curiously, the source sometimes varied in brightness in a span as short as a few days.

Shortly thereafter, optical astronomers found that this radio source coincided positionally with BL Lac. Because no star had

▼ **HISTORIC HARVARD COLLEGE OBSERVATORY** This is the observatory as it appeared in 1899, well after the advent of the use of photography in astronomy. The largest dome on the right still houses the 15-inch “Great Refractor,” which is primarily used today for public observing nights ([cfa.harvard.edu/hco/grref.html](http://cfa.harvard.edu/hco/grref.html)).

## Could BL Lacs be black holes?

been discovered before with such peculiar radio properties, astronomers conducted a comprehensive visible-light campaign on this object. They confirmed historical observations that indicated the light curve varied by up to several magnitudes with no obvious pattern. Even stranger things were discovered, however. The visible light was also polarized, and the direction of the polarization varied, sometimes from day to day.

But the most amazing thing was the spectrum — astronomers were amazed and aghast to find that it was completely

featureless. Examining the spectrum was exactly like looking at a sheet of blank paper. It conveyed no information, preventing astronomers from learning about the true nature of BL Lac. The only thing they did know was that the spectrum was unlike anything they had observed before. There were some peculiar white dwarfs with spectra superficially similar to BL Lac's. However, photometric analysis ruled out the white dwarf scenario. But something else came up: To their surprise, astronomers noted that BL Lac fell close to quasars on

a *color-color diagram*, where the differences in brightness in several wavebands are plotted for comparison. This suggested that perhaps BL Lac was extragalactic. If it were truly at the distance of quasars, that would make it one of the brightest objects in the universe.

There was one problem with this line of inquiry. Without any emission or absorption lines in the spectrum, it was impossible to determine BL Lac's redshift and hence measure its distance. And, at the time, no other method for establishing cosmological distances was available.

One curious footnote to this flurry of observations was written when famed astronomer Halton Arp observed BL Lac using the 200-inch Mount Palomar reflector. He noted that BL Lac was not stellar in appearance and speculated that it might be a peculiar planetary nebula.

Curiouser and curiouser!

### Rounding up the Unusual Suspects

Astronomers knew that finding more candidates would help them in their investigations. They scoured variable star catalogs and identified many possibilities, but when they crosschecked against lists of radio sources none proved to be similar to BL Lac.

So they tried it the other way around. Astronomers searched through databases of radio sources and selected a sample with flat spectra and highly variable polarization, then compared their positions with those of known variable stars. This exercise proved quite fruitful. Soon they had identified about three dozen possible candidates.

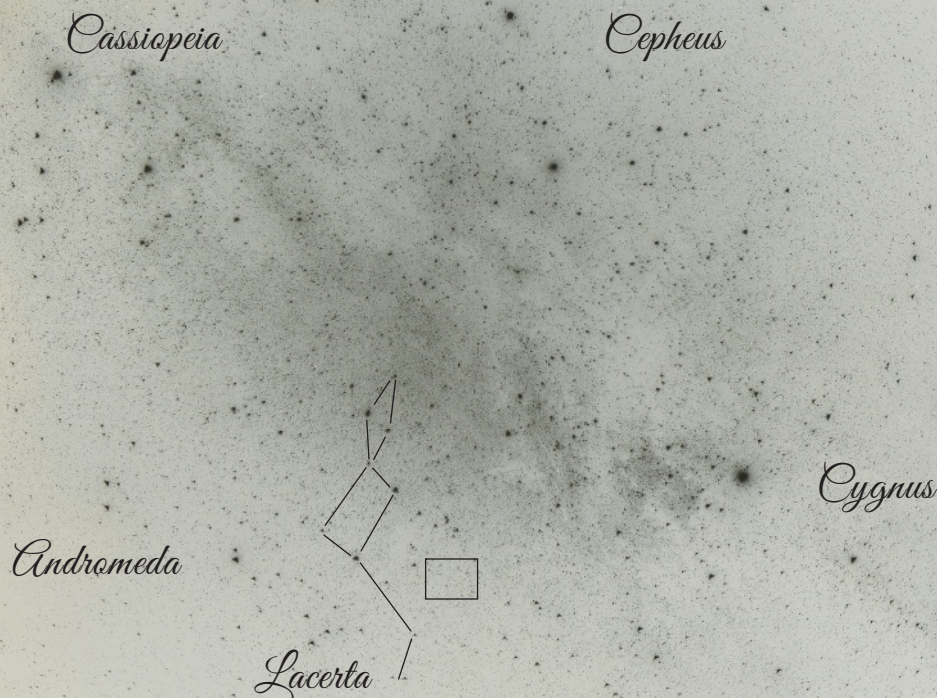
In the meantime, astronomers chomped at the bit to come up with an explanation for BL Lac. Three scenarios prevailed:

- If BL Lac were extragalactic, then one possibility was that it was a blueshifted quasar. Back when quasars were first identified, not everyone agreed they were at the great dis-





**FINDING BL LAC** Cuno Hoffmeister would have perused a plate very much like this one (taken by Harvard astronomers on the evening of November 1, 1934, in Oak Ridge, Massachusetts) when he discovered the “variable star” that turned out to be BL Lac (position approximated by the box).



tances their redshifts implied. Some astronomers searched for blueshifted quasars to counter the implied extragalactic distances of the redshifted ones. In fact, in 1967, Peter Strittmatter and Geoffrey Burbidge of UCSD proposed a set of properties to describe blueshifted quasars, and it turned out that BL Lac exhibited many of these.

- BL Lac might be an unusual planetary nebula, as had been suggested by Arp, amongst others.
- BL Lac was a black hole within our galaxy that was accreting matter. This theory, proposed in 1974 by Stuart Shapiro and James Elliot of Cornell University, fit just about everything observed in BL Lac.

But ultimately BL Lac’s nature depended on determining its distance, and in the 1960s and into the 1970s there was no reliable way of measuring this.

Then two astronomers came up with an interesting idea.

### Investigating the Crime Scene

James Edward Gunn and John Beverley Oke (both at Caltech) took on the challenge of determining BL Lac’s distance. They accepted that the spectrum was of no help due to the lack of emission or absorption lines. Instead, they proposed that BL Lac was the core of a galaxy. If this were the case, then perhaps they could devise some way of observing the galaxy itself.

The galaxy had to have been very faint, otherwise it would have been detected by now. Halton Arp’s earlier observations had hinted at an extension, but obtaining a spectrum of that faint outer region was challenging due to BL Lac’s overwhelming brightness.

In the early 1970s, Gunn and Oke used the largest telescope at the time, the Mount Palomar 200-inch Hale telescope, in order to collect as much light as possible. They fabricated a special mask that blocked the light from BL Lac but allowed the immediate surrounding region to shine



through. Using this method, they obtained a spectrum that revealed emission lines, the analysis of which suggested that they originated from a giant elliptical galaxy. Using these lines, they calculated BL Lac's redshift and determined that it corresponded to a distance of 1.1 billion light-years.

So BL Lac was indeed not only extragalactic but also at a great distance from our galaxy!

There then followed a series of back and forths between different observing groups using a variety of telescopes, including the 120-inch Shane reflector at Lick Observatory, that failed to reproduce the emission lines. A group using the Kitt Peak 84-inch reflector instead detected the presence of an elliptical galaxy. Subsequent observations by Gunn and Oke, again with the 200-inch Hale telescope, confirmed their earlier analyses. Gradually the community began to accept that BL Lac was indeed the core of a giant elliptical galaxy more than one billion light-years away.

Within a short time, astronomers determined the redshifts of several other objects similar to BL Lac using Gunn and Oke's masking technique. One extreme example was PKS 0735+178, discovered with the Parkes Radio Telescope in Australia. It was originally mistaken for a planetary nebula, but astronomers subsequently measured its distance: 8 billion light-years! All these sources sharing the observational properties of BL Lac collectively came to be known as "BL Lac Objects," or simply "BL Lacs."

## A Profile of the Unsub

So what are BL Lacs? This is what astronomers presumed they knew in the 1970s:

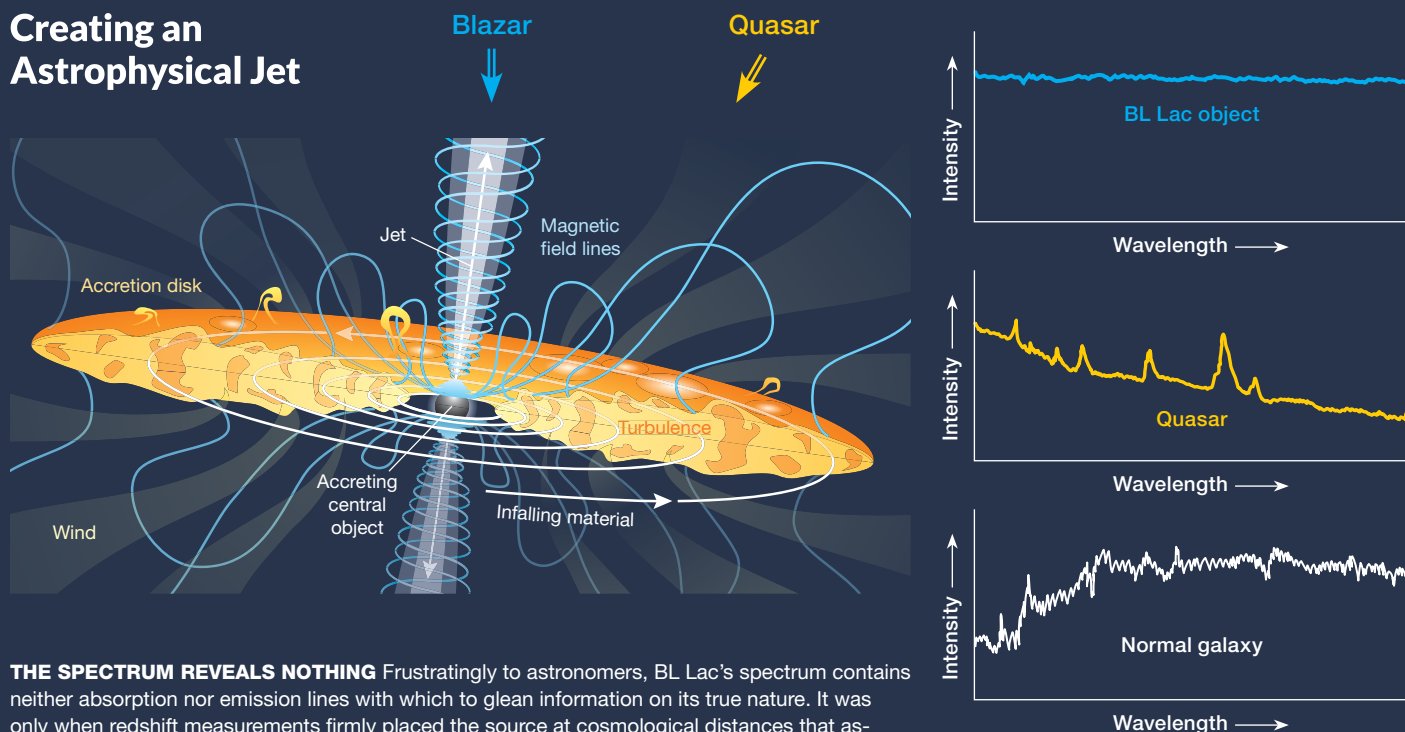
1. They are the cores of galaxies.
2. They lie at great distances from Earth.
3. At these great distances, they have to be the most luminous objects in the universe.
4. Their energy output varies frequently and irregularly.
5. Spectra of their cores display no lines, either in emission or in absorption.
6. Radio and optical emission is polarized, with the direction of the polarization varying on short timescales.
7. Energy pours out constantly.

So what type of object could explain all of this behavior? Astronomers went through the list of possible suspects and eliminated them one by one.

Stars could not be the source of this great outpouring of energy. BL Lac's spectrum precluded any known or postulated star. In fact, there were good arguments against such a star existing at all, given the known laws of physics. Normal stellar fusion processes could not produce the types of energy output seen from BL Lacs.

Astronomers also eliminated white dwarfs. Their energy output was minuscule in comparison, even at galactic dis-

## Creating an Astrophysical Jet



**THE SPECTRUM REVEALS NOTHING** Frustratingly to astronomers, BL Lac's spectrum contains neither absorption nor emission lines with which to glean information on its true nature. It was only when redshift measurements firmly placed the source at cosmological distances that astronomers grasped that BL Lac might be the shining core of a galaxy far away. The type of object observed — for example, blazar or quasar — depends on line of sight, as shown by the arrows.



tances. And while some unusual white dwarfs do exhibit flat spectra, none matched the spectra of BL Lacs. Neutron stars are also too faint and small. No theorist could fit the known properties of neutron stars to the characteristics of BL Lacs.

Could BL Lacs be black holes?

Remember that theory proposed in 1974 by Shapiro and Elliot of Cornell University? Well, it *did* fit just about everything regarding BL Lacs. But Shapiro and Elliot were considering black holes *within* our galaxy. BL Lac Objects were presumed to be the cores of distant galaxies — could they *actually* be black holes?

The problem was the extraordinary energy output arising from processes other than fusion, assuming astronomers were interpreting the spectra correctly. This implied a black hole with an unheard of, even unimaginable, mass. If BL Lacs were indeed black holes, they had to be the most massive objects in the universe. The energy output demanded this. And “very large mass” here means millions if not billions of suns.

Thanks to the work of Yakov Zel’dovich and Igor Novikov in the USSR, Edwin Salpeter in the U.S, and Donald Lynden-Bell in the UK, who each independently demonstrated that these gargantuan black holes were the only possible explanation for these enormous outpourings of energy, the idea began to take hold.

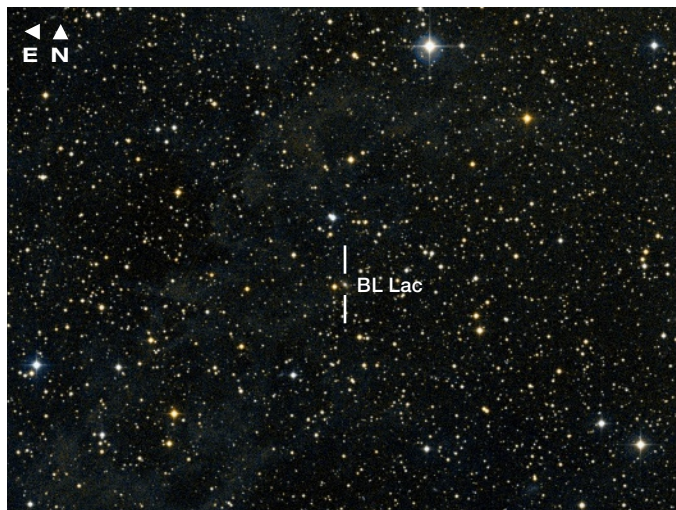
And this scenario fit the observations. In time, as the theory became established, these black holes at the centers of galaxies earned the moniker “supermassive” to denote their extraordinarily high masses (as opposed to “stellar-mass” black holes, which are generally the remnants of stars after supernovae events).

The model emerging from physics looked like this: BL Lac Objects are composed of a supermassive black hole gobbling up matter from its host galaxy. As this matter — gas, dust, and disrupted stars — approaches the supermassive black hole through a process known as *accretion*, it heats up as it swirls inward in a flat structure surrounding the black hole known as the “accretion disk.” Eventually, as the matter reaches maximal temperature near the black hole’s event horizon, it is ejected perpendicular to the disk, spewing out in highly relativistic jets.

These jets are threaded by magnetic field lines that twist, turn, and recombine. It’s this magnetic field that polarizes the jet’s radiation. As the magnetic field contorts, the polarization varies too, producing changes on timescales that can be as short as hours.

Eventually it dawned on astronomers that quasars and BL Lacs (and their cousins, *Seyfert galaxies*) are all galaxies at cosmological distances with central supermassive black holes and highly relativistic jets viewed from different angles.

Different components of the supermassive black hole/accretion disk/jets system contribute to the broadband spec-



▲ **A SPECK AMONG MANY** BL Lac appears distinctly star-like in this  $25' \times 20'$  field of view. It is therefore not surprising that in the 1920s astronomers originally thought the target was a star, and due to the frequent changes in brightness, it is even less surprising that they awarded it a variable star designation.

trum, which extends from radio wavelengths to high-energy gamma rays, to varying degrees depending on orientation. If the orientation is such that one of the jets is pointed directly at the observer along the line of sight, then the jet’s brightness swamps the radiation arising from any of the system’s other physical components, resulting in the featureless spectrum characteristic of BL Lac.

## Mystery Solved?

Since the seminal observations of the 1970s, BL Lac and its companions — collectively known as *blazars* — have been observed across the electromagnetic spectrum, from the radio to the very high-energy gamma rays, confirming the basic morphological structure of a supermassive black hole accreting matter from a host galaxy and subsequently ejecting this matter via relativistic jets. However, many questions still remain: How do supermassive black holes arise? How do jets form? How do black holes power jets? How do the magnetic field lines form and interact with their environment? Is there a limit to the power of accretion?

This is currently where we stand with this detective story. What will the next chapter look like? Only time will tell.

■ **DAVID NAKAMOTO** is an aerospace engineer who worked at JPL for two decades developing instruments and systems for Hubble, Galileo, etc. He’s been an amateur astronomer for almost 50 years and a Los Angeles Astronomical Society member since 1989. He can be reached at [dinakamoto@hotmail.com](mailto:dinakamoto@hotmail.com).

**FURTHER READING:** For more information on supermassive black holes, accretion disks, jets, and blazars, read “The Universal Jet Set” by C. Renée James in the April 2010 issue of *Sky & Telescope*. To find some of these blazars, see “Blazar, Blazar, Burning Bright” by Steve Gottlieb, in the same issue.



# Polar Alignment

## with Camera and Spreadsheet

Digital photography and a computer spreadsheet offer a new twist for precision polar alignment of equatorial telescopes.

Observers in the Northern Hemisphere enjoy having second-magnitude Polaris as an approximate guide to the north celestial pole when aligning an equatorial telescope mount.



One of the best-known methods for polar aligning an equatorial telescope mount, the drift method, dates back more than a century. At that time chemical photography was tedious, and only dreamers imagined machines doing complex mathematical calculations. Now, however, there's a new method for polar alignment that makes use of digital cameras and computers.

It's based on an image taken with a camera attached to a telescope mount and the polar axis turned while the shutter is open. The resulting image shows star trails that revolve around the exact point in the sky where the mount's polar axis is aimed. The user defines the rectangular coordinates (pixel locations) at the end points of three selected stars and enters them into a spreadsheet that calculates what, if any, altitude and azimuth adjustments to the mount's polar axis are necessary to align it with the celestial pole. These can be converted to the necessary number of turns of the mount's adjustment screws, thus allowing the user to approach the pole very directly without much trial and error. The spreadsheet and detailed instructions for use are available free at [sternwarte-nms.de/ext-links/downloads](http://sternwarte-nms.de/ext-links/downloads).

The method is easy to use, quantitative, and exact. In the calculation, an accuracy of 1 arcminute is attainable, corrected for the influence of atmospheric refraction. It is applicable both in the Northern and Southern Hemispheres, and it is nearly foolproof since faulty star-position measurements or incorrect star identifications produce an error warning.

A spreadsheet program such as Microsoft *Excel* or *Open Office* is required, and an image-processing program is recommended to determine the pixel coordinates at the end-

points of the star trails. The freeware program *Fitswork* ([fitswork.de](http://fitswork.de)) is very accurate for this purpose as it calculates the center of the point-spread function of the star images. And the user can transfer pixel coordinates to the spreadsheet using copy and paste.

It's also helpful to have a planetarium program to aid in identifying stars in your image and obtaining their right ascension and declination values, though the spreadsheet does provide data for a small selection of stars.

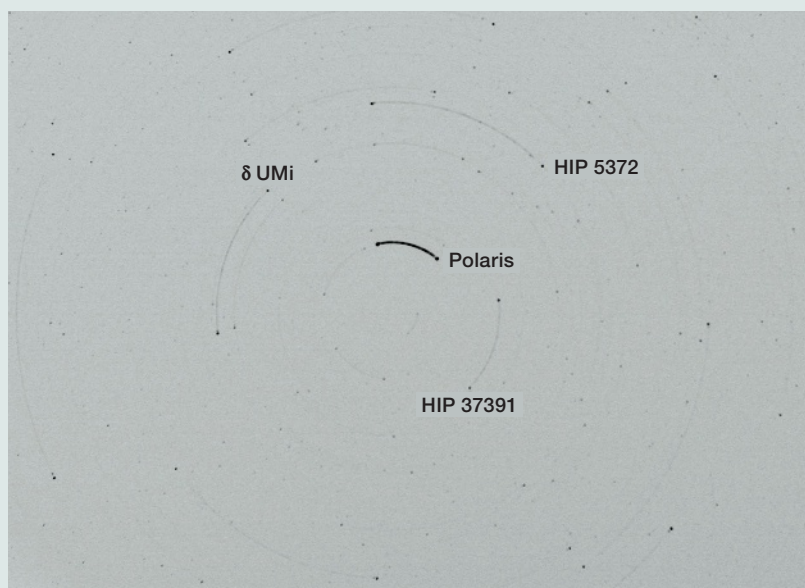


▲ To make the photograph used for the alignment process, you can attach the camera anywhere on the telescope tube or moving parts of the mount and point it toward the celestial pole. A sturdy camera mount is highly recommended.

## Photography and Evaluation

To make the necessary star-trail image, you need to attach a digital camera with a standard or a short telephoto lens to your equatorial mount or telescope tube and direct it at the celestial pole. I recommend first taking a static image to help with identifying stars — for example, a 15-second exposure at f/4 and ISO 1600.

Next you make a time exposure while rotating the polar axis. It's best to begin and end this image with a few seconds of static exposure to clearly mark the star positions. In other words, open the shutter, wait a few seconds before starting



▲ Left: As explained in the accompanying text, data for the spreadsheet is obtained by measuring star positions at the ends of trails made by rotating the mount's polar axis while the camera shutter is open. Right: The author's spreadsheet calculates the amount of altitude and azimuth adjustment of the mount's polar axis needed to align it with the celestial pole. Detailed instructions for using the spreadsheet are included when the free spreadsheet is downloaded.

1	Polar alignment with a rotating camera							
2	Polar alignment of an equatorial mounting using a star trail image from a rotating camera							
3	Release 3.0							
4								
5	Juergen Kahlhoefer, Sternwarte der Volkshochschule Neumuenster, Germany							
6	juergen.kahlhoefer@sternwarte-nms.de							
7								
8	constants:	pi/180 =	0.017453293	180/pi =	57.29577951			
9								
10	color code:	yellow	input of current data					
11		orange	input of standard data					
12		purple	results					
13		red	error index, error message					
14								
15	For calculation of hour angle from right ascension, enter the data of a reference star for a							
16	specified location and time. (Read data from a planetarium program, e.g. „Stellarium“)							
17	location	longitude*	date	time	ref. star	RA (h.m.s)	hour angle	
18	Solingen	7.06	02.08.2013	23.00	beta UMi	14:50.41	03:24.01	
19	time difference from UT (hours):							
20	2							
21	(+ for eastern / - for western time zones)							
22								
23	Star trail image:		moment of exposure		Observatory	longitude	latitude	
24	photographer	image (no.)	date	time	location	(E +  W  - (N +  S  -		
25	jk	4149	11.08.2013	23.52	Menzelstr.	10.014	54.064	
26	time difference from UT (hours):							
27	2							
28	(+ for eastern / - for western time zones)							
29								
30	X and Y coordinates of 3 stars at both ends of their trails							
31	(X and Y axes at right angles, orientation and scale arbitrary)							
32	Star	RA (h.m.s)	declination	X1	Y1	X2	Y2	
33	delta UMi	17:27.59	86.577	792.59	1802.85	981.11	1254.24	
34	HIP 5372	01:10.49	86.328	1374.89	936.26	2019.44	1171.5	
35	HIP 37391	07:46.17	86.986	1852.8	1677.61	1744.06	2608.2	
36								
37	required correction of azimuth (deg)					1.23 (+ go east, - go west)		
38	required correction of polar altitude (deg)					0.82 (+ higher, - lower)		
39								
40	combined error index:		0.20		-)			
41								
42	An error message before completion of all inputs is meaningless.							



# Quest for the North Pole

If the title here conjures thoughts of snow, ice, bitter cold, and dog sleds, don't worry, there are no dog sleds involved. The prize sought in this adventure is the north celestial, not terrestrial, pole.

Like several generations of amateur astronomers, I've turned to the diagram in *Burnham's Celestial Handbook* when I've wanted the accurate location of the north celestial pole among the stars. Robert Burnham's chart, reproduced at right, details more than 300 years of the pole's precessional drift through Ursa Minor (the Little Dipper). The chart's limiting magnitude and image scale have always been sufficient for my needs, which typically involved my efforts to accurately align equatorial telescope mounts.

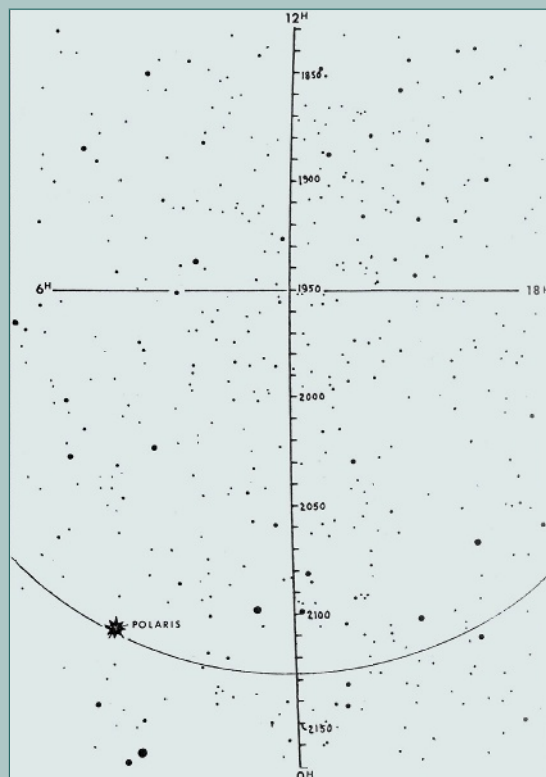
Several years ago I began testing computerized mounts and software that offered precision alignment routines. And that got me wondering about the accuracy of Burnham's hand-drafted chart done half a century ago. With a bit of effort I convinced myself that the chart is, indeed, very accurate, but the story didn't end there. In the process I stumbled upon something unexpected that bears directly on how accurately most amateur equatorial mounts can be aligned. Here's how it happened.

One good way to determine the exact

location of the celestial pole is to use a fixed camera to make a time exposure of the sky and note the point that the stars appear to revolve around. Digital photography has made it easier than ever to create one of these classic images, but the devil is in the details. A standard camera lens lacks the resolution and magnitude reach to pinpoint the celestial pole as accurately as it's shown on Burnham's chart. The best solution is to use a telescope in place of a conventional camera lens.

During a moonless spell in December 2011 I did just that when the long, cold winter nights offered more than 12 hours of astronomical darkness. I set up a DSLR camera attached to an 85-mm f/7 refractor on my elevated wooden deck. The camera body was attached to a sturdy tripod, and the front of the telescope rested on the deck's railing for additional support. The camera made 30-second exposures every 5 minutes throughout the night. But when the images were composited together in the morning, the stars didn't appear to move in anything resembling smooth circles. It turns out my deck was gyrating like a hula dancer during the night.

So I repeated the process with the telescope solidly attached to a German equatorial mount in my observatory. It seemed like overkill since the mount was only acting as a fixed support for the scope and camera (the drive was off). This time the composite image created smooth star "trails" that allowed me to pinpoint the pole's location well enough to verify the accuracy of Burnham's chart. But here's the rub — on close inspection the trails were not exactly circular. Once again the camera and scope had moved during the night, and the reason why was only obvious in hindsight. Thermal contraction of the mount and



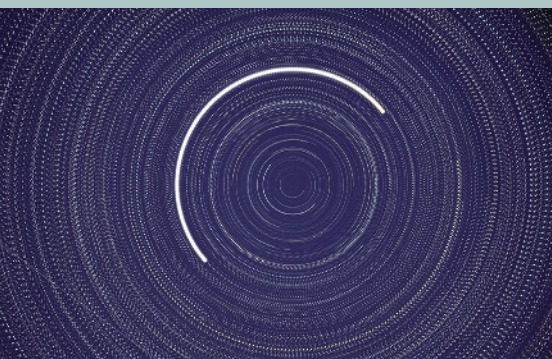
PATH OF THE NORTH POLE from 1850 to 2150 AD. The portion of the circle is 1° in radius, centered on the position for 1950.

▲ Drafted by Robert Burnham, Jr., for his classic *Celestial Handbook*, this chart of the north celestial pole's precessional drift among the stars of the Little Dipper has served amateur astronomy for nearly half a century.

steel pier had shifted everything, including the mount's polar alignment, by nearly an arcminute during the exposures. And while situations vary, this likely happens to some degree with all telescope mounts.

In practice such a slow, small shift of polar alignment during the night is of no concern. But it does raise the question of how accurately a mount can be polar aligned. Adjusting the position of a computerized mount and having software report that your alignment is within a few arcseconds of the celestial pole may be very satisfying, but it's likely true only for the current conditions. Metal expands and contracts as the temperature changes, and any supporting material involving wood can also vary with the humidity. These small changes aren't big problems, but they do serve as reminders for those of us trying to tweak a polar alignment to within a few arcseconds of the celestial pole. At best, achieving a "perfect" alignment is a fleeting success story.

**Dennis di Cicco**



▲ In order to assess the accuracy of Burnham's polar chart, Dennis di Cicco made this 12-hour star-trail image of the north celestial pole in December 2011 shooting through an 85-mm f/7 refractor. While it did verify the accuracy of Burnham's chart, it also revealed an unexpected aspect of most telescope mounts, which is explained in the accompanying sidebar.



to slowly turn the polar axis through an angle of at least  $30^\circ$ , and wait a few more seconds after you stop turning the axis before closing the shutter. It's also possible to use two static exposures made before and after you turn the polar axis, but you must be careful if you touch the camera not to disturb its position between the exposures.

The spreadsheet was developed in *Open Office* and converted to *Excel* format. An overview of the mathematics is given in the instructions that you download with the spreadsheet.

Two stars would be sufficient for the calculation of the center of rotation in the star-trail image and its deviation from the celestial pole. But with three stars the accuracy improves. Moreover, three stars offer a way to check the input data, since the angles of a triangle formed by the stars in the image should be similar to those of the triangle in the sky. If there was an error in the identification of a star or a faulty coordinate entered in the spreadsheet, the angles would not match.

### Practical Experience

From where we live in the Northern Hemisphere (Germany), my colleagues and I have successfully aligned multiple telescope mounts to the celestial pole with this method. Analysis shows the method to be accurate to about  $0.01^\circ$ .

An important precondition for good results is the rigidity of the camera support and the stability of the mount itself. In one case we had two cameras on the telescope at the same time. One camera was mounted on a small ball head, and its results differed significantly from those of the other camera

mounted on a solid wooden support. I'd rather trust the latter. Stability of the lens is another critical point. The focusing mechanism should have no play, and a lens with a fixed focal length may be better than a zoom lens.

When all precautions have been taken to make a good image and an exact evaluation, it is highly desirable to make the necessary adjustment to the altitude and azimuth of the mount's polar axis with the same degree of accuracy. But this is not always easily done. A heavy mounting may have jerky movements, and it may be difficult to hit the target exactly. Or the alignment can change in unexpected directions when the mount's screws are tightened.

If the mounting has no calibration marks on its adjustment screws for the altitude and azimuth, the spreadsheet can give some support by conversion of the necessary corrections to the number of turns of the screws. But you may want to monitor the corrections by watching a star in a calibrated reticle eyepiece. In any case, you can make a new star-trail image after the corrections to verify the result.

So far we have had no opportunity to use this method in the Southern Hemisphere, but it should be applicable there too. I welcome feedback from other users, especially those in the Southern Hemisphere.

■ **JÜRGEN KAHLHÖFER** is retired from a career as a medical physicist in radiotherapy and nuclear medicine. He is currently a board member of the observatory of the adult education center in Neumünster, Germany, and can be reached at **juergen.kahlhoefer@web.de**.

▼ Digital photography has made it easier than ever to create a classic fixed-camera image showing stars circling the celestial pole, as in this example made during the 2011 annual Stellafane convention in Springfield, Vermont. A similar image made by rotating the camera on an equatorial mount's polar axis serves as the data source for the author's polar-alignment spreadsheet.



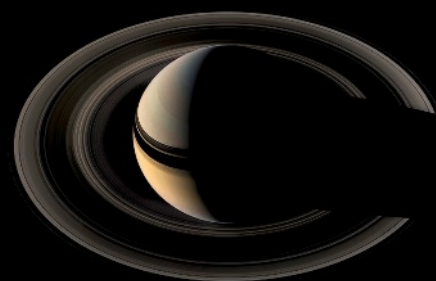




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**1 DUSK:** After sunset, Venus and Spica form a pretty pair a little more than  $1^\circ$  apart in the west-southwest. The duo anchors a graceful arc of planets that stretches to Mars in the southeast, with Jupiter and Saturn along the way.

**5 DAWN:** At northern latitudes, the zodiacal light is visible in the east beginning some two hours before morning twilight. Look for a tall pyramid of dim light tilted toward the right. If you can find a dark viewing spot, you might see this phenomenon over the next two weeks.

**5-6 DAWN:** Mercury poses in the east  $1\frac{1}{2}^\circ$  above Regulus in Leo before the Sun rises. Look for the tiny but bright planet to the left of the star the following morning. Binoculars help.

**7 EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:29 p.m. EDT.

**13 DUSK:** The waxing crescent Moon, Jupiter, and Alpha ( $\alpha$ ) Librae, or Zubenelgenubi, form an almost perfect equilateral triangle with sides some  $4^\circ$  long in the hours after sunset.

**15 EVENING:** Look toward the southwest to see the Moon, one day shy of first quarter, hanging some  $8^\circ$  above Antares and flanked by regal Jupiter and ringed Saturn.

**16-17 EVENING:** On the 16th the first-quarter Moon has crept up on Saturn and sits  $8^\circ$  right of the ringed planet; the following evening the Moon has leapfrogged over the planet and now poses  $4\frac{1}{2}^\circ$  to Saturn's left.

**19 EVENING:** Continuing its trek eastward, a fattening Moon visits Mars and hovers some  $4^\circ$  above the burnished planet. Follow this duo as they set together in the west-southwest.

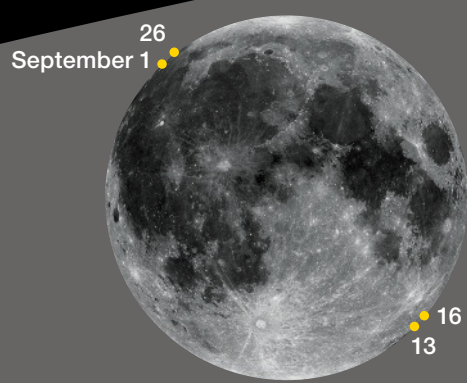
**22 AUTUMN BEGINS** in the Northern Hemisphere at the equinox, 9:54 p.m. EDT.

**27-28 NIGHT:** Algol shines at minimum brightness for roughly two hours centered on 9:09 p.m. PDT (00:09 a.m. EDT).

**30 NIGHT:** The waxing gibbous Moon rises in the late evening, soon followed by Aldebaran. Less than  $1^\circ$  separates the pair by midnight local time.

This recent image of Messier 8, or the Lagoon Nebula, was taken during February 12-18, 2018, using the Hubble Telescope's Wide Field Camera. The nebula itself is some 55 by 20 light-years, but the image here only shows an area spanning some 4 light-years. NASA / ESA / STSCI





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

MOON PHASES

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

**LAST QUARTER**  
September 3  
02:37 UT

**NEW MOON**  
September 9  
18:01 UT

**FIRST QUARTER**  
September 16  
23:15 UT

**FULL MOON**  
September 25  
02:52 UT

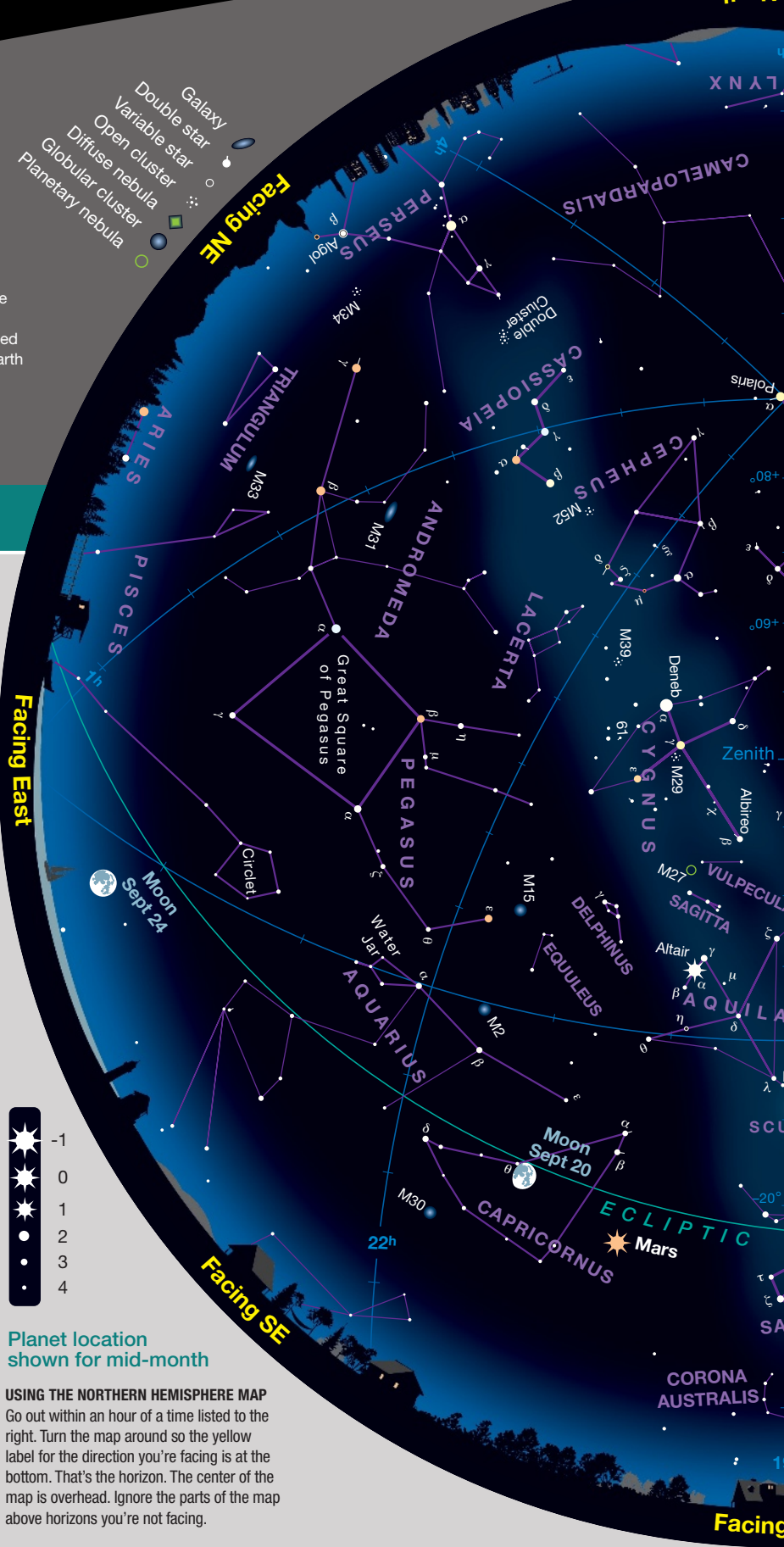
DISTANCES

Perigee	September 8, 01 <sup>h</sup> UT
361,351 km	Diameter 33' 04"
Apogee	September 20, 01 <sup>h</sup> UT
404,876 km	Diameter 29' 31"

FAVORABLE LIBRATIONS

- |                     |              |
|---------------------|--------------|
| • Galvani Crater    | September 1  |
| • Peirescius Crater | September 13 |
| • Hamilton Crater   | September 16 |
| • Xenophanes Crater | September 26 |

- Double star
- Galaxy
- Variable star
- Open cluster
- Diffuse nebula
- Globular cluster
- Planetary nebula



Planet location shown for mid-month

**USING THE NORTHERN HEMISPHERE MAP**  
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.





**Binocular Highlight** by Mathew Wedel

## A Peek Behind the Curtain

**A** drum that I happily bang in my public talks is that if you want to understand the large-scale structure of our galaxy, binoculars are often more useful than a telescope. The vast dust lanes and star clouds that spangle the Milky Way from Cygnus to Scorpius — and beyond, if you can get far enough south — are mostly too big to appreciate in all but the richest-field telescopes.

The **Scutum Star Cloud** is a prime example. Neatly framed between Beta (β) Scuti and Epsilon (ε) Scuti, the densest part of the cloud is about 3.5° across. A lot of small scopes will show that much, but to fully appreciate the Scutum Star Cloud you need to take in more sky. To the southeast, the star cloud fades gently into the rich star fields of the Milky Way. But to the north and west, the cloud cuts off abruptly, as if it had suddenly run out of stars. The sharp cutoff is particularly pronounced on the northeast edge of the cloud, where the sickle-shaped dark nebula B111 lies immediately north of M11, the Wild Duck Cluster.

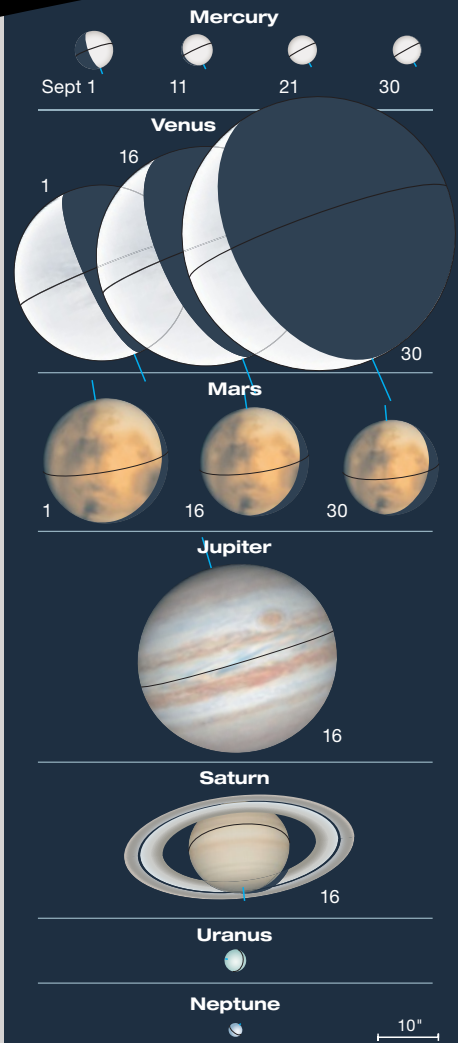
Dark nebulae exemplify the mind-bending reality of the inner Milky Way: The darkness is a *thing*, clouds of dust in the foreground of our view, and the bright blaze of the galaxy mostly represents the more distant swarms of stars that populate the inner spiral arms and galactic bulge. We see the Scutum Star Cloud not because it's intruding into our view against a dark background, but because chance has pulled back the curtain of dust to give us a glimpse of the glories beyond. It's a vertiginous view, but falling in can't hurt you, so I say take the plunge.

■ Just once, **MATT WEDEL** would like to observe the Milky Way with no dust in the way. And as long as he's dreaming, he'd like a pony.

### WHEN TO USE THE MAP

Late July	Midnight*
Early Aug	11 p.m.*
Late Aug	10 p.m.*
Early Sept	9 p.m.*
Late Sept	Nightfall
*Daylight-saving time	





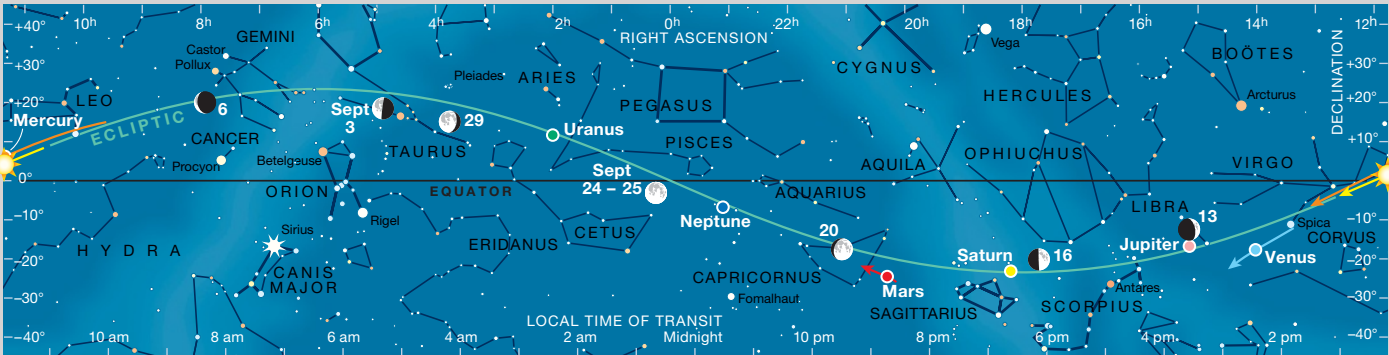
**PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

**PLANET VISIBILITY** **Mercury:** visible at dawn through the 11th • **Venus:** visible at dusk • **Mars:** visible at dusk, highest before midnight • **Jupiter:** visible at dusk, sets early evening • **Saturn:** highest at dusk, sets near midnight

September Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	10 <sup>h</sup> 39.6 <sup>m</sup>	+8° 28'	—	−26.8	31' 42"	—	1.009
	30	12 <sup>h</sup> 24.0 <sup>m</sup>	−2° 36'	—	−26.8	31' 56"	—	1.002
Mercury	1	9 <sup>h</sup> 35.8 <sup>m</sup>	+15° 04'	17° Mo	−0.8	6.4"	65%	1.056
	11	10 <sup>h</sup> 44.4 <sup>m</sup>	+9° 55'	9° Mo	−1.4	5.3"	93%	1.280
	21	11 <sup>h</sup> 53.8 <sup>m</sup>	+2° 19'	2° Ev	−1.8	4.8"	100%	1.387
Venus	30	12 <sup>h</sup> 50.7 <sup>m</sup>	−4° 42'	7° Ev	−1.0	4.8"	98%	1.407
	1	13 <sup>h</sup> 21.2 <sup>m</sup>	−12° 01'	45° Ev	−4.6	29.1"	40%	0.572
	11	13 <sup>h</sup> 48.5 <sup>m</sup>	−15° 58'	43° Ev	−4.7	33.6"	34%	0.496
Mars	21	14 <sup>h</sup> 09.9 <sup>m</sup>	−19° 11'	39° Ev	−4.8	39.3"	26%	0.425
	30	14 <sup>h</sup> 21.1 <sup>m</sup>	−21° 10'	34° Ev	−4.8	45.5"	18%	0.367
Jupiter	1	20 <sup>h</sup> 07.5 <sup>m</sup>	−26° 00'	140° Ev	−2.1	20.9"	94%	0.449
	16	20 <sup>h</sup> 16.7 <sup>m</sup>	−24° 38'	128° Ev	−1.7	18.2"	91%	0.514
	30	20 <sup>h</sup> 34.8 <sup>m</sup>	−22° 46'	119° Ev	−1.3	16.0"	89%	0.587
Saturn	1	14 <sup>h</sup> 58.8 <sup>m</sup>	−16° 04'	69° Ev	−1.9	34.8"	99%	5.668
	30	15 <sup>h</sup> 17.7 <sup>m</sup>	−17° 26'	45° Ev	−1.8	32.7"	100%	6.035
Uranus	1	18 <sup>h</sup> 10.0 <sup>m</sup>	−22° 42'	114° Ev	+0.4	17.3"	100%	9.611
	30	18 <sup>h</sup> 11.9 <sup>m</sup>	−22° 46'	86° Ev	+0.5	16.5"	100%	10.080
Neptune	16	1 <sup>h</sup> 58.9 <sup>m</sup>	+11° 32'	141° Mo	+5.7	3.7"	100%	19.081
Neptune	16	23 <sup>h</sup> 04.8 <sup>m</sup>	−6° 59'	172° Ev	+7.8	2.4"	100%	28.945

The table above gives each object's right ascension and declination (equinox 2000.0) at 0<sup>h</sup> Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see [skyandtelescope.com/almanac](http://skyandtelescope.com/almanac).



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



# Harvesting the Autumn Skies

Be prepared to gaze in wonder upon September's diaphanous delights.

In September you have to observe right after nightfall to catch the Sagittarius Milky Way at its highest. But there's more than just our galaxy's glow to enjoy on September evenings. Those skies offer us a generous helping of virtually every kind of deep-sky object possible.

**September's star clouds and diffuse nebulae.** Many patches of brighter naked-eye radiance shine along the so-called summer Milky Way. Six that are both prominent and well-known are: the Cygnus Star Cloud, the Scutum Star Cloud, the Large Sagittarius Star Cloud, the Small Sagittarius Star Cloud (M24), the Lagoon Nebula (M8), and the big open star cluster M7. The next of these bright naked-eye patches is an impressively intense one that seems to have escaped naming and therefore fame. A few years back in this column I dubbed it both the Gamma Scuti Star Cloud and also a name befitting its mysteriousness: "the Seventh Glow."

The Seventh Glow forms a compact equilateral triangle with two famous Messier nebulae that require optical aid to see properly. One of these is M16, the Eagle Nebula or Star Queen Nebula, of Hubble Space Telescope photographic fame with its "Pillars of Creation." The other is M17, most often called the Omega Nebula, but also variously known as the Swan Nebula, Horseshoe Nebula, and Checkmark Nebula (see Howard Banich's *Going Deep* column, *S&T*: Sept. 2017, p. 57). The triangle of M16, M17, and the Seventh Glow is only about  $2\frac{1}{2}^\circ$  to a side and yet each of the three is in a different constellation — Serpens (M16), Sagittarius (M17), and Scutum (the Seventh Glow star cloud).

**September's strip of planetary nebulae and a poignant supernova remnant.** I always find it remarkable that the two most famous and prominent planetary nebulae, along with

two other notable planetaries, are all located within a surprisingly small strip of the heavens. M57, the Ring Nebula in Lyra, and M27, the Dumbbell Nebula in Vulpecula, lie on a line with the renowned double star Albireo, or Beta ( $\beta$ ) Cygni, which shines about midway between them. Considerably farther to the southeast are the other planetaries, both in Aquarius: the small, intense Saturn Nebula (NGC 7009) and the great-in-total-brightness but huge and thus low surface brightness Helix

evenings every major globular from late spring's M3 and M5 to autumn's M15 and M2 is reasonably well placed. Fine open clusters for September evenings include M11 (midway up the sky); M6, M7, and M25 (fairly low but quite visible); M39 (high); and the Double Cluster in Perseus (still pretty low but climbing). Summer and winter are poor seasons for galaxies other than our Milky Way, but by September the visually greatest external galaxy, M31, is high enough for good evening views.



Nebula (NGC 7293). Of the sky's finest planetaries, others can be found in this general region of the heavens — for instance, NGC 6826, the Blinking Planetary, in Cygnus.

Near the other wing of Cygnus, the Swan, is a stellar aftermath more ancient than the planetary nebulae, one formed from a much mightier stellar demise. It's a supernova remnant, its arcs and shreds of radiance forming the roughly  $3^\circ$ -wide Cygnus Loop. The easiest section of the Loop to find is NGC 6960, the Veil Nebula.

**September's globulars galore — but also key open clusters and a galaxy.** Summer is the great season of globular star clusters, but on September

**Red, double, variable stars, and more.** September brings us great views of red Mu ( $\mu$ ) Cephei (Herschel's Garnet Star); Epsilon ( $\epsilon$ ) Lyrae (the Double Double) and Albireo; Delta ( $\delta$ ) Cephei and Rasalgethi (both stars that are fascinating variable stars *and* colorful doubles). There's a dearth of very bright stars at the time of our all-sky map: The only ones of 1st-magnitude or brighter are Arcturus, Vega, Altair, Deneb, and Antares. But at least this year Venus, Jupiter, Saturn, and Mars all help brighten our September evenings.

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To find out what's visible in the sky from your location, go to [skypub.com/almanac](http://skypub.com/almanac).

# Autumn Arrives

As summer gives way to fall, lengthening nights offer planet-spotting from dusk to dawn.

In these September dusks, Venus flames up to maximum brightness but moves deeper into the Sun's afterglow with each passing week. Jupiter is upper left of Venus, and the gap between them shrinks until late in the month. Around nightfall, Saturn is at its highest in the south and the fading-but-still-brilliant Mars is in the south-southeast. At dawn, Mercury is visible only early in September.

## DUSK AND EARLY EVENING

Venus was at greatest eastern elongation on August 17th but as September

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

progresses becomes quite poorly placed for viewing at mid-northern latitudes. The sunset altitude of the planet drops from about 15° to 7° during September for observers around latitude 40° north. The interval between sunset and Venus-set dwindles from roughly 85 minutes to 45 minutes. But at least the resplendent planet brightens from -4.6 to an even more dazzling -4.8. The phase of Venus narrows from 40% to 17% in September while its apparent size grows from about 29" to 46".

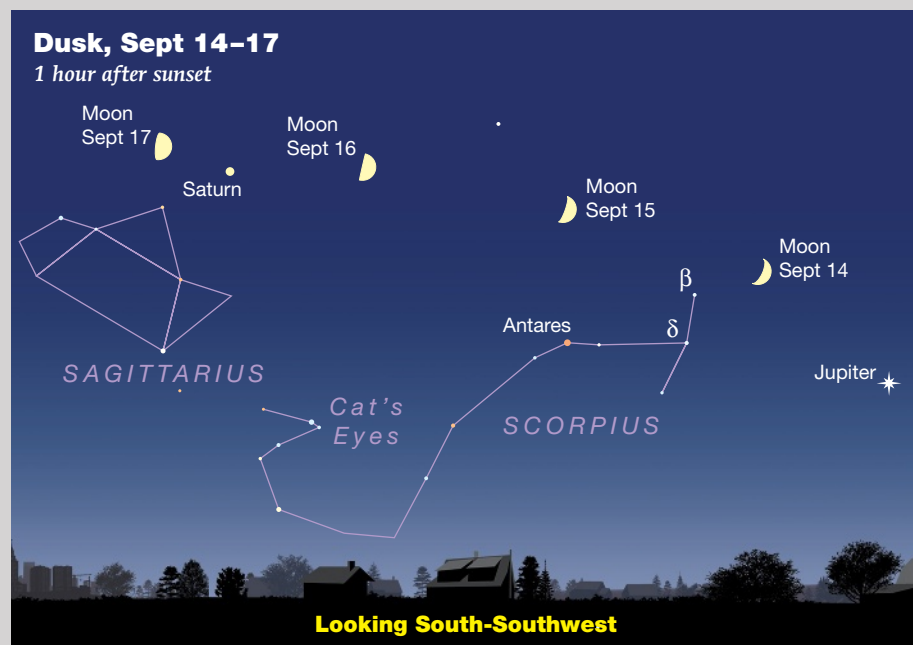
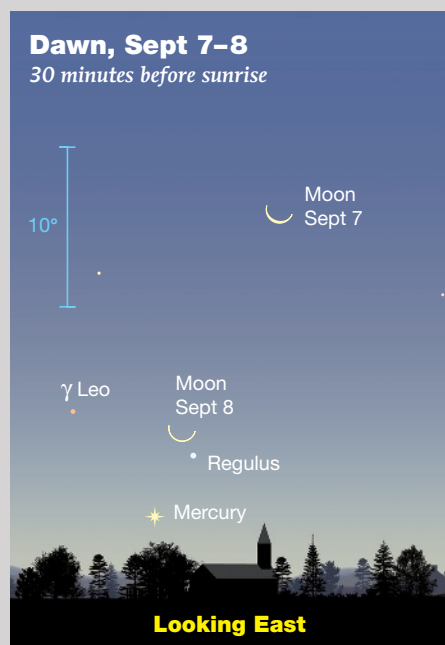
On September 1st Venus is only about 1½° lower left of Spica (binoculars help to see the star). Venus is more than 23° lower right of Jupiter but closes the gap in the next few weeks. Late in the month, however, the eastward motion of Venus slows drastically as it starts to come "around the corner" of the near side of its orbit. On the

evenings of September 27–29, Venus and Jupiter will be at a minimum separation of less than 14°.

Jupiter is very much dimmer than Venus this month, and its radiance diminishes from magnitude -1.9 to -1.8. Jupiter begins September a little more than 2° upper left of Alpha (α) Librae (Zubenelgenubi) but is moving eastward, away from the double star. Jupiter's disk appears less than 33" wide by late September. The planet sets around 10:15 p.m. as September opens and a bit less than 2 hours earlier as the month closes.

## DUSK TO AFTER MIDNIGHT

Saturn shines at magnitude +0.4 to +0.5 this month. It's at its highest in mid-twilight in early September. On September 6th, Saturn halts its retrograde (westward) motion 2° above or

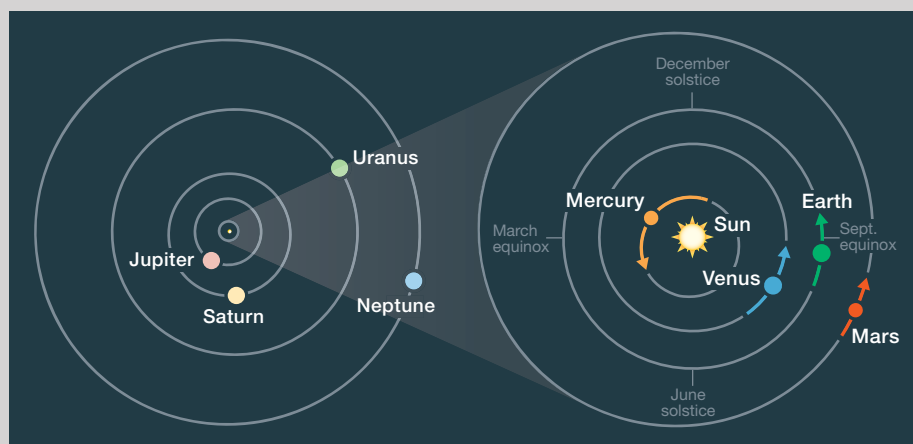
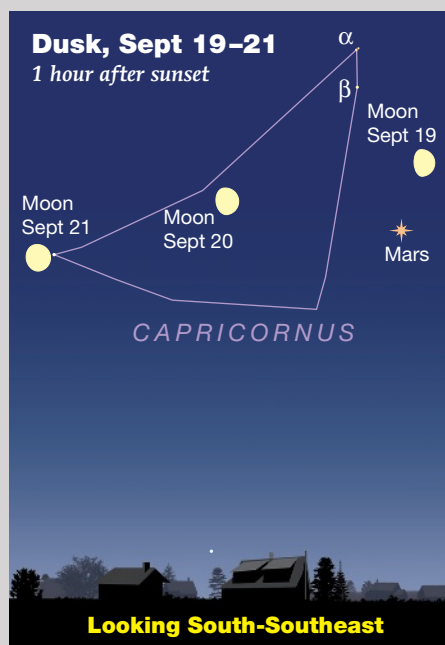




upper left of M8 (the Lagoon Nebula) and east of M20 (the Trifid Nebula), and slowly begins to move eastward in northern Sagittarius. During the month, the gap between Saturn and Jupiter closes from about  $45^\circ$  to  $41^\circ$ . On the other side — eastward — Mars increases its separation from Saturn from  $27^\circ$  to  $33^\circ$  during September. Saturn's rings look even more three-dimensional than usual this month with Saturn passing through eastern quadrature ( $90^\circ$  east of the Sun) on September 25th. Saturn sets a little after 1 a.m. local time on September 1st and a little after 11 p.m. on September 30th.

**Mars** begins the month at a bracing magnitude  $-2.1$ , still a bit brighter than Jupiter. The imposing orange-yellow beacon loses half of its brightness during September, however, fading to magnitude  $-1.3$ . Its apparent diameter also dwindles from  $21''$  to  $16''$  this month — but even this is wider than Mars has been in any of the past 13 years, bar one. Furthermore, Mars reaches its highest in the south conveniently early in the night this month, passing the meridian around 10:20 p.m. on September 1st and a bit before 9 p.m. on September 30th.

In space, Mars reaches perihelion, 1.38 a.u. from the Sun, on September 16th. In the heavens, Mars is trekking back from Sagittarius into Capricornus.



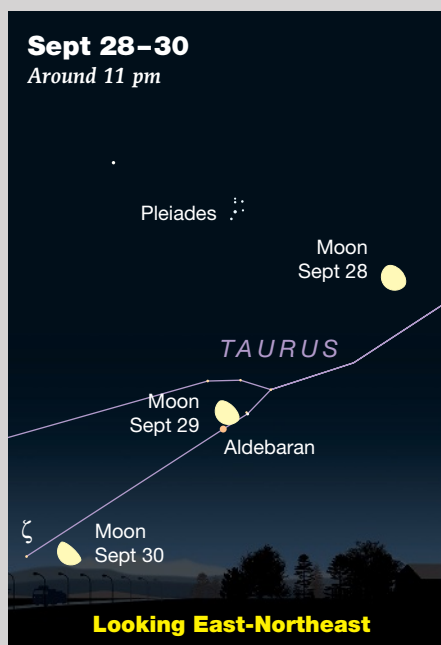
## ORBITS OF THE PLANETS

The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

The Red Planet sets not long before 3 a.m. as September begins and a little after 1:30 a.m. as the month ends.

## ALL NIGHT

**Neptune** reaches opposition, visible all night in Aquarius, on September 7th. It shines at magnitude 7.8 and is  $2.4''$  wide in telescopes. **Uranus** glows in southwestern Aries this month, two magnitudes brighter than Neptune and appearing considerably larger at  $3.7''$ . Neptune transits the meridian roughly around midnight, Uranus about three hours later. Finder charts for these two planets are on pages 48–49.



## DAWN

**Mercury** appears low in the east-northeast 30 to 45 minutes before sunrise in the first week of September. On September 5th and 6th, 1st-magnitude Regulus may be glimpsed with optical aid a bit more than  $1^\circ$  from Mercury, which shines at magnitude  $-1$ . Mercury is lost to view around September 11th and reaches superior conjunction with the Sun on September 20th.

## SUN AND MOON

**The Sun** passes through the September equinox at 9:54 p.m. EDT on September 22nd, marking the start of autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

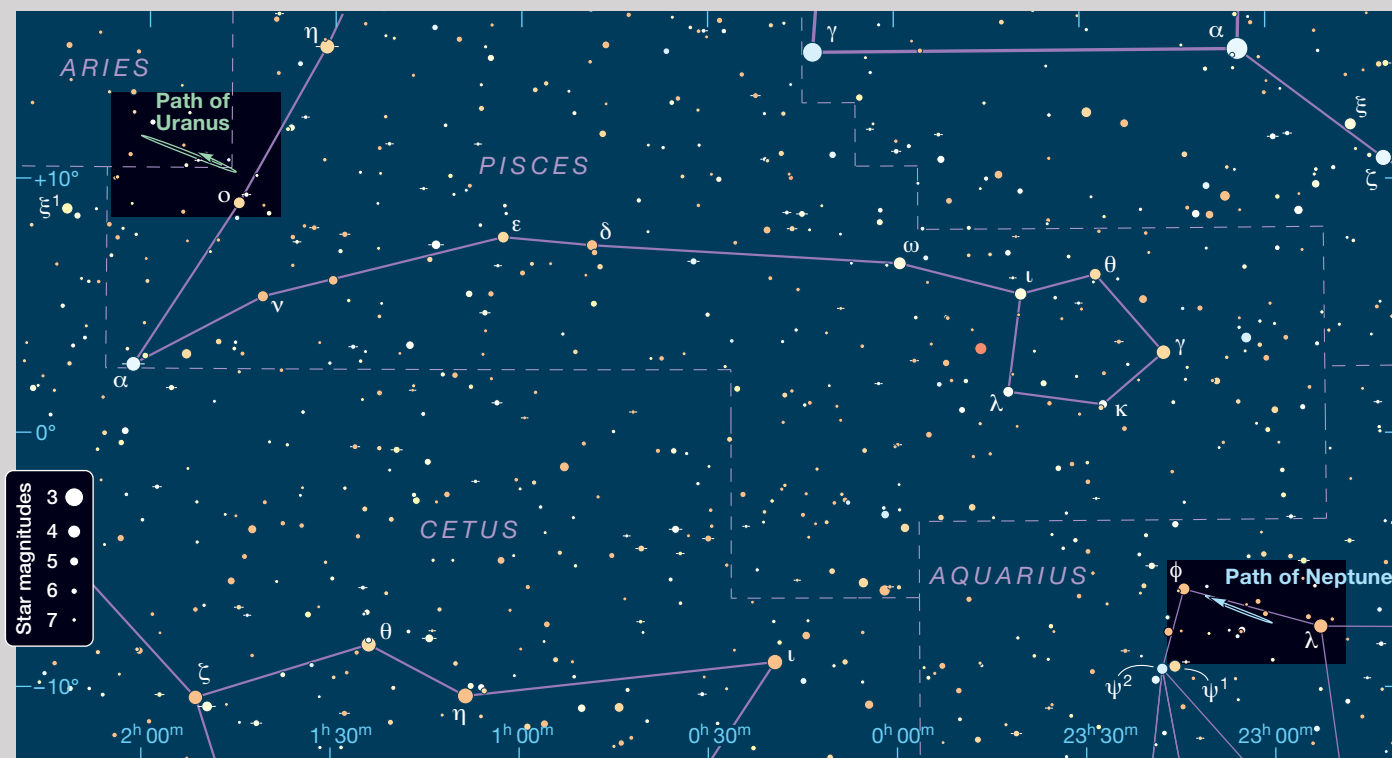
**The Moon** is a thin waning crescent  $1\frac{3}{4}^\circ$  above Regulus (use binoculars) at dawn on September 8th. The waxing lunar crescent is  $9^\circ$  upper right of Venus at dusk on September 12th, but only some  $4^\circ$  upper right of Jupiter the next night. On September 17th a slightly gibbous Moon is  $4^\circ$  left of Saturn. A fatter Moon is almost  $4\frac{1}{2}^\circ$  above Mars on the evening of September 19th. On the night of September 29–30, the waning gibbous Moon passes less than  $1^\circ$  from Aldebaran for North America.

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# Gas Giant Season

Uranus and Neptune return to the evening sky.



Many observers look forward to the arrival of autumn, when night falls earlier and darkness lasts longer. Autumn also marks the return of the gas giants to the evening sky, at least for the foreseeable future. Neptune arrives at opposition on September 7th, Uranus on October 23rd, so we've reached the ideal part of the calendar for observing them. During the next few months, Uranus is in the southwest corner of Aries (it visits Pisces in December and January) while Neptune is in Aquarius. The charts here show their positions south and east-southeast of the Great Square of Pegasus.

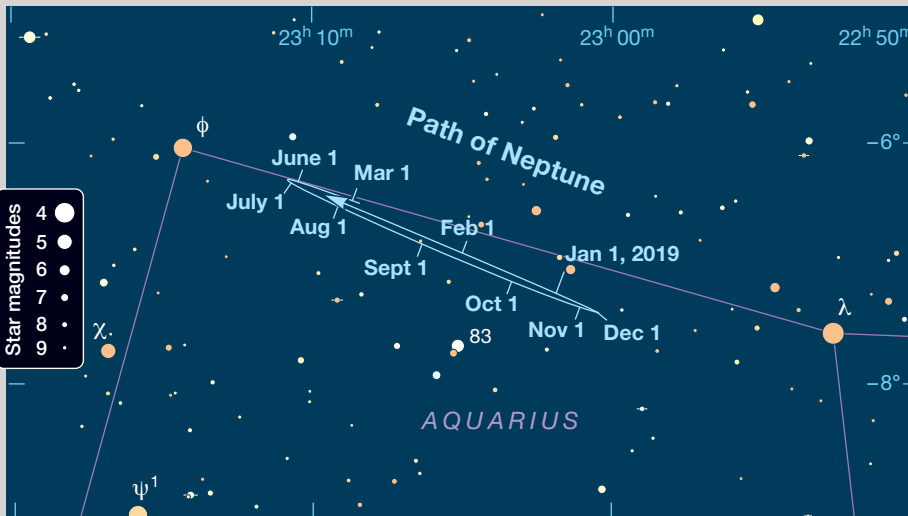
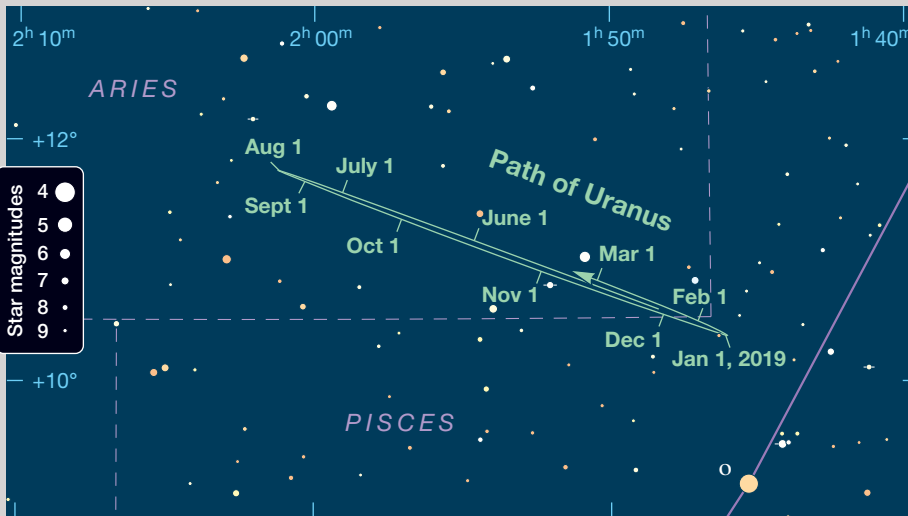
If you poll people at your next star party, you may discover that many will have seen Uranus, but few will have

The chart above spans almost 60°, or 4 hours of right ascension, beneath the Great Square of Pegasus. On the smaller, deeper finder charts on the facing page, use the ticks marking the start of each month to determine the position of each planet for your observing date.

seen Neptune. Uranus is a much easier target. It's still a late-night object in September; by mid-month, it's about 30° high at 11 p.m. local time. As opposition draws closer, it stands higher earlier in the evening. At magnitude 5.7, Uranus is technically a naked-eye object, but dark, transparent skies are needed to see it without optical aid. It's easily discernible as an "extra star" in the field of view of binoculars, however.

It's a long star-hop to the planet from the brighter stars in Aries, so you may begin your journey at Omicron (ο) Piscium. Uranus appears 3.7" wide through mid-December, which means that under magnification it will look slightly fatter than the surrounding stars. It may even show a hint of cyan. More aperture and magnification will draw out the turquoise, though color perception is subjective.





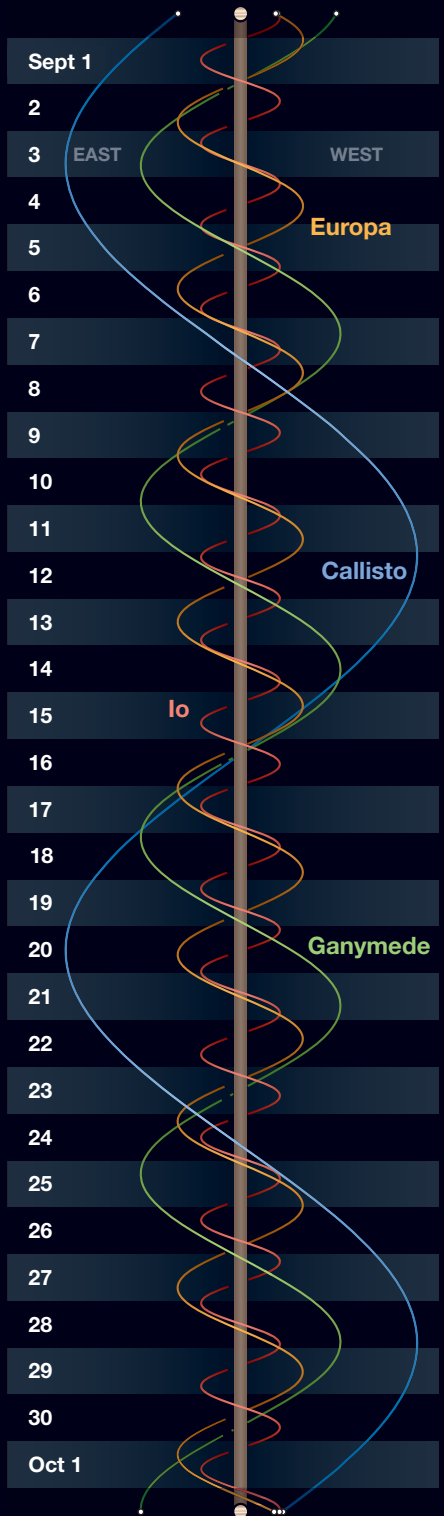
▲ Damian Peach captured this image of 3.68"-wide Uranus on October 21, 2015, using a color astronomy camera with an RG-610 long-pass filter on a 14-inch Schmidt-Cassegrain.

Neptune, though the fourth-largest planet by diameter in our solar system, is a true telescopic/big bino object, thanks to its distance from Earth. It shines at magnitude 7.8 and appears

only 2.4" wide at opposition. In my 130-mm reflector, it doesn't look much more than stellar, but the 10-inch can bring out both form and color, a pale, pleasing blue. It usually looks more gray than blue to me, though, especially with more magnification. The atmospheres of Neptune and Uranus consist primarily of hydrogen, helium, and methane. It's this last molecule,  $\text{CH}_4$ , that reflects light on the blue-green end of the spectrum.

Sometimes it's difficult to convince yourself that you're seeing what you're supposed to be seeing. Sketch the starfield with as much detail as you can and clearly mark the dot you think is the planet. Return to the field on the next clear night and make a fresh sketch. If your dot has moved to a new position, you've rediscovered a gas giant.

## Jupiter's Moons



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





# Asteroid Occultation

**EARLY ON THE MORNING** of September 16th, the 11.8-magnitude asteroid 80 Sappho hides a 7.2-magnitude star in Taurus. The A2-type star, HD 33864 (HIP 24403), lies in the region of the Bull’s horns, about 5½° from Zeta (ζ) Tauri.

Asteroid 80 Sappho is one of five small bodies detected by British astronomer Norman Pogson from the Madras Observatory in the latter half of the 19th century. Spotted on May 2, 1864, the asteroid was named on the advice of John Herschel, who thought Sappho was “a suitable name for a small planet.” Spectroscopic studies indicate Sappho is an S-type Main Belt asteroid, with a siliceous, or stony, composition.

The predicted path of visibility crosses North America from Central California to Maine. The 4.6-magnitude drop in brightness is predicted to occur within a minute or two of 8:48 UT for Sacramento and Salt Lake City (1:48 a.m. PDT and 2:48 a.m. MDT, respec-

tively), 8:49 UT (3:49 a.m. CDT) for Sioux Falls, and 8:51 UT (4:51 a.m. EDT) for Peterborough, Ontario, and Augusta, Maine. The involved star shines reasonably high in the sky at these times, though it’s lower in the west than the east (about 25° for California compared to around 60° for Maine).

Although some photometric measurements of 80 Sappho have been gathered, data from this event will help improve the asteroid’s shape model. About a week before the event, more precise predictions and a path map will be available from Steve Preston’s minor planet occultation website ([asteroidoccultation.com](http://asteroidoccultation.com)). For more on planning and setting up your equipment, visit the International Occultation Timing Association (IOTA) website ([occultations.org](http://occultations.org)). Occultation enthusiasts may also join an active online discussion group at [groups.yahoo.com/neo/groups/IOTA-occultations](http://groups.yahoo.com/neo/groups/IOTA-occultations).

◀ Astronomers have created rough shape models showing the basic characteristics and shape of 80 Sappho. Refinements to the model depend on amateur and professional astronomers acquiring more data for the asteroid.

▼ With autumn returning, Perseus is rising into the northeastern sky. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness with respect to the comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).



## Minima of Algol

Aug.	UT	Sept.	UT
1	19:58	2	8:52
4	16:46	5	5:40
7	13:35	8	2:29
10	10:23	10	23:18
13	7:12	13	20:06
16	4:00	16	16:55
19	0:49	19	13:43
21	21:38	22	10:32
24	18:26	25	7:21
27	15:15	28	4:09
30	12:03		

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554 + 2.867324E, where E is any integer. For a comparison-star chart and more info, see [skyandtelescope.com/algol](http://skyandtelescope.com/algol).

DAMIT / ASTRONOMICAL INSTITUTE OF THE CHARLES UNIVERSITY / JOSEF DURECH / VOUTECH SIDORIN

## September Equinox

If the reappearance of the gas giants in the evening sky isn’t enough to convince you that summer is over, maybe this will: Astronomically speaking, fall comes to the Northern Hemisphere on September 23rd at 1:54 UT (September 22nd at 9:54 p.m. EDT), the moment the Sun passes over Earth’s equator. This north-to-south crossing is called the September equinox. On this date, the Sun rises due east and sets due west from every location on Earth, and should you be standing on the equator, the Sun would pass exactly overhead at midday.

Thanks to the 23½° tilt of Earth’s axis with respect to its orbital plane, the Sun’s highest point in the sky changes depending on the time of year. The tilt tips one side of Earth or the other toward the Sun as it hurtles around its orbit. For those of us in the Northern Hemisphere, the Sun appears to climb higher in the sky each day from late December to late June, and drop lower in the sky from late June to late December. An equinox marks the point when the Sun is halfway through its up-and-down journey.



# Action at Jupiter

**JUPITER, LOW IN THE WEST-SOUTH-WEST** on September evenings, is becoming increasingly difficult to observe from mid-northern latitudes. The gas giant is on its way to a conjunction with the Sun on November 26th. On September 1st, Jupiter sets a little more than hour after the end of twilight. By the end of the month, the planet drops below the horizon within minutes of twilight's end.

When the sky is dark and the seeing is relatively steady, any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on page 49 to identify them at any date and time.

All of the September interactions between Jupiter and its satellites and their shadows are tabulated at right. Find events timed for when Jupiter is at its highest in the early evening hours.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

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

**Sept. 1**, 1:39, 11:34, 21:30; **2**, 7:26, 17:22; **3**, 3:18, 13:13, 23:09; **4**, 9:05, 19:01; **5**, 4:57, 14:53; **6**, 0:48, 10:44, 20:40; **7**, 6:36, 16:32; **8**, 2:28, 12:23, 22:19; **9**, 8:15, 18:11; **10**, 4:07, 14:03, 23:58; **11**, 9:54, 19:50; **12**, 5:46, 15:42; **13**, 1:37, 11:33, 21:29; **14**, 7:25, 17:21; **15**, 3:17, 13:12, 23:08; **16**, 9:04, 19:00; **17**, 4:56, 14:52; **18**, 0:47, 10:43, 20:39; **19**, 6:35, 16:31; **20**, 2:27, 12:22, 22:18;

**21**, 8:14, 18:10; **22**, 4:06, 14:02, 23:58; **23**, 9:53, 19:49; **24**, 5:45, 15:41; **25**, 1:37, 11:33, 21:28; **26**, 7:24, 17:20; **27**, 3:16, 13:12, 23:08; **28**, 9:03, 18:59; **29**, 4:55, 14:51; **30**, 0:47, 10:43, 20:38.

These times assume that the spot will be centered at System II longitude 292°. If the Red Spot has moved elsewhere, it

will transit 1½ minutes earlier for each degree less than 292° and 1½ minutes later for each degree more than 292°.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases the contrast of red features.

## Phenomena of Jupiter's Moons, September 2018

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears (**D**) and ends when it reappears (**R**). A transit or shadow passage begins at ingress (**I**) and ends at egress (**E**). Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

# A Nod to Lunar Libration

Every month, the Moon's face wobbles enough to give you a peek at some of its hidden farside.

Have you ever settled in with your telescope for a little lunar observing, only to sense that something about the Moon was “off”? Maybe you suspect that some of its landmark features aren't quite where they should be. Or maybe you spot something along the limb that doesn't look familiar.

This subtle shifting happens all the time — every month, in fact — due to a periodic nodding of the lunar disk called *libration*. And rather than being an annoying distraction, libration is actually a good thing. It lets you view portions of the lunar farside that are typically hidden from view.

We all learn in school that the Moon shows us the same half of its globe all the time — and keeps the other half constantly out of view — thanks to a permanent lock between its rotation rate and orbital period. But what your grade-school teacher likely didn't tell you is that it's not a perfectly 50:50 proposition. Thanks to libration, any portion of the lunar limb can become shifted toward Earth by as much as 8° or 9°. Over time, and when your timing's right, you'll be able to glimpse 59% of the Moon's surface — including some tantalizing features that periodically pop into view along the limb.

## A Geometric Trifecta

Three different motions contribute to the nodding of the lunar disk observable on any given night.

The largest component, *libration in longitude*, is evident as a shift along

the eastern or western limb. It arises because the Moon's orbit is distinctly not circular, with an eccentricity of about 0.06. This causes the Moon to move faster than average when near perigee and slower than average when near apogee — even though its rotation rate remains constant. So sometimes the Moon's orbital position can be either a little behind or ahead of its spin, which manifests as a back-and-forth nod of the disk. This can be as much as 8° in longitude or 240 km (as big as the prominent nearside crater Clavius).

Next is *libration in latitude*, an effect that's nearly as pronounced. The plane of the Moon's equator is tipped 6.7° with respect to the plane of its orbit. So

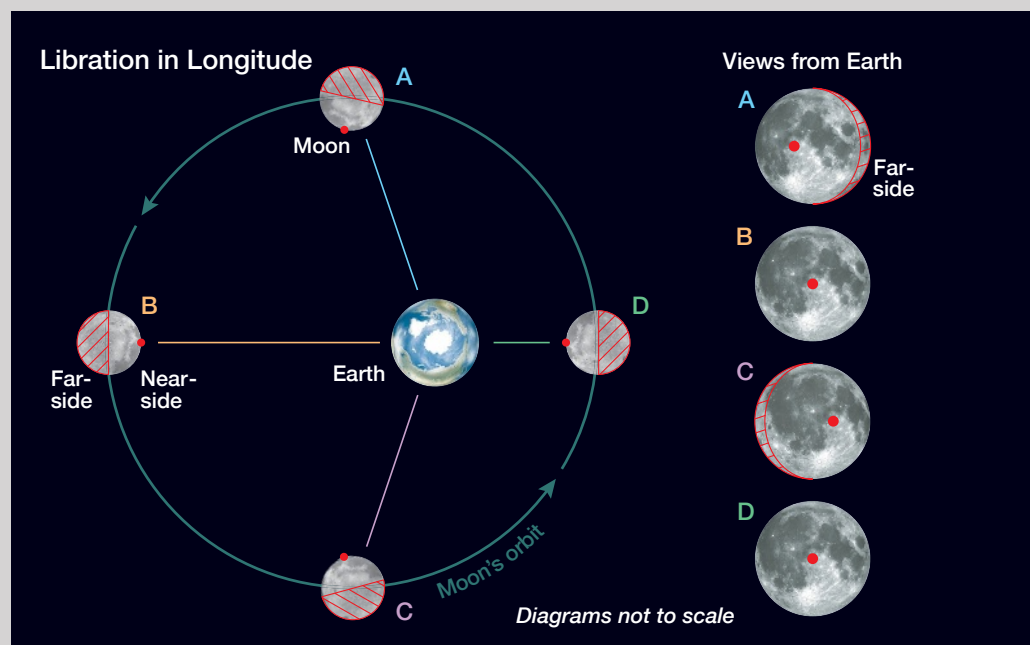
◀ A snapshot from a passing spacecraft shows the side of the Moon visible from Earth (at right) and a portion of the unseen farside (at left). The giant impact basin *Oriente* is just below center.

the lunar north pole is tipped in our direction for half of each orbit and the south pole is tipped toward us for the other half. These shifts in latitude allow you to peer deeply into the far-side polar regions.

*Diurnal libration*, the third component, has nothing to do with the Moon itself. Instead, it's created by our changing vantage point on a rotating Earth. As the diagram on the next page shows, we're on one side of Earth when we view the Moon rising in the east but on the opposite side of our planet when it sets in the west.

The total amount of this swing is about 9,000 km at the latitude of the contiguous U.S. states, Europe, and Australia, enough to experience an additional  $\pm 0.7^\circ$  of libration in longitude. You can use this to your advantage by remembering that it favors the eastern lunar limb (celestial west) at moonrise and the western lunar limb (celestial east) at moonset.

You might think that librations in longitude and latitude should occur at the same part of each lunar phase cycle month after month. But they don't,





mostly because the Moon's *sidereal* orbital period (as gauged by its position among the stars) is 27.3 days, while its *synodic* period (new Moon to new Moon) is 29.5 days. They're not in sync.

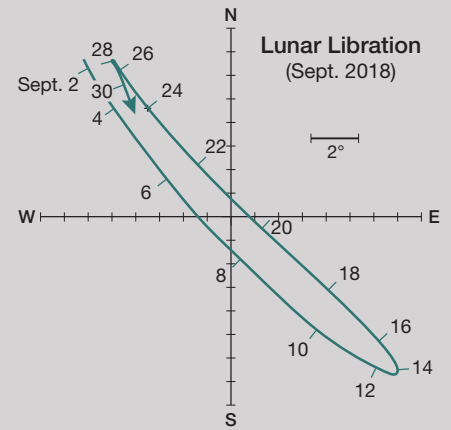
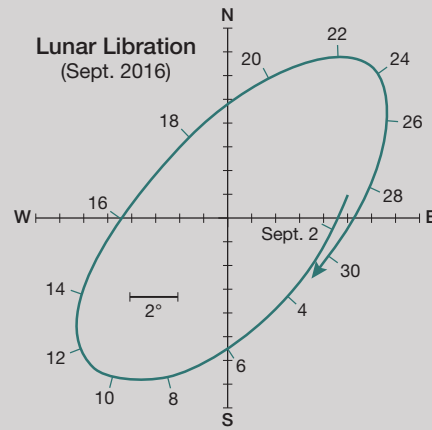
The librations in longitude and latitude aren't even in sync with each other. Their relationship evolves in a weird, 6-year-long cycle before starting to repeat. Every point around the Moon's limb, at one time or another, becomes the region most favorably tipped to our view.

## Observing at the Edge

So what does all this bobbing and weaving bring into view? What rare bits of *luna incognita* await the libration-savvy observer?

First, you need to pay attention to the Moon's phase. Suppose you get ready for a really favorable libration along a particular spot along the eastern lunar limb — a section best seen when the Moon is near first quarter — but then you realize that right now the Moon is near last quarter and your target zone is in darkness. Better luck next time!

One no-hassle way to view good libration targets is to flip to page 42 of this issue. At upper left is an image of the Moon with dots labeled 1, 13, 16, and 26. At lower right are four lunar features — the craters **Galvani**, **Peires-**



▲ The combined effects of libration in longitude and latitude can vary dramatically from month to month — as evidenced by these plots showing the lunar limb's tilt toward Earth in September of 2016 and 2018.

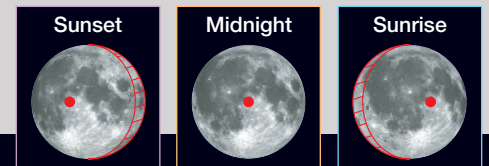
**cius**, **Hamilton**, and **Xenophanes** — which you can glimpse along the lunar limb on their respective dates. In every issue, on that same page, you'll find targets with favorable librations chosen by S&T's editors. We've been offering these since 1987.

The libration zones offer plenty of interesting sights. The most spectacular farside feature that you can hope to see — and probably the most elusive — is **Mare Orientale**, a sizable "sea" of lava sitting in middle of a dramatic impact basin roughly 900 km (600 miles) across. It's a bit south and west of the lava-floored crater **Grimaldi**. Although the exact age of Orientale isn't known, it's the Moon's youngest basin-forming

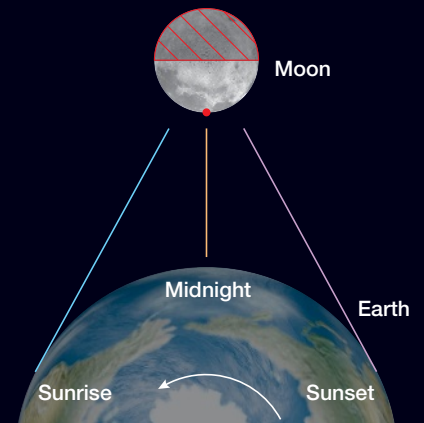
impact — as evidenced by a nearly perfect bull's-eye of three concentric rings of uplifted mountains that surround the lava plain at their center.

Every now and then, when libration swings them into view along the western limb, you can glimpse the basin's two outer rings: **Montes Cordillera** and the outer **Montes Rook**. Get a little luckier, and you can spot **Lacus Veris**, a dark "finger" of pooled lava lying just inside the ridge of Rook peaks. To

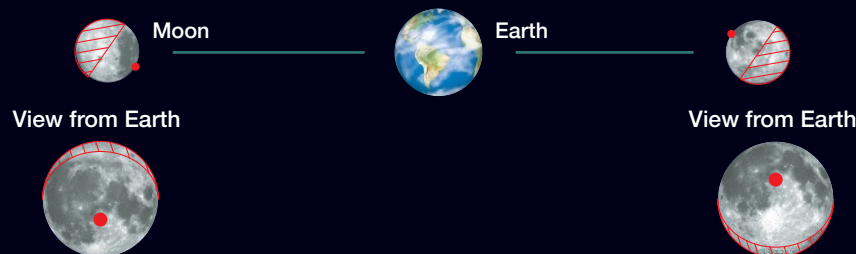
## Views from Earth



## Diurnal Libration



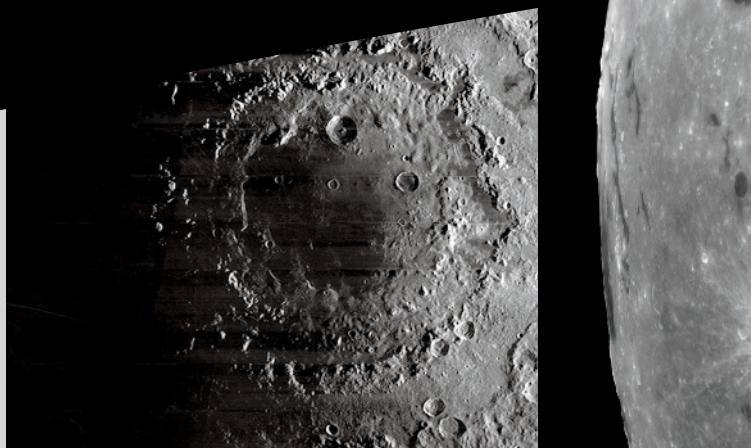
## Libration in Latitude



◀ *Libration in longitude* occurs because the Moon's orbital speed isn't constant. It allows you to view beyond the usual east and west edges of the lunar disk.

▲ *Libration in latitude*, which can create a tilt of up to  $6\frac{1}{2}^\circ$ , permits you to observe more of the Moon's polar regions.

► *Diurnal libration* occurs every day, as our planet's rotation carries you from one side of Earth to the other and changes your lunar perspective slightly.



◀ Orientale is a dramatic, bull's-eye-shaped basin that lurks just beyond the nearside limb. But you can glimpse parts of it during especially favorable librations of the Moon's southwestern terrain.

see Mare Orientale itself requires lots of patience, because it peeks into view clearly only every few years. My suggestion is to find a calendar for 2020 and circle October 10–11. Those will be especially good nights for spotting Mare Orientale on a last-quarter Moon.

Another challenging target is the crater **Lorentz**. It's a whopping 371 km across, larger than any crater on the Moon's nearside. But it's also ancient, and over the eons its rim has become indistinct. Fortunately, you'll have an especially good chance to glimpse Lorentz on the nights of August 29th to September 1st. To track it down, draw an imaginary line across Oceanus Procellarum from **Aristarchus** through the small but sharp crater **Lichtenberg** until you reach the limb.

Four lesser-known lunar seas slip into view relatively often on the opposite side of the disk. Start by locating **Mare Crisium**, the distinctly oval dark lava plain that's always in view (when

sunlit) along the eastern limb. Use it as a judge of whether the libration in that region is favorable: If it's very close to the edge, don't bother. But if it's well separated from the limb, keep looking!

To Crisium's immediate right is the dark, irregular circle called (rather obviously) **Mare Marginis**. Trail a bit southward along the limb, past the large but strongly foreshortened crater **Neper**, to reach **Mare Smythii**. Then keep sliding southward until you reach the clutch of dark smudges marking **Mare Australe**. September's target craters Peirescius and Hamilton are there, as is a prominent, lava-filled saucer named **Lyot**. The fourth "marginal" sea along the Moon's eastern limb is **Mare Humboldtianum**, a dark and compact spot well above Crisium at a latitude of 60° north.

### Libration Resources

I'll close with some helpful aids to expand your libration-assisted observ-

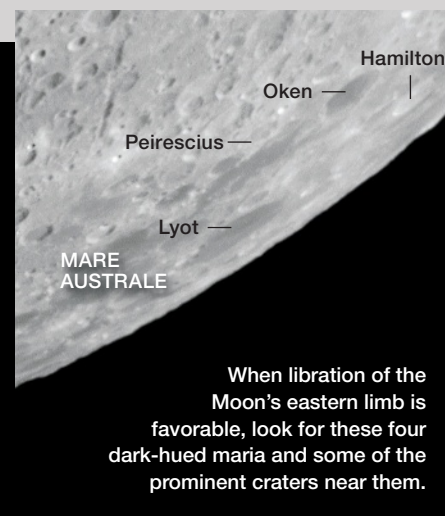
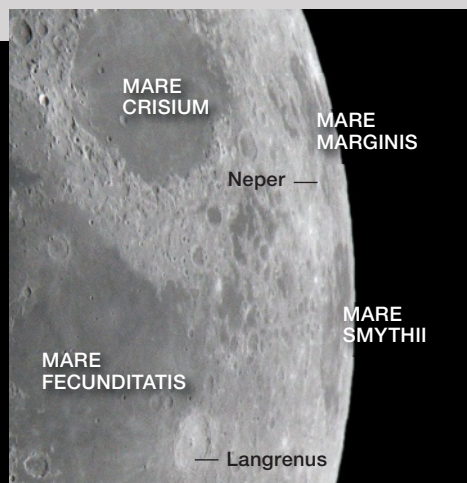
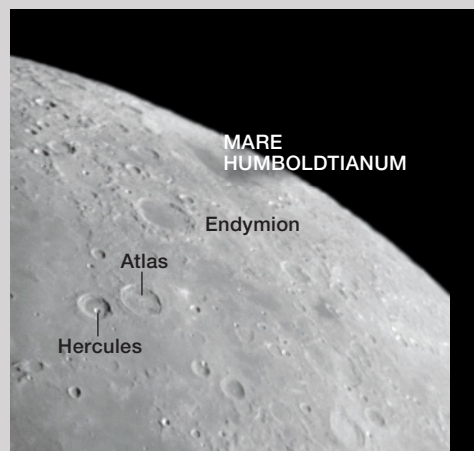
ing. For a WYSIWYG view of what's viewable along the lunar limb on any given night, you can't beat *Virtual Moon Atlas*. A labor of love by veteran French observers Christian Legrand and Patrick Chevalley, it's available as a free download at [ap-i.net/avl/en/download](http://ap-i.net/avl/en/download). Tip: Once you've installed it, open the Configuration menu, make sure the Topocentric button is selected, and then enter your site's latitude and longitude (the default location is in France).

Fred Espenak, though justifiably famous for his eclipse-chasing skills, also provides daily data on lunar libration in tabular form (and much, much more) at his [astropixels.com](http://astropixels.com) website. A shortcut to the lunar ephemerides is <https://is.gd/librations>.

Finally, an essential aid to knowing what you're seeing along the lunar limb is Sky & Telescope's *Field Map of the Moon*, which utilizes an excellent portrayal of nearside surface features by the late Antonín Rükl. The map's outer limb extends more than 8° onto the far-side, thus showing and identifying any libration-aided feature you'd want to see. It's available from [shopatsky.com](http://shopatsky.com).

So why settle for viewing only 50% of the Moon's surface? Thanks to libration, you can squeeze in another 9% with just a little advance planning. Happy hunting!

■ Senior Editor KELLY BEATTY has been exploring the Moon's nooks and crannies since the early 1960s.



When libration of the Moon's eastern limb is favorable, look for these four dark-hued maria and some of the prominent craters near them.

SPACE VIEW: NASA / NORTHEAST REGIONAL PLANETARY DATA CENTER; EARTH VIEW: SEAN WALKER; VIEWS OF MARIA: GARY SERONIK (3)



# Lacerta sive Stellio

This tiny celestial reptile is speckled with stars.

Ceres, offended at his foul grimace,  
Flung what she had not drunk into his face,  
The sprinklings speckle where they hit the skin,  
And a long tail does from his body spin;  
His arms are turn'd to legs, and lest his size  
Shou'd make him mischievous, and he might rise  
Against mankind, diminutives his frame,  
Less than a lizzard, but in shape the same . . .  
A name they gave him, which the spots exprest,  
That rose like stars, and varied all his breast.  
— Ovid, *Metamorphoses*



Affronted by the rudeness of a young lad while she was desperately seeking her lost daughter, the goddess Ceres turned the hapless boy into a lizard. Perchance this star-speckled lizard inspired Johannes Hevelius to raise the little constellation Lacerta into our sky when he introduced it in his wonderful 1687 atlas, *Firmamentum Sobiescianum*. Placed just south of Cepheus, the new constellation figure bore the Latin name *Lacerta sive Stellio*, which means “Lizard or Stellation.” In early usage, a stellion was a lizard with starlike spots. Stellation now refers to a particular species, commonly called a star lizard, found in lands cradling the Mediterranean Sea.

Since some of Lacerta’s spots can only be enjoyed with a telescope, let’s focus on a few that come to us in the form of double stars.

**Struve 2876** (Σ2876 or STF 2876) beams at us from southern Lacerta, 48’ west of 1 Lacertae in the lizard’s tail. My 130-mm refractor at 37× gives a pleasing separation, and the contrast between the pale-yellow primary and its golden companion to the east-northeast shows nicely. Pushing the scope to the opposite side of 1 Lacertae, **Struve 2894** joins the view. It’s a brighter and wider duo, offering a creamy-white primary teamed with a yellow attendant to its south-southwest. Although some entries

in double star catalogs aren’t physically related, measurements indicate that these are bound pairs.

Continuing our eastward trek for 3.5°, we’ll bump into the little-known star cluster **Teutsch 39**. It dangles 1.4° south-southwest of 10 Lacertae and embraces the 7th-magnitude star HD 214263. Through the 130-mm scope at 63×, this bright beacon marks the top of a skewed kite soaring north-northwest.

An orange gem east-northeast of the kite’s bottom star lends a touch of color to the group. I count 20 stars, but they’re so loosely scattered that the cluster is easy to overlook. Its given size and position vary a bit from source to source. The data in our table spring from the online version of the Catalog of Optically Visible Open Clusters and Candidates (<https://wilton.unifei.edu.br/ocdb/>), which provides a distance and age of about 2,600 light-years and 20 million years.

In the far southeastern corner of Lacerta, **h975** (HJ 975) is one of thousands of double stars found by the great English polymath John Herschel. It’s a very wide pair even at 23×, and the components differ by 3.5 magnitudes. The bright primary glitters with an icy blue-white hue, and its fetching reddish-orange companion lies west-southwest. Boosting the magnification to 63×, the elliptical galaxy **NGC 7426** appears in the field of view as a little fuzzball only 3.8’ east of h975. At 117× its oval face is cocked east-northeast and grows slightly brighter toward the center. The dim halo covers roughly 1’ × ¾’ at 164×, and the galaxy’s heart holds a small, brighter core. NGC 7426 is about 220 million light-years distant

## Looking at the Lizard

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Σ2876	Double star	8.1, 9.8	11.8’’	22 <sup>h</sup> 12.0 <sup>m</sup>	+37° 39’
Σ2894	Double star	6.2, 8.9	16.1’’	22 <sup>h</sup> 18.9 <sup>m</sup>	+37° 46’
Teutsch 39	Open cluster	—	17’	22 <sup>h</sup> 36.5 <sup>m</sup>	+37° 45’
h975	Double star	5.7, 9.2	52.1’’	22 <sup>h</sup> 55.7 <sup>m</sup>	+36° 21’
NGC 7426	Galaxy	12.3	1.7’ × 1.4’	22 <sup>h</sup> 56.0 <sup>m</sup>	+36° 22’
IC 1442	Open cluster	9.1	5.0’	22 <sup>h</sup> 16.0 <sup>m</sup>	+53° 59’
NGC 7245	Open cluster	9.2	5.0’	22 <sup>h</sup> 15.3 <sup>m</sup>	+54° 20’
NGC 7226	Open cluster	9.6	2.0’	22 <sup>h</sup> 10.4 <sup>m</sup>	+55° 24’
Be 98	Open cluster	—	6.0’	22 <sup>h</sup> 42.7 <sup>m</sup>	+52° 25’
NGC 7394	Cluster?	—	10’	22 <sup>h</sup> 50.4 <sup>m</sup>	+52° 09’
h1820	Double star	9.7, 13.4	11.0’’	22 <sup>h</sup> 50.5 <sup>m</sup>	+52° 09’

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

and is known to sport two lengthy tails of hydrogen whose origins remain mysterious.

Let's wander up to northern Lacerta, where dwell the only two stars on the little lizard that carry Bayer designations, Alpha ( $\alpha$ ) and Beta ( $\beta$ ) Lacertae. Our lizard's nose and head are deeply dipped in the misty river of the Milky Way, so we find more star clusters adorning this part of his domain.

Alpha and Beta point directly to **IC 1442**. This cluster may be confusing because it's plotted 5' to 6' too far northeast on some atlases. In the correct position, the 130-mm scope at 117 $\times$  reveals a northeast-southwest band of faint to very faint stars measuring 4'  $\times$  1½'. It's flanked by a 9th-magnitude star to the southeast and a 3-star line of 11th- and 12th-magnitude stars to the northwest, which roughly parallels the band. At 164 $\times$  about 20 stars round out the group. IC 1442 isn't very conspicuous even in my 10-inch scope at 116 $\times$ , but half again as many stars pop out.

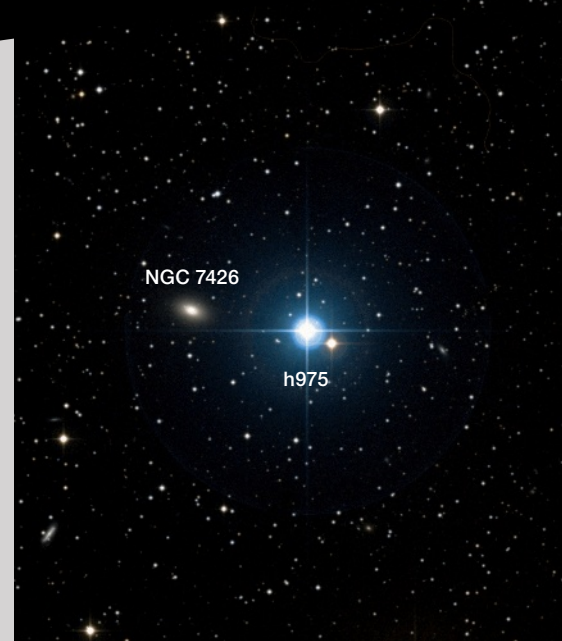
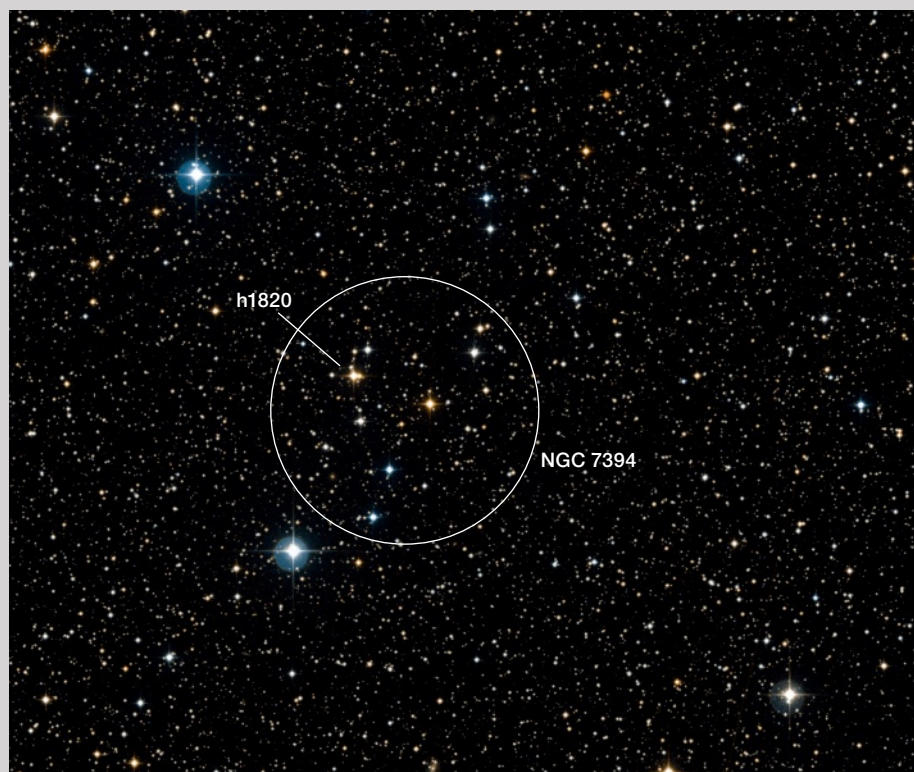
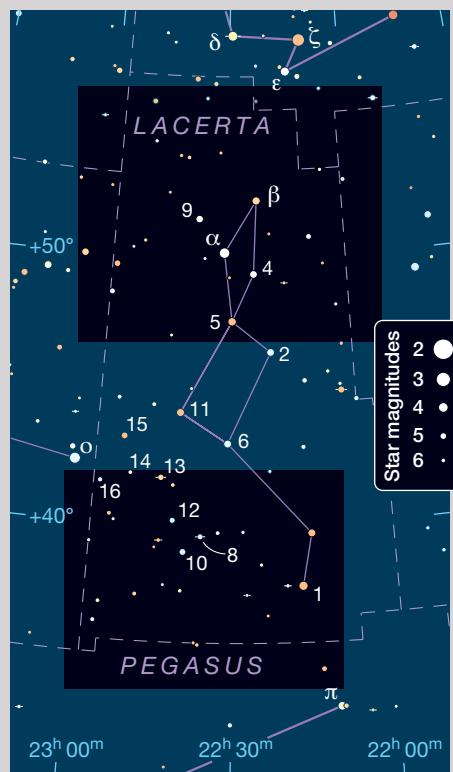
► The components of double star h975 are separated by some 52 arcseconds, making this a fairly easy split under low magnification. A bit more power will draw out the faint elliptical galaxy NGC 7426 just east of the star pair.

In a low-power view of IC 1442, you may notice a hazy patch 22' to the north-northwest, **NGC 7245**. Through the 10-inch reflector at 166 $\times$ , it's a pretty group, rich in very faint stars. They bunch together in the cluster's central 1½' and then thin to outliers that expand the group's diameter to 5'. NGC 7245 is about 12,400 light-years away from us, while its neighbor is a bit more distant at 7,700 light-years.

While in the area, let's border-hop into the neighboring constellation Cepheus, where the 2' open cluster **NGC 7226** resides. The 130-mm scope at 63 $\times$  shows a fairly faint glow with

an 11th-magnitude star perched on its northern edge, and even at 234 $\times$  only a few feeble stars or stellarings pop in and out of view. The 10-inch scope at 166 $\times$  plainly discloses several faint stars, while others are intermittently seen. The charm of this cluster comes through in a large scope. A flower

▼ Two 7th-magnitude stars act as sentinels for the open cluster NGC 7394. While the stars of this group may not be physically related, they still pose prettily as a group in the eyepiece. Look for the yellow-orange double star h1820 east-northeast of the cluster's center.



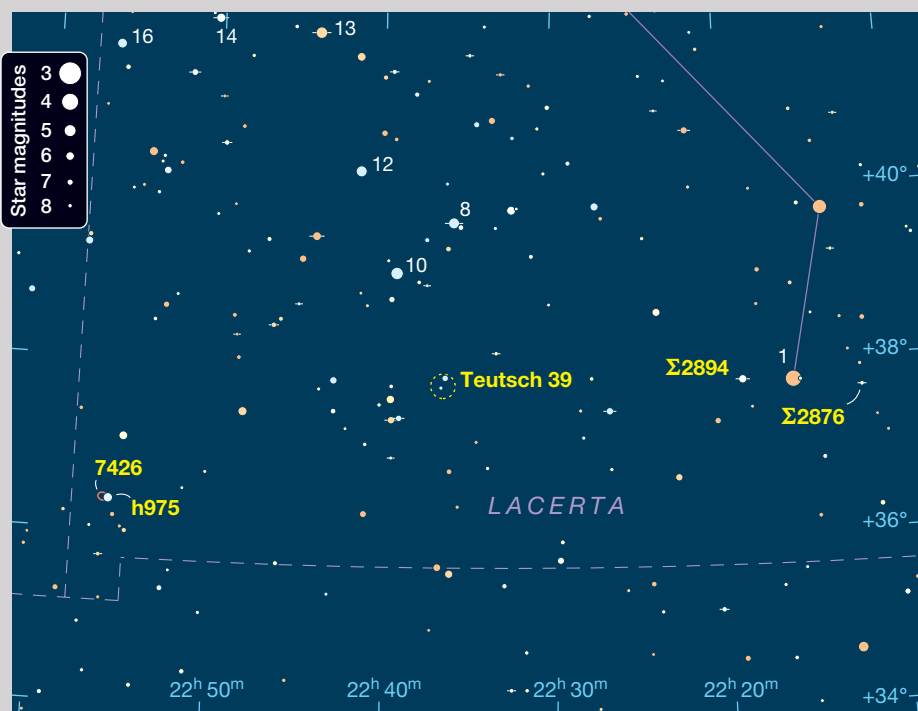


blooms within the cluster through my 15-inch reflector at 345×. In the cluster's southern reaches, 16 stars neatly outline two wide, basal leaves. The bright star in the north is the flower's blossom, and a solitary star between it and the leaves indicates a curved stem, with the flower drooping above the western leaf. Although most of the stars dimly shine at about 14th magnitude, I thought it a great treat to pick out this shy little wallflower.

Back in Lacerta, let's travel 2.9° east of Beta to the open cluster **Berkeley 98**. At 63× the 130-mm scope serves up seven faint stars in a skinny, 4½'-long wedge that points northeast. A power of 164× places 13 stars in the wedge and two more within the nominal 6' span of the cluster, while 234× draws out a total of 18 stars. A better view comes with the 10-inch scope at 187×, which awards the group at least 25 stars. When you gaze at Berkeley 98, you're seeing an exceptionally elderly cluster, about 2.5 billion years old. The stars in most open clusters disperse within a few hundred million years.

Our final visit will be paid to **NGC 7394**, situated 1.2° east-southeast of Berkeley 98. Two 7th-magnitude stars 13' apart and tangent to the cluster's eastern side help pinpoint the group. The northern jewel gleams yellow-white, while the southern one shines yellow. My 130-mm refractor 23× tenders a gathering of 11 faint stars stretching northwest from the southern star of the pair. At 63×, I see about 20 stars in a band that's 10' long and 4' to 5' wide. The group's brightest gem glows a warm yellow-orange. The 10-inch scope at 68× boosts the star count to 25, and at 166× the yellow-orange star gains a very faint companion 11' to the west. This is another of John Herschel's doubles, **h1820**.

While NGC 7394 looks like a reasonably obvious collection of stars, its existence as a physical group is somewhat dubious, and indeed it doesn't appear in most cluster catalogs. The majority of the star clusters listed in the *New General Catalogue of Nebulae and Clusters of Stars* (NGC) were discovered



by their appearance through a telescope or on a photographic plate, at a time when determining their true nature was generally not possible. Some remain questionable to this day. The next time you eyeball NGC 7394, ask yourself

whether or not you'd log it as a possible open star cluster.

■ Contributing Editor **SUE FRENCH** likes all manner of critters, including lizards with or without stars.

# A Celestial Set Piece

If your sky is dark, you'll enjoy scrutinizing this cluster-galaxy combo.

Picture in your mind two deep-sky objects: They're totally different types, completely unrelated, similar in angular size and apparent brightness, *and* visible in a single telescopic field of view. That describes the open cluster **NGC 6939** and spiral galaxy **NGC 6946** (also known as the Fireworks Galaxy, famed for its numerous supernovae), located just 39' apart on the Cepheus-Cygnus border.

Much of what's been written about this unusual duo concentrates on the alluring face-on galaxy. My desire here is to treat both items equally as a celestial set piece that can be appreciated at a wide range of magnifications in a variety of apertures.

## Taking Their Measure

Frankly, NGC 6939 is no prize. Almost 6,000 light-years from Earth and 1.0–1.3 billion years old, the cluster has become a slowly dispersing family of several hundred evolved suns, some having reached the red giant stage. For experienced telescope users, the "vital signs" of NGC 6939 are hardly noteworthy: a total visual magnitude of 7.8, no members better than magnitude 11.4, and a ragged diameter of perhaps 10'. By any measure, it's only a modest catch among the many glittering glories along the Milky Way.

NGC 6946 is a challenging study. Its relatively close distance — 18 million light-years — seems telescope-friendly, but NGC 6946 lines up less than a dozen degrees from the crowded galactic equator. The 8.8-magnitude object would be nearly two magnitudes brighter if it resided farther from the

obscuring band of the Milky Way. Moreover, the galaxy's sprawling  $11.5' \times 9.8'$  dimensions yield an overall surface brightness of a measly 13.8 magnitudes per square arcminute. Unless your sky is velvety dark, you'll declare NGC 6946 an armless ghost.

But, hey, if we assessed deep-sky wonders by statistics alone, we'd never get outside to observe. In truth, our coarse cluster and gauzy galaxy together display a unique, if subtle, beauty. Let's have a look.

## A Rare Pair

For two specimens so different, NGC 6939 and NGC 6946 in certain circumstances appear amazingly alike. My 4¼-inch f/6 reflector at 22× detects them simply as twin pale clouds. A 7.2-magnitude foreground star (HD 196085) beams blue-white two-thirds of the way from the southeastern cloud

(the galaxy) to the northwestern one (the cluster).

Even in my 10-inch f/5.5 Newtonian at 34×, the tandem targets remain comparable in size since barely more than the central portion of the bigger cloud — the galaxy — materializes. An undramatic scene, yes, but the low-power view includes an attractive bonus. NGC 6939 is enclosed by a diamond-shaped asterism, 12' by 16' in extent, delineated by four 10th-magnitude stars. If we add the 7.2-magnitude foreground star and a few others, the asterism outlines a kite whose tail of ribbons extends to a 7.8-magnitude star (HD 196053) a little more than 30' south of the cluster and some 20' west of the galaxy. Nice!

A longer inspection in the 10-inch at 47× is tantalizing. The galaxy is still extremely diffuse; however, it's heftier in the middle and clearly elongated north-northeast by south-southwest. At the northeast end the misty mass bends eastward, while at the southwest end it veers westward — a hazy-lazy backward S. By contrast, the cluster is a crisp, grainy patch. Patient staring at 58× morphs the grain into a salting of suns detached from the surrounding stars of the Milky Way.

## The Cluster in Detail

NGC 6939 sparkles in my 18-inch f/4.5 Dobsonian. Fully resolved at 69×, the cluster exhibits two remarkably straight



PINWHEEL AND KITE: GIANLUCA MASI / VIRTUAL TELESCOPE PROJECT / MICHAEL SCHWARTZ / TENAGRA OBSERVATORIES, LTD.; NGC 6946: GIANLUCA MASI / VIRTUAL TELESCOPE PROJECT; NGC 6939: GIANLUCA MASI / VIRTUAL TELESCOPE PROJECT



chains of stars at right angles to each other. At lower magnifications (about 50× for my 18-inch), the chains blur into seemingly solid lines. Knowing where to stare, I can follow them in my 10-inch, too.

The lines, approximately 5' to 6' in length and not equally obvious, meet at a pinpoint vertex — the cluster's 11.4-magnitude lucida. The stronger line comprises 12th- and 13th-magnitude stars slanting southeastward from the vertex, roughly in the direction of NGC 6946. The fainter line is delineated by 13th- and 14th-magnitude stars trending northeastward across

the cluster's moderate central condensation. If I double the power, the many extremely dim stars in that mild concentration tend to break up the straight-line illusion.

Remember my kite asterism? The 9.9-magnitude star marking the kite's east corner is accompanied by an easily spotted 13.5-magnitude companion 20" eastward. High-power scrutiny of the 10.5-magnitude star at the top of the kite shows it harboring a 14.6-magnitude attendant 16" east, plus a wee dot 14" north. Indeed, I count eight or nine 13th- to 15th-mag stars within a 90"-wide area encircling the 10.5-mag-

nitude star — a teensy cluster aside "gigantic" NGC 6939.

## "Arming" the Galaxy

It was on a perfect September night in 2011 that I truly got to know NGC 6946. The backwards S effect was sublime at 78× in a friend's 20-inch f/4 Dobsonian (effectively f/4.6 using a Tele Vue Paracorr coma corrector). Upping the power to 137× revealed the most prominent arm and its lesser inboard companion curling counterclockwise from the northeast end. At the southwest end, a fan-shaped arm angled sharply northward. South of center, a stubby fila-



◀ **PINWHEEL AND KITE** The impact of NGC 6939, a loose open cluster, and NGC 6946, a face-on spiral galaxy, is quite different in photographs than in telescopes. Unlike the impression given here, the cluster is easier to see in the eyepiece than the low surface brightness galaxy. Tracing the pinwheel shape of NGC 6946 in large optics is a challenging but rewarding exercise. Wide-field scopes can trace the delightful "kite" asterism that captures NGC 6939. The field of view is approximately 60' × 60'.

◀◀ **PALE COMPLEXION** The pallid face of the spiral galaxy NGC 6946 is enlivened by densely packed star clusters and immense H II regions. The nebulous knots labeled 1 and 2 are visible in mid-size reflectors and correspond to the same knots in S&T: July 2013, p. 60.

▲ **SEEING THINGS** In the open cluster NGC 6939, two linear chains of stars form a right angle whose vertex is marked by the cluster's 11.4-magnitude lucida. The chains can blur into solid lines at low magnification. Note the galaxy PGC 166193 (marked with an arrow) a little more than 3" northeast of the topmost star of the kite. The author has not been able to detect this minute mist, likely because of interference from an overlaying 16th-magnitude star.

ment protruded southwestward a short distance. So, three arms for sure and maybe a fourth.

The pallid pinwheel showed best in a 13-mm Ethos ocular that delivered (with the Paracorr) 180×. Numerous stars were scattered across the galaxy, and a wavering nucleus emerged in its oval core. The adjacent east-end appendages diverged from the core, the inner arm heading southward, the outer arm curving past a 14th-magnitude star, then extending tenuously southeastward to a fuzzy knot. The fan-shaped third arm at the core's opposite end stretched northward. The stubby fourth arm south of center was traced to a dim double of 20" separation. Northwest of it, a vague haze — the start

of a fifth arm — extended westward to a broader knot.

The knots intrigued me. I figured they were H II regions, yet they vanished when I applied an Ultra High Contrast nebula filter. In a *Going Deep* column two years later (*S&T*: July 2013, p. 60), Steve Gottlieb cleared the mystery when he referred to the larger knot as “a huge stellar and gas complex spanning 2,000 light-years and containing more than a dozen tightly packed clusters.” Those nebulous-looking knots are incredibly rich in luminous blue giant stars!

**Pushing Deeper**

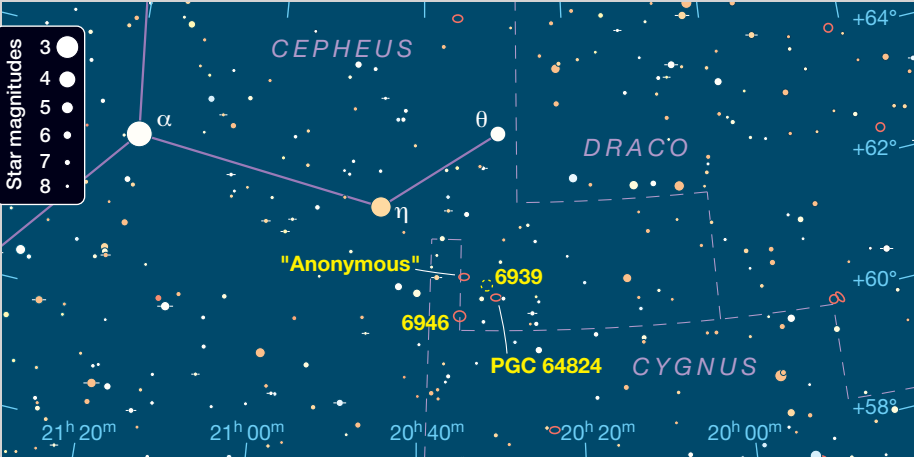
I'm always poking around my chosen telescopic subjects for obscure “back-

ground” galaxies. During this project, I struck pay dirt twice.

**PGC 64824**, a 13.7-magnitude galaxy of very low surface brightness, lies almost three-quarters of the way from the 7.2-magnitude star in the tail of my “kite” to a 7.7-magnitude star (HD 195607) 20' east. Measuring 2.3' × 0.6', PGC 64824 is a thin vapor elongated east-west. A 14.6-magnitude star flickers near its eastern tip. I glimpsed the feeble fog in my friend's 20-inch Dob at 290×, then again in my 18-inch at 228×, on the perfect night mentioned above. The high magnification was helpful, as it permitted me to exclude an unwanted “streetlamp” — the 7.7-magnitude field star. I also noticed an **anonymous galaxy** 90" south of a 10.5-magnitude star about 20' east-northeast of NGC 6939. In my scope at 228×, the mystery smudge was tiny and faint.

Let me end with some encouragement for owners of smaller telescopes. As I indicated earlier, a 10-inch will provide at least partial access to these delicate wonders. I once observed essentially everything described here (except the “fog” galaxy) in a 15-inch f/5 Dobsonian. Cruising at 146× in crystal-clear conditions, the 15-inch gave me three good arms and both knots on NGC 6946. The neighboring cluster was fabulous. Never forget: The key to appreciating this seriously attractive combo is a seriously dark sky.

■ Contributing Editor **KEN HEWITT-WHITE** probes the deep sky from the 6,000-foot summit of Mount Kobau in southern British Columbia.



## On the Border of Cygnus and Cepheus

Object	Type	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
NGC 6939	Open cluster	—	7.8	10'	20 <sup>h</sup> 31.5 <sup>m</sup>	60° 40'
NGC 6946	Spiral galaxy	13.8	8.8	11.5' × 9.8'	20 <sup>h</sup> 34.9 <sup>m</sup>	60° 09'
PGC 64824	Irregular galaxy	13.9	13.7	2.3' × 0.6'	20 <sup>h</sup> 30.2 <sup>m</sup>	60° 26'
“Anonymous”	Undefined	—	—	—	20 <sup>h</sup> 34.3 <sup>m</sup>	60° 46'

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



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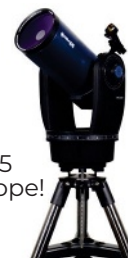
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# Autumn

## in the Suburbs

The right telescope and a little persistence will help you see these subtle wonders.

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**A**fter moving from my urban neighborhood to the suburbs a few summers ago, I was thrilled to be able to observe the deep sky from the backyard again. No more gathering all the gear and driving 20 miles to a dark site. I could enjoy star clusters, nebulae, and galaxies without leaving home.

It was wonderful viewing prominent summer objects like M13 and M57 from the comfort of the backyard. When fall began, however, observing became more difficult. Autumn's sky has some bright deep-sky wonders, but most are subdued compared to the glories of summer. Fall backyard observing is harder and requires a different telescope than the one I'd used in summer.

In the summertime, my ultra-portable 4-inch refractor did amazingly well on the season's bright objects. Unfortunately, it wasn't up to the challenge of autumn's delicate marvels. For them, more power was required in the form of a larger, but still portable, 10-inch Dobsonian reflector. I also found myself spending more time observing objects in an effort to pick out faint details. It wasn't unusual for me to spend at least half an hour on each.

Let's begin tonight's autumn suburban sky tour in a "summer" constellation, little Lyra, the Lyre, which still rides high in the west as fall comes in. Lyra is famous for two things: its brightest star, the beautiful and luminous zero-magnitude

Vega, and M57, the Ring Nebula. Have a look at the Ring if you like — I'll wait — but we're after dimmer quarry tonight.

**M56** (NGC 6779), a magnitude-8.3 globular star cluster with a 5.0' diameter sounds as if it should be easy. Its specs lead you to believe that while it's no M13, seeing it shouldn't be difficult with a small telescope. That's what I assumed when I was a young astronomer observing the Messier objects

for the first time from my parents' backyard. But M56 is far from easy, as novice me found out after hunting it fruitlessly all summer long with my 4-inch Newtonian reflector. Finally, on a cool, clear, and dry early autumn night, I spotted something in the correct spot, a dim smudge just on the edge of visibility.

The problem is M56's central area is loosely packed with stars. It's a Class X (10) on the 12-step Shapley-Sawyer scale that organizes globular clusters according to their central concentration from "tight" to "loose." That looseness makes the cluster

tend to melt right into the sky. Use at least 8 inches of aperture and a medium-magnification eyepiece. An eyepiece yielding 125–150× will darken the sky background but won't magnify the cluster so much that its light is spread out and dimmed.

With M56 centered in the 10-inch, I see a dim globular just beginning to resolve around its periphery. Many of the tiny stars tend to wink in and out of view and are best seen

**But M56 is far from easy, as novice me found out after hunting it fruitlessly all summer long with my 4-inch Newtonian reflector.**



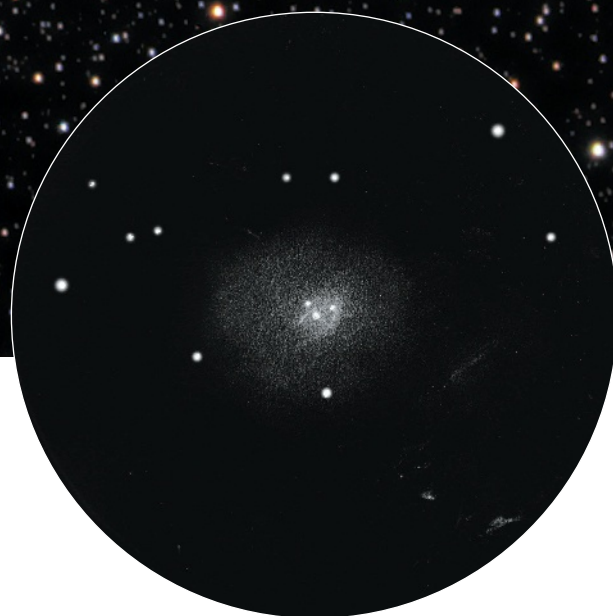


► **CHALLENGING CHASE** Time your hunt for M56 to a forecast for clear, dry air. Because stars only loosely pack the center of this globular cluster, finding it with a small scope can be tough.

with averted vision, by looking away from the cluster instead of directly at it. That brings the eye's dim light receptors, the rods, into play. There's also a trio of brighter stars near the core, but that's it. Yes, it looks better than it did to my teenage eyes, but not *that* much better.

Moving from the sinking summer constellations brings us to the heart of the fall sky, to Andromeda for **NGC 404**, a magnitude-10.3 elliptical galaxy. "Magnitude 10.3" and "elliptical galaxy" make it sound like a difficult target, but it shouldn't be hard with an 8- or 10-inch telescope — if you know how to see it.

This sprite is frequently called "Mirach's ghost" because it's a mere 7.0' northwest of the brilliant magnitude-2.0 star Mirach, Beta ( $\beta$ ) Andromedae. The dim, nearly round galaxy looks just like a faint reflection of the star in the eyepiece, a ghost image of Mirach.



To see the ghost, train your telescope on NGC 404's position, then ease Mirach out of the field of view. With the star in sight, the galaxy may be rendered invisible. An eyepiece that yields about 150 $\times$  will help the galaxy stand out better and will keep Mirach well outside the field.

In the 10-inch, the view was thought-provoking. In my logbook, I noted, "At times I can fool myself into thinking I see some sort of detail in NGC 404, but it's really just a gray oval of light with a bright, small center." While many deep-sky object catalogs list the galaxy as being round, it appears slightly oval visually. In photographs, the glare of nearby



Mirach tends to drown the galaxy out in all but short exposures, so it's difficult to tell what NGC 404's true shape is.

What is Andromeda's most famous deep-sky object? Even novice astronomers know about Messier 31, the Great Andromeda Galaxy. M31 is certainly not difficult. Nor is the brightest of its satellite galaxies, M32. But there's another small galaxy orbiting M31 that can be a significant challenge without being impossible from the backyard. **M110** (NGC 205) is a magnitude-8.5 elliptical galaxy that spans a large  $17.8' \times 9.8'$ . As always, for a given brightness, "bigger" means dimmer.

M110 is famous largely because it's close to M31 — it's just  $37.0'$  northwest of the center of the big galaxy. Otherwise, it can be distinctly lackluster in smaller instruments. In fact, I found the galaxy completely invisible in my 4-inch refractor on poorer nights. In an 8-inch or larger scope, however, M110 can put on quite a show.

Elliptical galaxies tend to be boring visually; they're just



▲ **CELESTIAL SPECTER** Sometimes "faint fuzzies" aren't all that much to look at, and on its own, NGC 404 might not offer much of a view. But this ghostly galaxy pairs with Beta (β) Andromedae (Mirach) to form an eye-catching tableau.

huge balls of ancient stars and don't show much detail. On a superior evening, however, M110 is attractive and interesting. It's strongly elongated and at  $200\times$  and higher magnifications it looks a lot like M31 does in a pair of binoculars: it shows a nebulous streak with a brighter center. On the best nights, my 10-inch shows a tiny star-like nucleus and even (very) faint hints of dark structure. M110 is a beauty and worthy of extended observation.

Not all autumn objects are challenging. There are a few spectacular ones as well. Let's take a break from the subtle and observe one of

the best globular star clusters in the sky, mighty **M2** (NGC 7089), a magnitude-6.5 ball of suns that spans  $16.0'$  of sky, nearly half the size of the full Moon.

You'll be impressed by M2 in the eyepiece. Even my 5-inch Maksutov-Cassegrain scope turns the cluster into a spectacle. While it's not completely resolved, there are enough cluster stars on display to make it very pretty. As always with globulars, higher power brings dimmer stars into view. While M2's impressively bright center wasn't resolved, it looked grainy at times, as if just on the verge of resolution. With the 10-inch, I can see stars all across the face of the cluster.

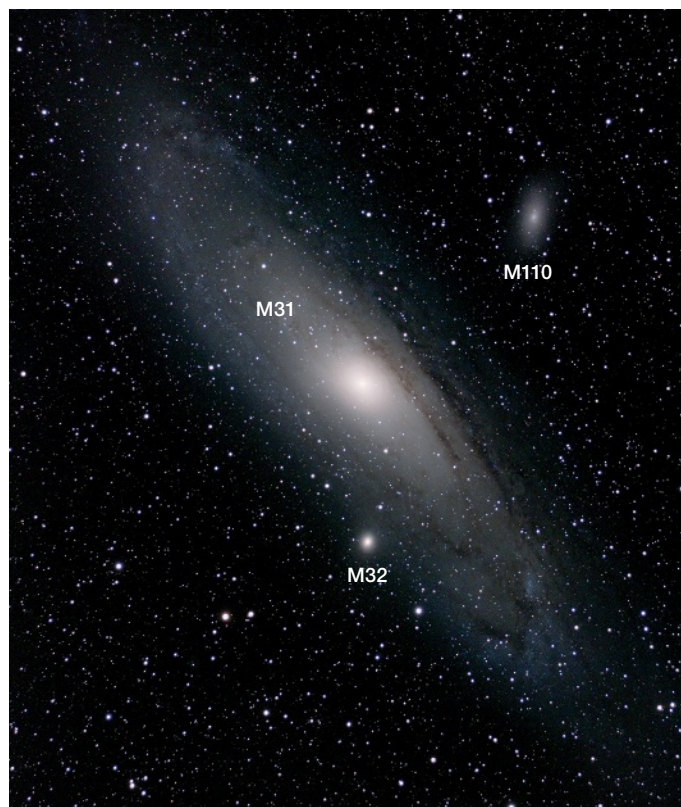
While we're in the neighborhood, let's visit Aquarius's other Messier globular cluster, **M72** (NGC 6981) — just don't expect too much. M72 is a magnitude-9.2 Class XI (11) cluster that's  $5.9'$  in diameter. It's dimmer and larger than troublesome M56 and even more loosely concentrated.

I don't think I ever saw M72 from my backyard as a novice. Today, it can still be challenging, even with a 10-inch and all my years of experience. The cluster is almost always visible in the Dobsonian, but it's just a smudge, a dim smudge, and doesn't show a hint of resolution.

When you spot M72, give it as much magnification as it will take given sky conditions. Usually it's just a dim fuzz ball, but occasionally it acts as if it almost wants to resolve in the 10-inch, showing considerable graininess. I have never, however, actually resolved its stars from the backyard.

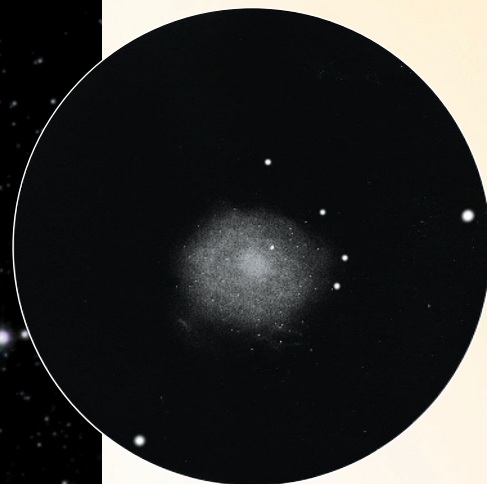
Before leaving the area, if you need to log **M73** (NGC 6994), a little group of four 10th-magnitude stars  $2.0'$  across that Charles Messier mistakenly thought was involved with nebulosity, move the telescope  $1^\circ 20'$  east of M72. Look for a dim but noticeable kite-shaped group of suns. While the group is occasionally referred to as an open star cluster, it appears the members are unrelated; it's just an asterism, a chance arrangement of stars.

Were you successful with M72? If so, try pushing forward the backyard frontiers even more with a galaxy in Aquarius's neighboring constellation Cetus: **NGC 1055**, a magni-



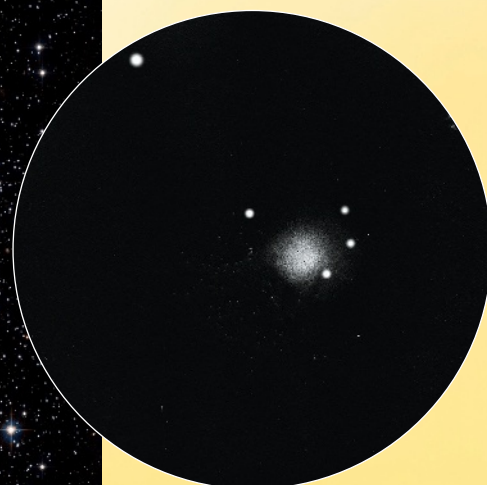
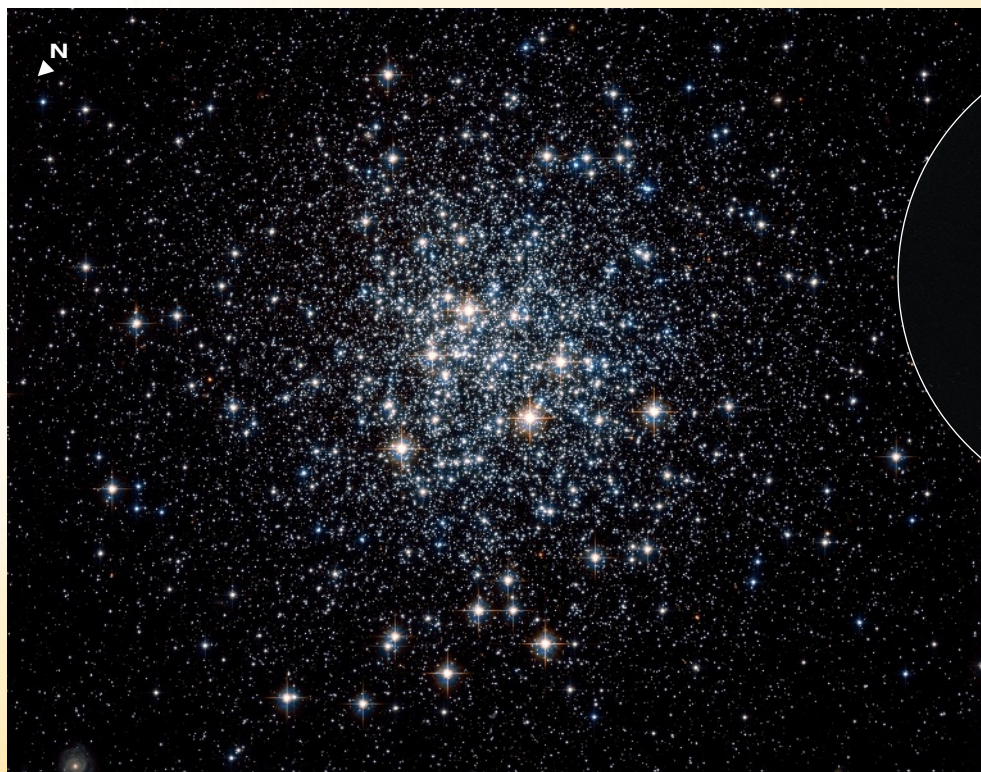
▲ **GOOD CATCH** The general region of M110 is easy to find, as even in the suburbs, its neighbor, M31, is visible to the naked eye. Digging M110 out of the deep takes more effort.





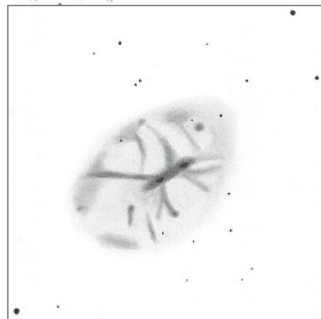
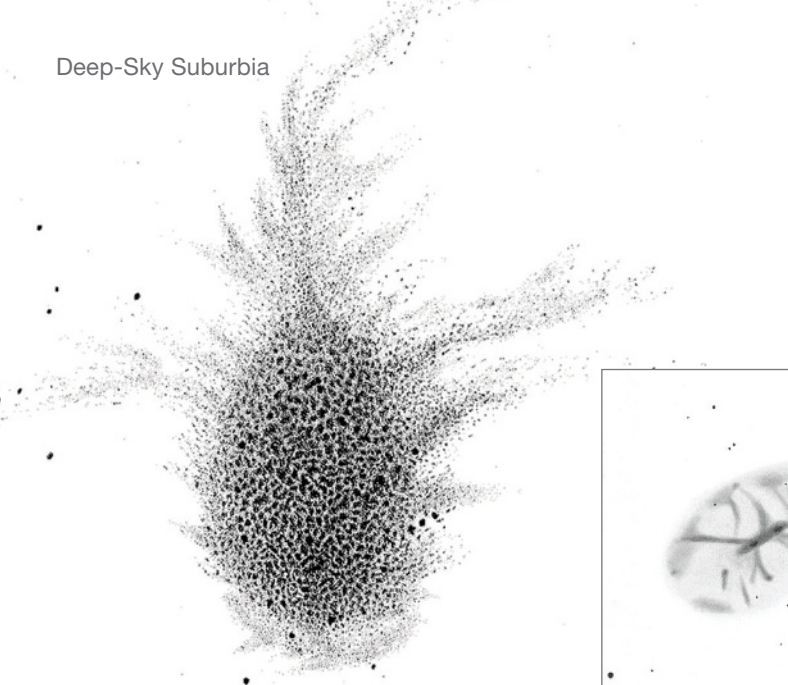
◀▲ **GLOBULAR GLORY** M2 offers an impressive view, with a grainy center surrounded by a thousand pinprick suns. The cluster forms a scalene triangle with Alpha and Beta Aquarii less than  $1^\circ$  south of the celestial equator.

**You'll be impressed by M2 in the eyepiece. Even my 5-inch Maksutov-Cassegrain scope turns the cluster into a spectacle.**



◀▲ **FEELS LIKE VICTORY** M72 has thwarted many experienced observers, so don't lose heart if you don't find it your first night out. It's dim, large, and loose, and doesn't look like much more than a smudge even in a 10-inch reflector such as the one used by the author to make the above sketch.





▲ **EYE OF THE BEHOLDER** What you see in the eyepiece can be very subjective, as shown by these two sketches of the supernova remnant M1. The details captured in the sketch by Uwe Glahn (*inset*) came via his 27-inch reflector at 366 $\times$ . His depiction differs greatly from that of William Parson, 3rd Earl of Rosse, who produced the first known sketch of this diffuse nebulosity as viewed through a 36-inch reflector with speculum mirror at magnifications from 250 $\times$  to 800 $\times$ . Though it seems to depict a pineapple, Lord Rosse's drawing gave rise to M1's nickname, the Crab Nebula.

tude-10.5 spiral with a size of 6.2'  $\times$  2.9'. For best results, look for the galaxy when Cetus is well away from the horizon.

In long-exposure photos, NGC 1055 is an impressive, nearly edge-on spiral with a prominent equatorial dust lane. You won't see any of that with a backyard telescope, of

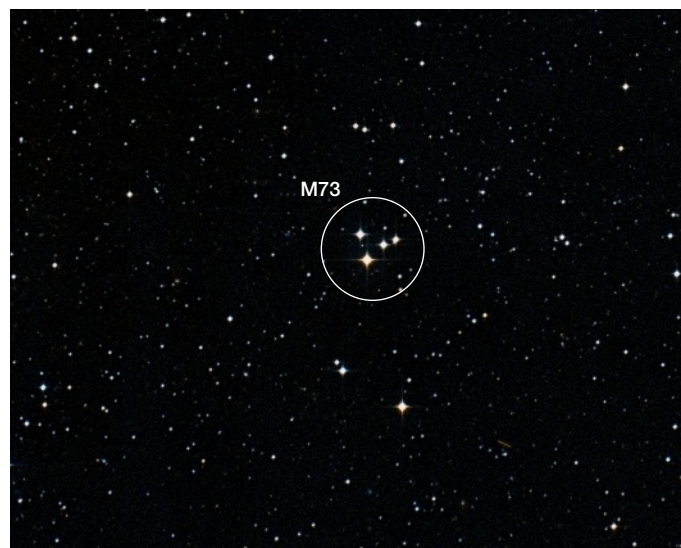
course. At 150 $\times$  with the 10-inch, it's a dim, round smudge. Eventually, I begin to see the galaxy is elongated east-west, but that's all. Two prominent 8th-magnitude stars lie 7.0' north of the galaxy and form an equilateral triangle with it. The effect is like a little happy face staring at you across the light-years.

With the night growing old, the winter stars have begun to rise, and with them Taurus and the supposedly spectacular **M1** (NGC 1952). Unlike M72, I was able to see our next destination, the famous Crab Nebula supernova remnant, from my boyhood backyard. Unfortunately, it didn't look like the beautiful pictures in the astronomy books in my school library. There, it was an amazing vista of intertwining wisps and tendrils of nebulosity. In my little reflector? It was a faint oval smudge.

The Crab, which spans 8.0'  $\times$  10.0' of sky, isn't terrifically dim, shining at magnitude 8.4. The problem is it's a *nebula*. Nothing is harmed more by backyard light pollution than nebulae. While some can be improved with light pollution reduction (LPR) filters, not all respond strongly to filters. Unfortunately, the Crab is one of those.

Use as much telescope aperture on M1 as possible. A 10-inch brings considerable improvement compared to a 4-inch. The nebula is not just brighter; it looks more like an S shape than a mere oval. I've been able to spot a few more details, hints of the crab's "claws," the tendrils of gas, from suburban skies, but it took a 24-inch Dobsonian to do that.

Let's return to Aquarius, which is now riding high, and end on **NGC 7293**. The Helix is a huge planetary nebula, the corpse of a long dead star. Its statistics make it sound



▲ **MISTAKEN IDENTITY** Charles Messier thought he detected nebulosity surrounding this modest group of stars; however, his conclusion must have been the result of a trick of the eye — or eyepiece. The stars of this asterism are not physically related.

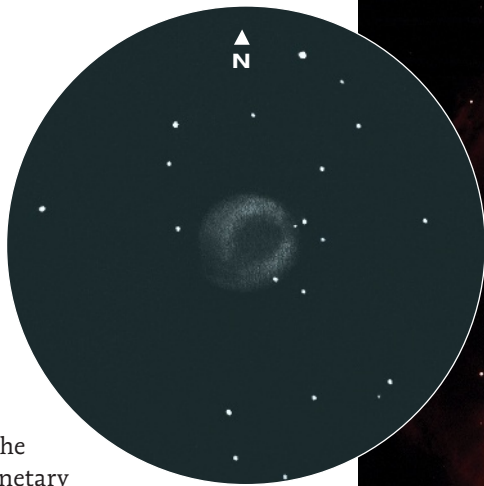


▲ **IMPRESSIVE EDGE-ON** Through amateur scopes, NGC 1055 appears as a round smudge, slightly elongated east-west. The galaxy forms an equilateral triangle with two 8th-magnitude stars to its north. NGC 105 lies about about 52 million light-years away in the direction of Cetus.

INSET: M1 SKETCH: UWE GLAHN; LORD ROSSE M1 SKETCH: PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON (1844) / PUBLIC DOMAIN; M73: POSS-11 / CALTECH / STSCI / PALOMAR OBSERVATORY; NGC 1055: ESO



► **YOU NEVER KNOW** NGC 7293, more commonly known as the Helix Nebula, is big and very, very dim — but that doesn't mean you shouldn't look for it! At first glance, it may seem like nothing more than a subtle brightening, but adding a light-pollution filter to your eyepiece can pull out its circular shape and possibly some of its wispi-ness.

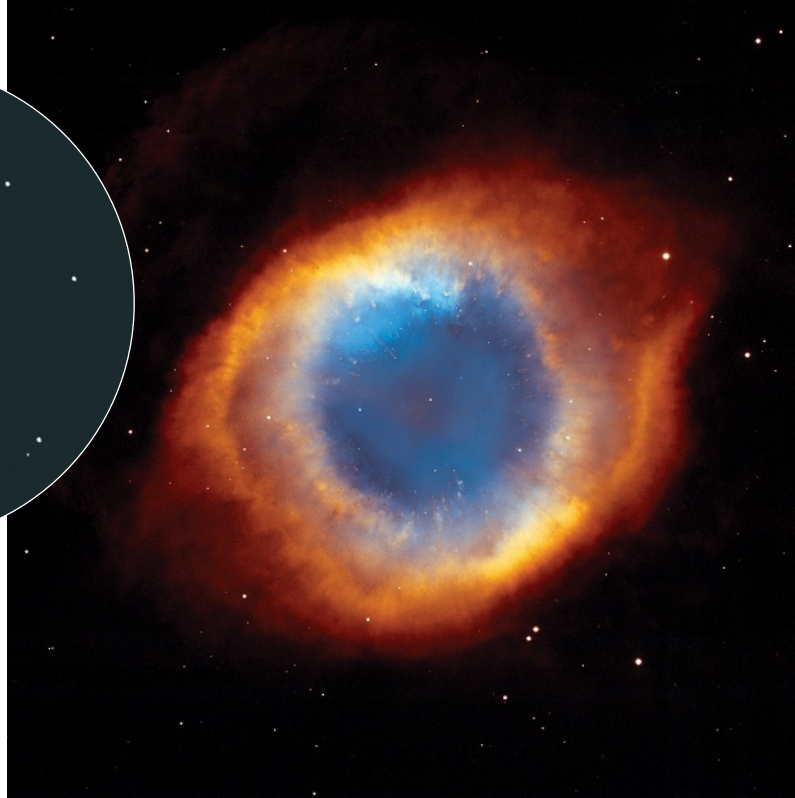


like a backyard no-no. Not only is it a nebula, it's a big nebula. The Helix is 15.3' × 12.0' — most planetary nebulae are less than 1.0' in size. While it's relatively bright at magnitude 7.3, its light should be considerably spread out due to the nebula's substantial size.

For years, I never tried to observe the Helix from the backyard, being content to view it from dark sites where it put on a good show in my 6-inch refractor. One night, however, I was in the backyard with the 6-inch and on a whim decided to have a look for the Helix.

I put my eye to the eyepiece without any expectations. Surprise! It wasn't bright, but the Helix was there. Adding an LPR filter to the ocular improved the view considerably. I could now see the Helix's ring shape. The darker center can occasionally be difficult even from country skies. Although I couldn't see any of the spiraling loops of nebulosity that give the Helix its name, I was thrilled with what I was seeing. In amateur astronomy, never assume. Try anyway.

And so, we come to the end of tonight's sky tour. There's much more to the autumn backyard sky than just the marvels we've admired here. For instance, we didn't visit any of



the multitudinous galaxies lurking in Pegasus. Many of those dim sprites are visible from the suburbs, but nevertheless, they're for another backyard evening. It's now time to take our faithful telescope inside and ruminate on the wonders we did see in our suburban night sky.

■ While he can still be found at star parties, Contributing Editor and retired engineer **ROD MOLLISE** now enjoys observing from his suburban backyard. While the skies aren't perfect, he can cruise the deep sky every clear night.

## Suburban Deep-Sky Sights

Object	Type	Constellation	Mag(v)	Size	RA	Dec.
M56	Globular cluster	Lyra	8.3	5.0'	19 <sup>h</sup> 16.6 <sup>m</sup>	+30° 11'
NGC 404	Lenticular galaxy	Andromeda	10.3	3.5 × 3.5'	01 <sup>h</sup> 09.4 <sup>m</sup>	+35° 43'
M110	Elliptical galaxy	Andromeda	8.5	17.8' × 9.8'	00 <sup>h</sup> 40.4 <sup>m</sup>	+41° 41'
M2	Globular cluster	Aquarius	6.5	16.0'	21 <sup>h</sup> 33.5 <sup>m</sup>	−00° 49'
M72	Globular cluster	Aquarius	9.2	5.9'	20 <sup>h</sup> 53.5 <sup>m</sup>	−12° 32'
M73	Open cluster	Aquarius	8.9	2.8'	20 <sup>h</sup> 58.9 <sup>m</sup>	−12° 38'
NGC 1055	Spiral galaxy	Cetus	10.5	6.2' × 2.9'	02 <sup>h</sup> 41.8 <sup>m</sup>	+00° 27'
M1	Supernova remnant	Taurus	8.4	8.0' × 10.0'	05 <sup>h</sup> 34.5 <sup>m</sup>	+22° 01'
NGC 7293	Planetary nebula	Aquarius	7.3	15.3' × 12.0'	22 <sup>h</sup> 29.6 <sup>m</sup>	−20° 50'

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

# Backyard Spectroscopy with *RSpec*

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Backyard spectroscopy used to be expensive and difficult, but Tom Field's affordable *RSpec* software and grating lets users identify elements in the atmospheres of stars and bright deep-sky objects.

It had been known for centuries that shining a beam of light through glass or crystal could produce a rainbow (Isaac Newton coined the term color spectrum for the rainbow produced by a prism), but they were mostly considered pretty curiosities until German physicist Gustav Kirchhoff came along in the 19th century. Early researchers had noted that some spectra showed curious vertical lines crossing the rainbow. Kirchhoff realized these lines were the fingerprints of the elements. Each element has its own particular set of lines at specific wavelengths.

Devices called spectroscopes were developed that could tease more information out of starlight beyond the elements that are present in the star's atmosphere. For example, we can study a star's spectrum to learn how massive and hot it is. Is the star old or young? How does it compare to other stars? With a sensitive camera and enough light-gathering aperture, you can even move beyond stars, analyzing the light of deep-sky objects including nebulae and galaxies. Amateurs have become involved in spectroscopy, but it typically required substantial investment in equipment in the form of a high-resolution spectroscope, a cooled CCD camera, and complex software. *S&T* Contributing Editor Tom Field's *RSpec* changes all that, making spectroscopy affordable and easy.

## RSpec Real-Time Spectroscopy

U.S. Price: \$109  
RSpec-astro.com

### What We Like

Remarkably effective for both capturing and analyzing spectra  
Works with inexpensive diffraction grating  
Intuitive

### What We Don't Like

Lacks a printed manual  
Sensitive to camera driver problems

## FOR ME, ASTRONOMY COMES IN TWO PARTS.

A portion of my time is spent as an astronomy educator, teaching the science of the universe. But I'm also an amateur astronomer, and in that aspect I've mostly confined myself to observing pretty stuff. Occasionally, however, I long to put a little more science into my amateur astronomy. I've found just the thing for that, a clever software program called "*RSpec*."

As you may have guessed from its name, *RSpec* is concerned with spectroscopy. This software, combined with a simple diffraction grating and a digital camera, allows users to record and analyze the spectra of bright stars to reveal which elements are present in these distant suns.

## Required Equipment

While *RSpec* works well analyzing spectra obtained with a spectroscope, the program can analyze spectra recorded through an inexpensive diffraction grating — a piece of glass ruled with thousands of lines that cause it to function like a prism. And though diffraction gratings are not as effective as a conventional spectroscope, they can still produce remarkably detailed spectra.



Amateurs interested in dipping their toes in the world of spectroscopy with *RSpec* can get started with the addition of a Star Analyser 100 Grating (\$195, available at <https://is.gd/RSPEC>). This diffraction grating is grooved with 100 lines per millimeter and mounted in a 1¼-inch filter cell that can be screwed onto the threaded nosepieces included with most astronomical cameras. There are also adapters available that allow the grating to be attached to the lens of a DSLR camera.

Most popular picture formats, including JPG, BMP, and FIT, are supported. The program is not demanding in terms of computing horsepower and worked fine with my seven-year-old laptop running Windows.

The only requirement is that the optical system has enough focal length to provide good resolution of spectra. In the interest of seeing how inexpensive I could keep spectroscopy, I employed my old ZWO ASI120MC, a color video-type camera paired with an 8-inch Schmidt-Cassegrain telescope and an f/7 focal reducer yielding an effective focal length of 1,500 mm. This turned out to be almost perfect for *RSpec*, providing bright images with an image scale of

close to the recommended 10 angstroms per pixel. Using the telescope at f/10 got me even closer, but it became difficult to fit the image of the star and its spectrum onto the small chip of my camera. The 8-inch aperture is more than enough to obtain the spectra of many stars and deep-sky objects.

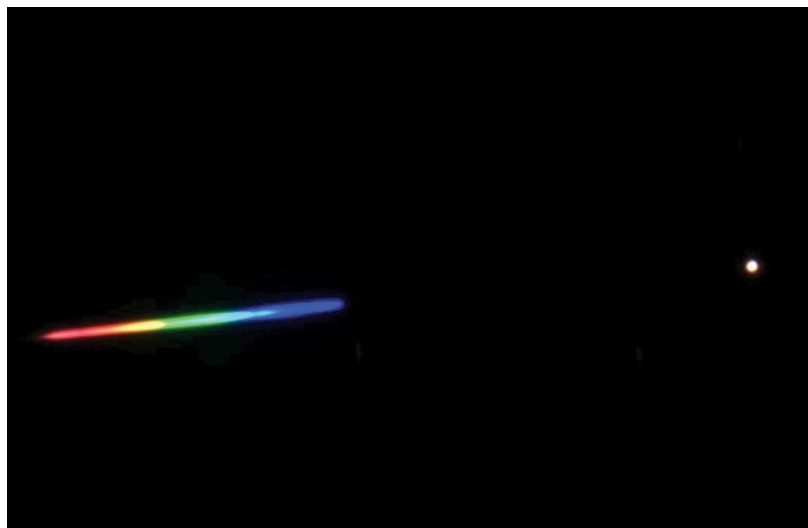
Lastly, there is the *RSpec* software. The program is available for Windows (XP and newer) as a downloadable compressed ZIP file from the *RSpec* website. Downloading and installing *RSpec* was quick and easy, and I was exploring its features within minutes.

The program's user interface is clean and relatively simple. The screen is divided into two halves, an imaging half that displays the camera's live feed or still images, and a "Profile" half. The Profile section in *RSpec* is the graph that represents the spectrum. Many amateur astronomers think of spectra as images of the spectral rainbow, but in professional astronomy in the computer age, spectra are almost always graphs like *RSpec*'s, plotting intensity on the vertical scale versus wavelength on the horizontal scale.



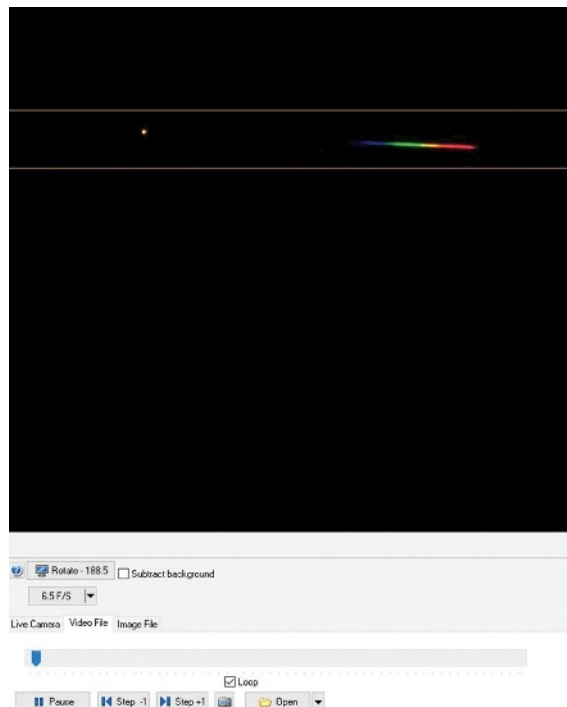
▲ *RSpec* accepts two 1¼-inch cell-mounted diffraction gratings required to spread your target's light into a spectrum that is then analyzed by the software. The Star Analyser 100 Grating includes 100 lines per inch that mounts on the nosepiece of your camera. The Star Analyser 200 Grating provides 200 lines per inch, better suited for use in filter wheels.

One issue I had involved my cameras. After connecting the ZWO ASI120MC camera to my laptop computer and opening *RSpec*, I had trouble getting the program to recognize the camera. An email to the author brought the suggestion that I install the latest drivers for my camera from ZWO's website. After doing so, the program connected to the camera immediately, and all was



▲ Using the Star Analyser 100 on the author's 8-inch Schmidt-Cassegrain with a ZWO ASI120MC camera produces two spectra of the target star (in this case, Vega) — one on each side of the target. Only one spectrum is required, so choose the brightest of the two.

► To begin analyzing a spectrum, you first need to import your spectrum image or video and rotate the image using the Rotate command to place the target star on the left and its spectrum on the right.



well thereafter. A similar issue occurred when I tried using a different camera, so make sure you have installed the latest drivers for your own cameras.

## Capturing Spectra

The process of recording spectra is simple. Select the Live Camera tab and choose your camera from the list that appears after clicking the Open button. Exposure and other adjustments are accessed with a Configure menu. One unfamiliar control for spectroscopy newbies is rotate. This slider allows the image to be rotated to the standard convention in spectroscopy, placing the star's image on the left of the screen and its spectrum to its right. This only affects the displayed image and is not saved with a recording. Finally, two onscreen "bars" are positioned with the mouse to frame the star and its spectrum. This tells *RSpec* to concentrate on the area between the lines.

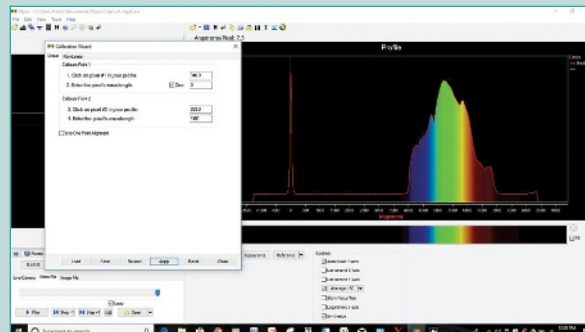
You may have wondered what the R in *RSpec* means: It stands for real-time, as in real-time spectroscopy. As soon as the star and its spectrum are properly placed in the video window, the spectrum's graph appears in the Profile section of the screen. You can analyze the star in real time without recording or saving any images. However, I preferred to concentrate on getting good recordings in the field and analyze the spectra the next day.

With star and spectrum onscreen, I clicked Record to capture my first target, Vega. It's a bright A-type star, and *RSpec*'s author warns users to begin with a star of that spectral type. These stars display strong hydrogen *Balmer lines*, which are useful for calibrating the program. Like any grating, the Star Analyzer produces two rainbows — two spectra, one on either side of the star's image, and one is brighter than the other. Use the brighter of the two.

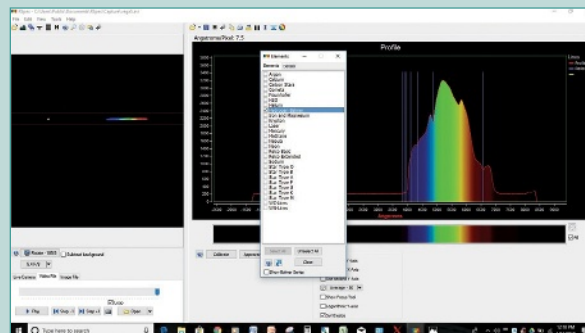
## Spectrometry

Browsing the *RSpec* website and asking Tom Field a question or two had been sufficient to allow me to capture spectra, but before beginning to analyze my stars, I thought I'd better read *RSpec*'s

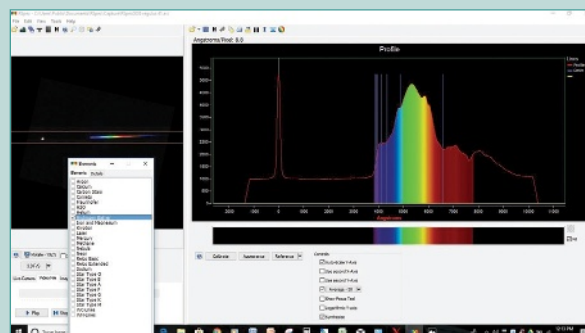
The final step before *RSpec* is ready to analyze spectra is to calibrate the program using an A-type star using the Calibrate function from the pull-down menu. Select the peak in the left side of the graph as Calibration Point 1, and select the first dip in the spectrum, which should represent the first Balmer line, H-Beta, and insert "4861" to denote its wavelength in angstroms.



When calibration is complete, you can open the Elements window in the Profile section and overlay the points of known elements. This screen shows the location of the hydrogen Balmer lines found in the spectrum of Vega.



Calibration should be saved so you can later apply it to other recorded spectra like that of Regulus seen at right.



manual, but I was somewhat surprised to learn that there is none. Well, at least no *written* manual. The program's website contains a library of professional-quality instructional videos detailing every aspect of the software. While I still wished for written instructions, they weren't really necessary. The process of calibrating and analyzing spectra is amazingly simple.

Before doing anything else, *RSpec* must be calibrated. First, the x-axis of

the Profile needs to be converted from pixels to angstroms (used to express wavelength). Once calibrated, the elements represented by the dips in the graph (the absorption lines caused by elements in the star's atmosphere) are easy to determine.

Calibration requires just a few steps. Open your video or image file of an A-type star and its spectrum. If the Profile is jumping around as the video plays due to atmospheric seeing, tick the



Average box at the bottom of the Profile screen. That will steady the graph down. I let my video play until I came to a section that showed the dips, the spectral lines, distinctly. I then paused the video and began the calibration process.

Open *RSpec*'s Calibrate window using Tools > Calibrate. Looking at the Profile, you'll notice a thin spike on the left separate from the rest of the graph. That is the star itself, which you use as the first calibration point. Move the mouse

cursor to the spike's peak and click. The star's pixel value will be automatically entered in the Calibrate Point 1 field. Below that is a field for wavelength. Tick the Zero box to its left.

Calibration Point 2 is on the actual spectrum to the right of the spike. The goal is to click on a dip caused by a known absorption line. That's why it's important to use a prominent A-type star for calibration. A-types show the hydrogen Balmer lines strongly, and the

H-beta line is particularly easy to locate; it's the first dip to the left of the Profile's peak. Click on that "valley" and enter "4861" in the wavelength field. And that's it — calibration is complete and should be saved for use with other stars.

The program can overlay lines of various elements on the calibrated Profile so you can verify your calibration is accurate. Clicking the Elements icon (three vertical lines) in the Profile section's toolbar yields a window with a list of various element lines. Tick the Balmer Series box and the Balmer lines will be drawn on the Profile. If the hydrogen beta line runs through the dip you selected, you are good.

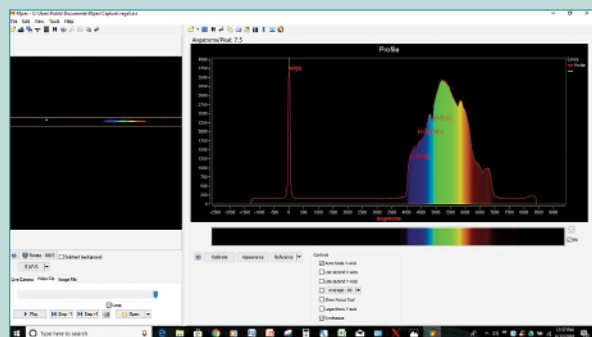
Note that due to poor seeing and other factors, spectral lines may not always coincide exactly with the Profile's valleys. Also, some of the dips may not be strong depending on the sensitivity of the camera and the spectral dispersion the telescope delivered. I was thrilled to see my graph showed the Balmer lines right where they should be.

*RSpec* offers plenty of features. You can use the Elements utility to identify other elements and features in the spectrum. Once calibrated, the profile graph can even be converted into a rainbow using the Synthesize function. While not really as useful as the graph, it's prettier and impresses my students.

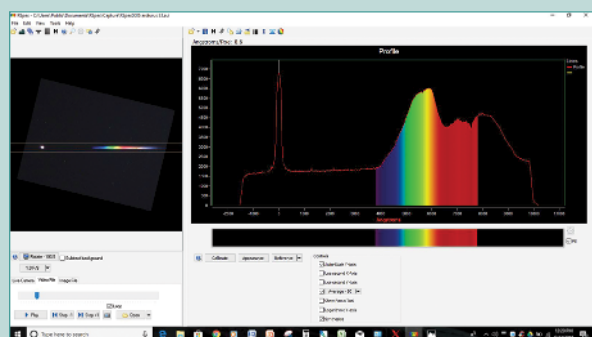
The next step is imaging different star types. Analyzing the spectra of various star classifications combined with a little reading can teach a lot about stars and stellar evolution. Once you are proficient at analyzing the absorption lines of stars, you might try examining the emission lines of nebulae.

Beyond that? Amateurs equipped with *RSpec* and modest telescopes like my 8-inch SCT are doing some amazing science, which range from analyzing the atmospheres of the solar system's gas giants, to determining the red shifts of distant objects including quasars. Thanks to *RSpec*, the limit is not your equipment but your imagination.

■ Contributing Editor ROD MOLLISE enjoys getting some real science out of his time at the telescope.



*RSpec* also allows you to label the elemental lines in your spectrum.



The spectrum of the K-type star Arcturus looks very different from that of an A-type star like Vega.



Another interesting feature of *RSpec* is its ability to overlay and compare the spectra of different targets. This graph compares the spectrum of Vega to that of another A-type star.

# A New Generation Picks Up the Torch

*Zane Landers carries on the grand tradition of telescope making.*

► This sharp smartphone photo of the Moon captured through Zane's 6-inch Dobsonian attests to the excellent quality of his optics.



**I CONSTANTLY HEAR PEOPLE FRET** about the aging of amateur astronomy and bemoaning the decline in popularity of amateur telescope making. While there is definitely some truth in both concerns, Connecticut amateur Zane Landers is quietly proving those fears to be unfounded.

Zane has been into astronomy since he was 12, which was only three years ago. He started with a 4-inch Go To Maksutov that he got for Christmas, but soon became frustrated with the telescope's computer system and its small aperture. He switched to a 6-inch Edmund Newtonian, which he reports "had good optics and worked very well except for the fact that it weighed 70 pounds, looked really ugly, and had stray light problems due to its very short tube." So he tried a 4-inch refractor, which was lighter and more

attractive than the Edmund scope but was uncomfortable to use. So he sold the refractor and bought an 8-inch Schmidt-Cassegrain, but the optics were terrible.

Unhappy with commercial scopes, Zane decided to make his own instead. In May of 2017 he started grinding a 6-inch blank using an old Edmund Scientific mirror kit, and he got it to a nice f/7 curve in relatively short order. Then he made his first major mistake: He decided to use the original rouge and pitch supplied with the 50-year-old kit. He added oil to the pitch to soften it, but the resulting tool was way too inconsistent in hardness and soon got stuck to the mirror.

Zane says, "I tried everything to get the pitch off, but all that resulted was a chipped mirror still stuck to the pitch lap. I did get them separated and

finished polishing/figuring with Gugolz and cerium oxide, but the chips (and a fracture near the edge) meant that it wasn't worth it to get it aluminized and build a scope out of it."

But Zane didn't give up. At Stellafane last summer he was given a 6-inch f/5 pre-generated blank from renowned ATM Dave Groski, who said he could have it for free but he couldn't chip the edges this time.

The grinding phase went very well, and the mirror didn't stick to the pitch, but after polishing for what Zane terms "a ridiculous amount of time (probably dozens of hours) to give the mirror as perfect a polish as I could give it," a Ronchi test revealed a severely turned-down edge.

"I polished like a maniac for about 14 hours over the course of a few days with short strokes to remove it," Zane said, and he was successful. Parabolizing was fairly straightforward, although it took about five times as long as the books and websites he consulted said it would. When he was finished, the mirror came in at f/4.5. Total time on this mirror: two and a half weeks.

Zane sold his 8-inch SCT to finance construction of the scope for his new mirror. He used an 8-inch Sonotube lined with cork painted flat black, and he made sure to extend the tube far enough to shield the focuser from stray light.

As for the mount, Zane says, "I'm proud of this part. I'd never done any woodworking before and only used a drill maybe once previously." Yet he



▲ Zane's second completed scope is a 16-inch f/5 (seen at left), which required that he refigure the primary mirror (right).







▲ Zane Landers with his first home-built, hand-polished 6-inch f/5 telescope.

came up with a perfectly serviceable Dobsonian mount. After experimenting with wood on furniture felt padding for the bearings, he finally settled on a vinyl record and Teflon for the azimuth bearing and PVC on Teflon for the altitude bearings. The primary mirror cell is constructed from plywood.

"First light was awesome," Zane says. His first object, the Pleiades, looked great at 21×. The Andromeda Galaxy (M31) showed a dust lane, M15 was resolved to the core, and he even spotted Neptune's moon, Triton. Zane has used the scope up to 250× and reports it would probably take more if he had a shorter eyepiece or a stronger Barlow.

Many people would stop there, but Zane quickly started right in on a 12-inch blank, then switched to a 16-inch mirror that needed refiguring. He then traded that mirror for another 16-inch and has just finished the scope to go with it. At this rate, he'll be building meter-class telescopes before he gets out of high school.

When I hear about someone like Zane, I don't worry about the future of amateur astronomy or amateur telescope making. Zane could carry the entire hobby by himself for a generation.

■ Contributing Editor JERRY OLTION fell down the ATM rabbit hole about the time Zane was born and wishes it had happened sooner.

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**GREEN FLASH**

Jim Grant

While observing from Sunset Cliffs in San Diego, California, on the evening of December 13, 2017, this stunning example of the elusive green “flash” over the Pacific Ocean occurred due to differential refraction in the atmosphere.

**DETAILS:** *Nikon D7000 DSLR camera with 300-mm lens at f/5.6. Total exposure: 1/2,000 second at ISO 200.*







### △ EMERGING VULTURE

Eric Africa

Number 777 in *Lynds' Catalogue of Bright Nebulae* is a dusty patch in Taurus known by some as the Vulture Head Nebula, located just 5° northeast of the Pleiades (M45).

**DETAILS:** Takahashi TOA 130F refractor with an SBIG STL-6303 CCD camera. Total exposure: 13.5 hours through LRGB filters.

### ◁ GRAND SPIRAL

Warren Keller, M. Hanson, S. Mazlin, R. Parker, T. Tse, P. Proulx

Messier 61 is a large barred spiral galaxy in the Virgo Cluster that is undergoing a high rate of star-birth activity.

**DETAILS:** RCOS Ritchey-Chrétien with FLI ProLine PL16803 CCD camera. Total exposure: 45 hours through LRGB color filters.

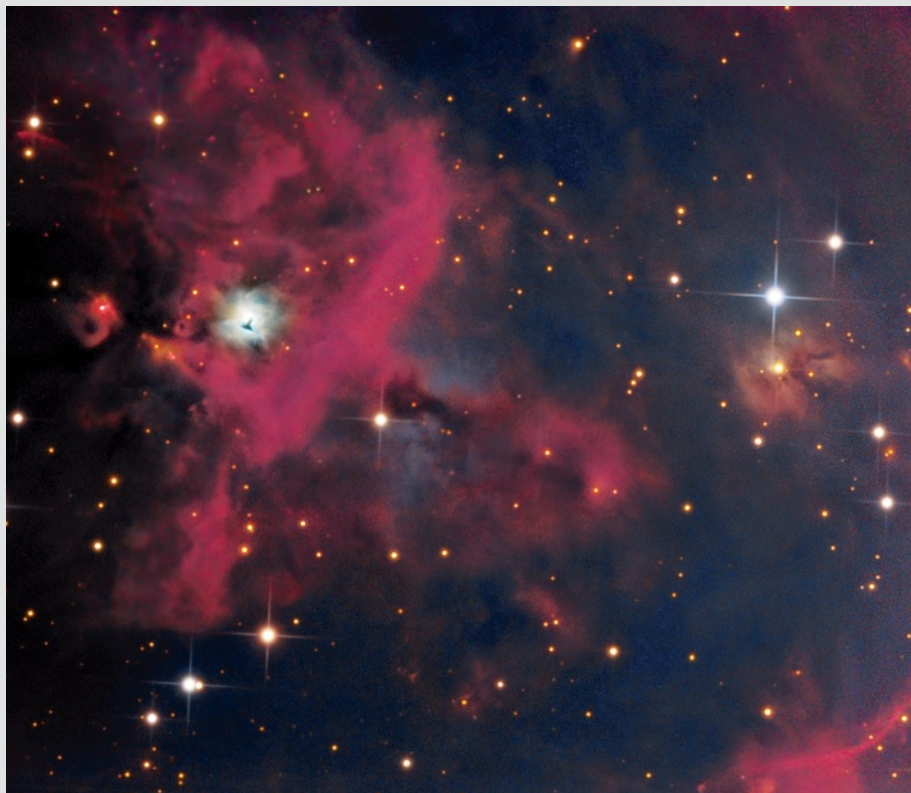


### ▷ HOLE IN SPACE

Bruce Waddington

The reflection nebula NGC 1999 at left in the image is surrounded by glowing red hydrogen emission nebulae that permeates the region. The black area in the middle of NGC 1999 is a void carved out by the fierce stellar wind of the young star V380 Orionis.

**DETAILS:** PlaneWave Instruments 12.5-inch CDK astrograph with QSI 640ws CCD camera. Total exposure: 9.8 hours through LRGB color filters.



### ▽ PINNACLE TWILIGHT

Bruce Burgess

Dissipating cloud wisps add an other-worldly quality to this evening twilight shot taken at Cape Split in Nova Scotia, Canada, on the evening of June 3rd.

**DETAILS:** Canon EOS 6D DSLR camera with 25-mm Carl Zeiss lens at f/2. Total exposure: 30 seconds.



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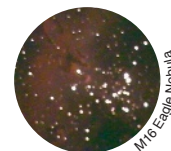
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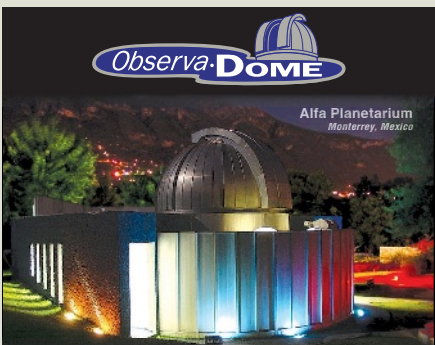
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# Event Calendar

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

- August 4-12  
**MOUNT KOBAY STAR PARTY**  
Osoyoos, BC  
[mksp.ca](http://mksp.ca)

August 5-10  
**NEBRASKA STAR PARTY**  
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August 7-12  
**OREGON STAR PARTY**  
Indian Trail Spring, OR  
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August 8-13  
**SASKATCHEWAN SUMMER STAR PARTY**  
Maple Creek, SK  
[sssp.saskatoon.rasc.ca](http://sssp.saskatoon.rasc.ca)

August 9-12  
**STELLAFANE CONVENTION**  
Springfield, VT  
[stellafane.org/convention](http://stellafane.org/convention)

August 9-12  
**STARFEST**  
Ayton, ON  
[nyaa.ca/starfest.html](http://nyaa.ca/starfest.html)
- August 10-19  
**SUMMER STAR PARTY**  
Plainfield, MA  
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August 23-26  
**THEBACHA AND WOOD BUFFALO DARK SKY FESTIVAL**  
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[www.tawbas.ca/dark-sky-festival.html](http://www.tawbas.ca/dark-sky-festival.html)

September 5-9  
**ACADIA NIGHT SKY FESTIVAL**  
Bar Harbor, ME  
[acadianightskyfestival.com](http://acadianightskyfestival.com)

September 7-9  
**BLACK FOREST STAR PARTY**  
Cherry Springs State Park, PA  
[bfsp.org](http://bfsp.org)

September 7-9  
**CONNECTICUT STAR PARTY**  
Goshen, CT  
<https://is.gd/CSP2018>

September 7-9  
**IDAHO STAR PARTY**  
Bruneau Dunes State Park, ID  
[isp.boiseastro.org](http://isp.boiseastro.org)

September 7-11  
**ALMOST HEAVEN STAR PARTY**  
Spruce Knob, WV  
[ahsp.org](http://ahsp.org)

For a more complete listing, visit [https://is.gd/star\\_parties](https://is.gd/star_parties).

# Star Struck

*A rare chance to observe through a 2-meter scope atop Maui leaves the author gobsmacked.*

**IT PAYS TO KNOW PEOPLE** in high places. My wife Kathy and I know two people who regularly observe on Haleakalā, the highest mountain on Maui, Hawai'i. One, Rob Ratkowski, works at Science City, the observatory on the summit, and the other, Cindy Krach, belongs to the Haleakalā Amateur Astronomers, who have a clubhouse there. (Yes, they have a clubhouse at 10,000 feet. With heat. And plumbing. Yes, I am envious.)

We had hoped for a night observing with Cindy's and Rob's 12-inch scopes in the shadow of the gigantic scientific instruments at the summit. But we had no idea that Rob was working behind the scenes to present us (and other HAA club members) with an even more amazing treat: time on the 2-meter Faulkes Telescope North. And not just research time, but actual observing time with an eyepiece.

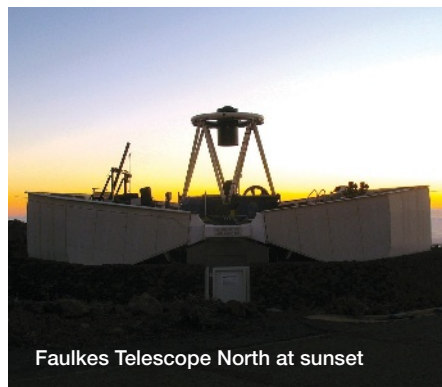
It was windy and freezing up there at 10,000 feet (3,000 meters), so we felt cold even in our coats, ski pants, hats, and gloves. But it was totally worth it. The scope itself is stunning. It's housed in a clamshell-style building that folds back and away, so at sunset it emerges like Botticelli's Venus on her half shell. Inside, its enormous bulk, supported by steel tubes the size of my body, reaches high overhead against the darkening sky.

The scope collects 64 times more light than my 10-inch trackball. A 31-mm Tele Vue Nagler eyepiece produces 645× and gave us a true field of view of about 7.6 arcminutes. My first look through the eyepiece left me speechless. We had aimed at the Trapezium Cluster in the Orion Nebula,

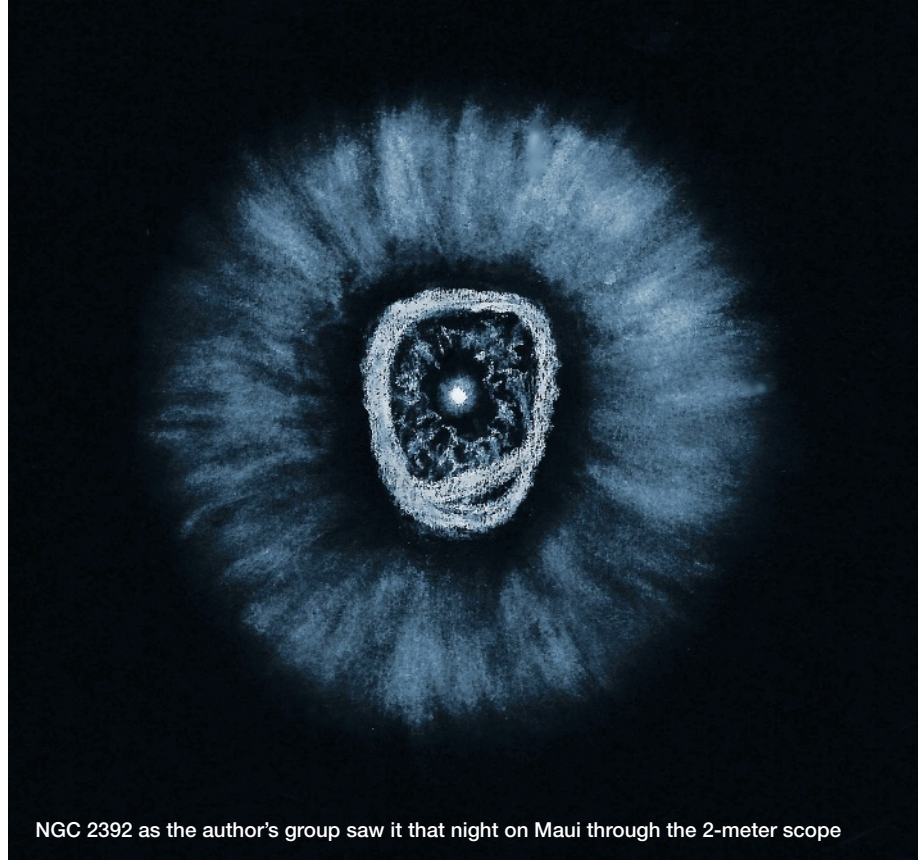
and as Arthur C. Clarke famously wrote in 2001: *A Space Odyssey*, "My God, it's full of stars!" The E and F stars, those two extras that prove elusive in 8- or 10-inch scopes, were obvious and steady as rocks, and I would have run out of alphabet trying to label the rest.

We looked at a globular cluster, NGC 1049, which was kind of "meh" after the Trapezium — until I realized it was in another galaxy 486,000 light-years away. And we were busting it into individual stars!

From there we moved on to NGC 2392. The first person to look through the eyepiece said, "Oh, holy \*\*\*\*!" and every one of us afterward said something similar. The nebula was spectacular! It



Faulkes Telescope North at sunset



NGC 2392 as the author's group saw it that night on Maui through the 2-meter scope

was by far the most impressive view of any planetary nebula I've ever seen. I could see the flattened oval of the "face," the "double chin," and filamentary detail in both the inner and outer rings. The central star was intensely bright and blue. There was too much detail to soak in during my turn at the eyepiece, but Cindy sketched it later from our collective memory. What you see here is what it actually looked like through the eyepiece that night.

Our observing time was over before we knew it, but I think another object like that would have made my head explode anyway. It was all I could think about for days afterward.

My deepest thanks to Rob and Cindy for setting this up, to Observatory Manager Mark Elphick and his assistant, JD Armstrong, for running the big scope, and to the Las Cumbres Observatory, parent organization for the Faulkes Telescope North, for making that amazing f/10 Ritchey-Chrétien available for our group of observers. I will remember that night for the rest of my life.

■ Contributing Editor **JERRY OLTION** now thinks of his 20-inch tri-Dob as "the little scope."



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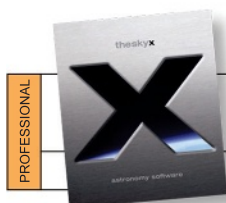
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