EXPLODING STAR! A look back at Supernova 1987A p. 28

MARCH 2017

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ASTRONOMY: ROEN KELLY

ON THE COVER

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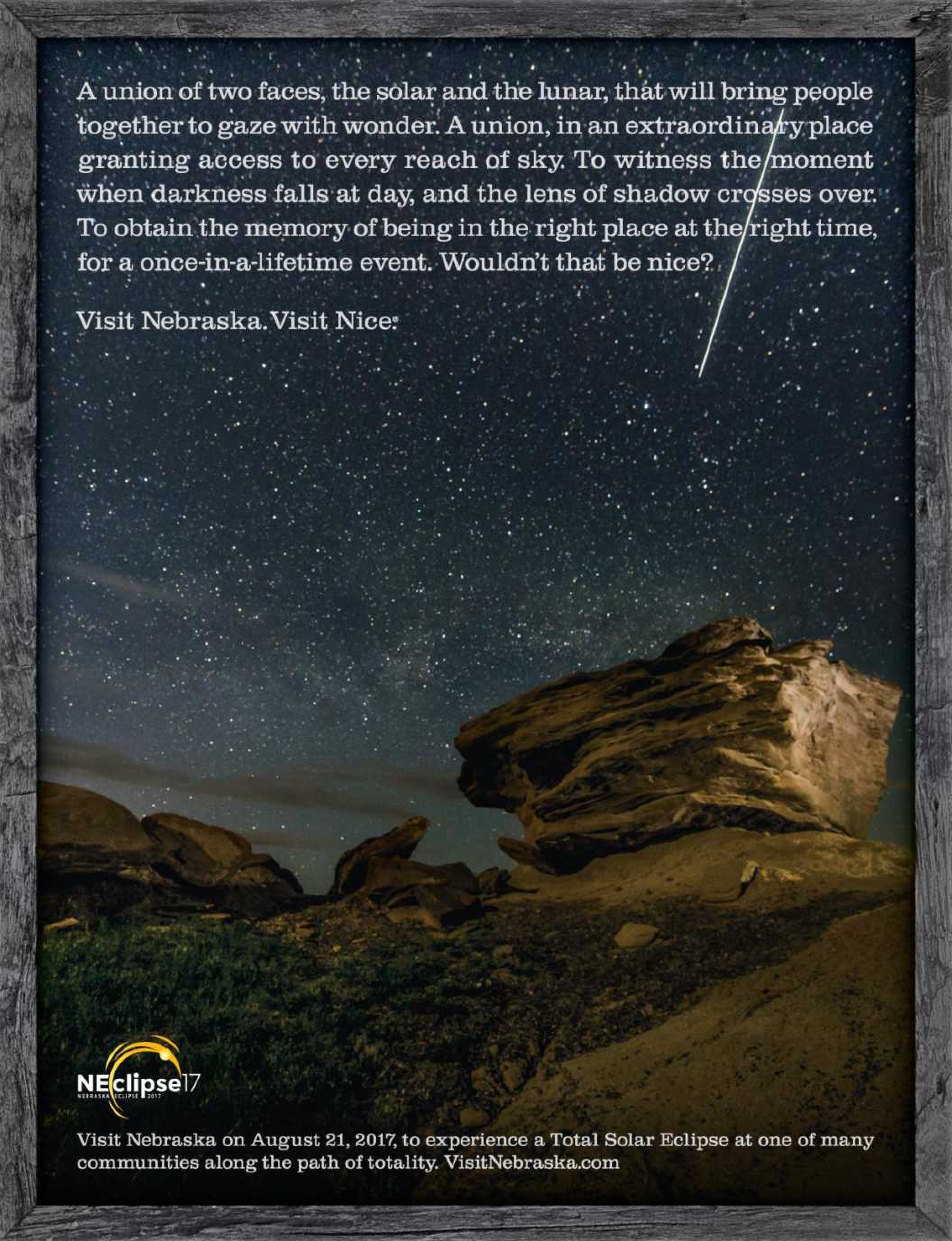
A union of two faces, the solar and the lunar, that will bring people together to gaze with wonder. A union, in an extraordinary place granting access to every reach of sky. To witness the moment when darkness falls at day, and the lens of shadow crosses over. To obtain the memory of being in the right place at the right time, for a once-in-a-lifetime event. Wouldn't that be nice?
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FROM THE EDITOR

BY DAVID J. EICHER

Story of a supernova

Thirty years ago, a massive star exploded in a nearby galaxy, the Large Magellanic Cloud. What followed over weeks, beginning February 24, 1987, was a naked-eye object visible in the Southern Hemisphere, the dazzlingly brilliant light from a star torn asunder.

Supernova 1987A peaked in brightness at magnitude 2.9 in May 1987 and became the brightest of its class since 1604, when Kepler's Star beamed forth at –3 magnitude. Because it was the closest supernova in modern astronomical history, the star was studied incredibly thoroughly, and helped astronomers understand supernovae better than they ever had before.

At a distance of 168,000 light-years, within the LMC, Supernova 1987A was not the next Milky Way supernova, the Holy Grail that some stellar astronomers seek. A Milky Way supernova could be hundreds or thousands of light-years away and would provide a far more dramatic sight and better data. But it was an explosive — ahem — event for understanding how massive stars die. In "Supernova 1987A: 30 years later," Contributing Editor Liz Kruesi describes the dramatic story of Supernova 1987A and how it rewrote our understanding of how stars interact with their surroundings.

Supernova 1987A was a Type II supernova, resulting from the rapid collapse and explosion of a massive star.

Supernova 1987A peaked in brightness at magnitude 2.9 in May 1987 and became the brightest of its class since 1604.

The progenitor star did what massive, old stars do — it ran out of fuel for nuclear fusion and its core catastrophically collapsed. The shrinking core then intensely heated, producing a runaway effect over milliseconds that created a massive explosion. Such an event is among the most energetic known in the universe, save for the Big Bang itself.

As far back as 1954, the English astronomer Fred Hoyle proposed that such exploding stars fuse lighter elements into heavier ones. So as you read the story on Supernova 1987A, consider that many of the elements in your body — argon, calcium, chromium, cobalt, iron, manganese, nickel, silicon, and sulfur among them — were created in these massive stellar explosions. You would not be here except for the likes of Supernova 1987A, and trillions of stars like it, that winked out but in doing so helped the enrichment of the cosmos through a massive, individual, and gradual program of stellar recycling.

The Large Magellanic Cloud of course lies deep in the Southern Hemisphere sky. For many of us northerners, it is a rare treat on an infrequent trip that allows us to gaze up and see this satellite galaxy of the Milky Way. The next (or first?) time you see it, think about this little star, now a blown-out remnant, that became the talk of the astronomy world 30 years ago, as it reminded us that we are all tied together in the chemistry of the universe.

Yours truly,

David J. Eicher
Editor

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EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES>>

TRENDING TO THE TOP

BOOM OR BUST
The Chicxulub impact in Mexico may have been ground zero for dino-deaths, but it may also have sheltered smaller mammalian life.

UP, UP, AND AWAY
The GOES-R satellite launched November 19 into geostationary orbit to study weather on Earth and provide better forecasting.

JUST ONE LOOK
A group called Project Blue hopes to directly image a planet around Alpha Centauri A or B. To date, no such planet has been confirmed.

SNAPSHOT

A universe with 10 times more galaxies

A stunning news story proposes at least 1 trillion galaxies inhabit the cosmos.

The beautiful face-on spiral galaxy IC 342, lying only about 11 million light-years away, is awash in a sea of a trillion or more galaxies.

TONY HALLAS; TOP FROM LEFT: KEN THOMAS (CREATIVE COMMONS); NASA/NOAA; EUROPEAN SOUTHERN OBSERVATORY

The year 2016 was a big one for astronomical news. Following gravitational waves, a planet orbiting Proxima Centauri, and more, came news that the estimated number of galaxies in the cosmos may have been woefully low.

Years ago, astronomers studied the Hubble Deep Field and extrapolated galaxy counts to work out an estimate of perhaps 100 billion galaxies in the universe. In late 2016, astronomer Chris Conselice of the University of Nottingham conducted a new study of galaxy densities using newer Hubble Deep Field exposures.

Conselice and his team were able to count galaxies in these fields out to approximately 13 billion light-years, about a billion light-years more distant than the older estimates permitted. They plotted the numbers of galaxies of various masses versus their distances from Earth. Then they multiplied the galaxy count to account for galaxies that would be too small and faint to image in the Hubble exposures, but that logically ought to exist. In a paper accepted for publication in *The Astrophysical Journal*, the count comes to at least 1 trillion galaxies, and perhaps upward of 2 trillion.

Of course, as they look farther out in greater precision, the larger numbers of galaxies that existed in the distant (early) universe would mostly have merged by gravitational attraction in the closer (later) universe, meaning that fewer galaxies exist now than did long ago.

The astronomers can conservatively say that their new number increases the numbers of galaxies thought to exist by a factor of 10. Now that is a big story. — **David J. Eicher**

ASTRO**LETTERS**

A sizable victory

I really enjoyed the article "Sizing up Space Rocks" by Michael Carroll in the November issue (p. 30). I'm an engineer, and I usually can estimate (and imagine) sizes of things in both systems of units, English and SI, but it is only after reading this story that I could truly appreciate the size of comets and asteroids. Before this, saying that an asteroid 160 feet across crashed into the Arizona desert never really struck a chord with me. Carroll's cleverly scaled photograph of two asteroids superimposed on a sports stadium was revealing enough, but the photo on the next page of Comet Hartley in scale with the Eiffel Tower really blew my mind! The last photo of an assortment of known asteroids and comets on a "tablecloth" was really quite illuminating. This was an excellent way to show how big these things really are and the impact they could have. **— Bob Found,** Indian Harbour, Nova Scotia, Canada

Crediting Rubin is lamentable

History tells us that prophets are persecuted during their lifetime, only to have their prescient theorems realized and acknowledged by the prevailing hierarchy decades or centuries later. The surety for the powers of intellectual obfuscation are twofold, literary malefic of the prophet or the assignment of credit posthumously to a masquerader of their time.

The assignment of forced credit to Vera Rubin as the authentic discoverer of dark matter (June 2016 issue, p. 26) is not only errantly untrue but lamentable in light of the hostile established guard advancing this fallacy, that was resistant to my father in his time, advancing literary assaults which became as common as grains of sand, but were equally unstable, holding no structure and thus becoming dissolute with the tide and time.

To ascribe credit to Rubin as the discoverer of dark matter pollutes the real contribution of her life's work, which is equally lamentable to the assigned forced credit displacing Fritz Zwicky. The advancement of bringing the gravitational phenomena of dark matter to light and into the modern consciousness of physicists worldwide would have regardless been unsealed from the echoes of my father's original work in 1933.

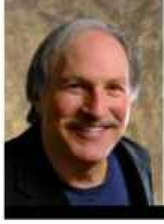
Fritz Zwicky: "I consequently engaged in the application of certain simple general principles of morphological research, and in particular the method of Directed Intuition that would allow me to predict and visualize the existence of as yet unknown cosmic objects and phenomena."

Zwicky's eidolon was realized from the results of his observations and published in the 1933 article *"Die Rotverschiebung von extragalaktischen Nebeln"* in *Helvetica Physica Acta.* Zwicky discovered dark matter and coined the term *dunkle (kalte) Materie* ("cold dark matter") in this article. The mass-radial acceleration discrepancy by measuring the speeds of galaxies in the Coma Cluster originated with Zwicky, not Rubin, as using the more challenging methodology of the virial theorem, by relating the total average kinetic energy and the total average potential energy of the galaxies of the Coma Cluster. He advanced that the virial for a pair of orbiting masses is zero, and he used the principle of superposition to craft the argument to a system of interacting mass points. Zwicky then used the position and velocity measurements to determine the mass of the galaxy cluster. **— Barbarina Zwicky,** Palm Springs, CA

Software solution

In the article, "Meet the next generation space telescope" by Korey Haynes in the May 2016 issue (p. 52), ways to block the central star's light are discussed. There is an extremely simple way to achieve the coronagraph effect. Software can be written to provide the observer with a virtual, steerable, variable-diameter "black spot" that would be moved by the observer to appear to overlay the central star and the diameter adjusted to just cover the star. That is a mechanism so that the software processing the telescope image would report any pixels within the "black spot" as black, and would thereby result in suppressing the central star's light. **— Bryan Hennington,** Oceanside, CA

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*



STRANGE**UNIVERSE**

BY BOB BERMAN

Going for gold

What Hollywood can teach us about putting on a spectacular show for budding amateur astronomers.

As we reach Oscar time — late February or early March — the lessons of Hollywood come to mind. We did a big article on this some 20 years ago and felt honored to get praise from famed comet hunter David Levy and others. So let's go there again, with some new suggestions.

The idea is simple. Most backyard astronomers excitedly show their favorite celestial wonders to family, friends or even visiting school groups. It's memorable for everyone, and it promotes astronomy. Our issue: Can you improve your telescope "show" so that your visitors are even more turned on to science? If so, it could change young minds and perhaps launch a lifelong hobby, or even a career choice. School kids don't get telescope tours very often. This might be the only occasion of their childhood. Make it count!

I'll be blunt: Most backyard astronomers offer only an OK presentation. The biggest mistake is showing their favorite objects first, then turning to ever-fainter targets and not wrapping it up until the crowd gets restless. The astronomer might wave goodbye saying, "Let's do this again sometime!" But for most of the kids, it's now, "Been there, done that."

Hollywood perfected the secrets of a good show long ago. They can work for us, too. You want to wow them, teach them, entertain them. In our smartphone age, fewer and fewer young people do hands-on activities like canoeing or bird-watching. You are competing with the universe on their little screens. They've already seen glorious Hubble images. Can you top that? (Yes, you can, but you must know how!)

Their experience will be a function of what they expect versus what they actually see in your telescope. For example, they've seen astonishing magazine and online images of the Andromeda Galaxy (M31) and Mars. But through your scope, M31 is a smudge, and Mars is a tiny jiggling blur. You cannot wow them with these. Don't try. They know nothing about astrophotography's advantages, so they'll merely think your telescope is pathetic. Never show either of those objects, ever. (Well, not quite never. If Mars is within two months of opposition and you have a rare perfectly steady night, go for it. But that's still essentially never.)

Instead, choose an object they've never seen. Then your image won't fail due to comparisons or expectations. The big exception is Saturn. It reliably astonishes at the eyepiece because there's some crazy vibe or essence when gazing directly at it that no photo can capture.

START WITH A BRIGHT KNOCKOUT TREAT, LIKE THE MOON OR SATURN, AND PLAN TO FINISH WITH YOUR FAVORITE OBJECT.

Plan on showing five or six objects. Then end it. You want them to go away wanting more, craving more astronomy. Leave them a little hungry.

Revolve your menu around diversity. With, say, an 8-inch telescope, your greatest "wow objects" are a globular cluster like the Hercules Cluster, the Orion Nebula, the Moon when it's between six and 11 days old, Saturn, Jupiter, a low-power treat like open cluster M35, a colorful double star like Albireo, and one secret esoteric goodie, which we'll get to in a moment. All of these look fine in less-than-perfect skies, which is probably what you have.

Start with a bright knockout treat, like the Moon or Saturn, and plan to finish with your favorite object. That's right, save the best for last. In Hollywood, the climax always has the biggest, most expensive action. Leave them smiling.

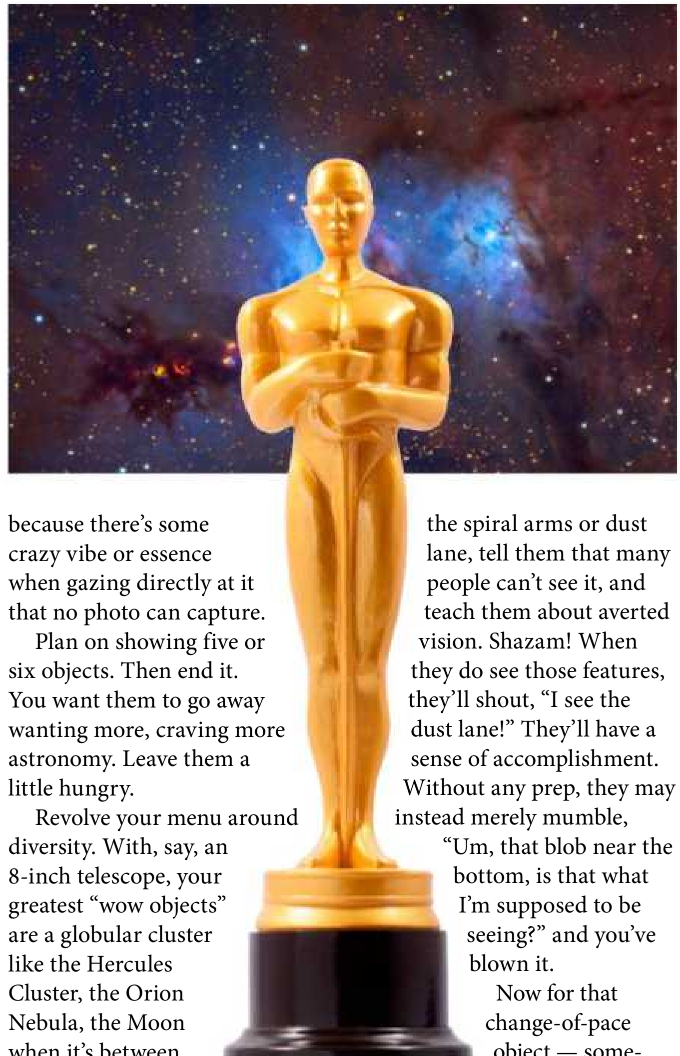
In between, vary the action. At one point you can do a faint target, but prep them for it first. If you have a 12-inch scope, then sure, go for the Whirlpool Galaxy or NGC 4565. But first show them a photo of it; prepare them for the spiral arms or dust lane, tell them that many people can't see it, and teach them about averted vision. Shazam! When they do see those features, they'll shout, "I see the dust lane!" They'll have a sense of accomplishment. Without any prep, they may instead merely mumble, "Um, that blob near the bottom, is that what I'm supposed to be seeing?" and you've blown it.

Now for that change-of-pace object — something very different, to keep them intrigued and entertained. Me, I attach a spectroscope and show them a bright star, usually spectral class A, like Vega or Sirius. Whoa! Gorgeous super-intense colors unlike anything else. And those obvious black hydrogen lines let you explain that this is how astronomers know what stars are made of. Their jaws will drop.

Or you might pass around binoculars and have them look at the Pleiades. Be sure to narrate it with some of M45's cool lore and legend. Then show your best object and say good night. They'll be hooked.

And you'll have earned that Oscar.

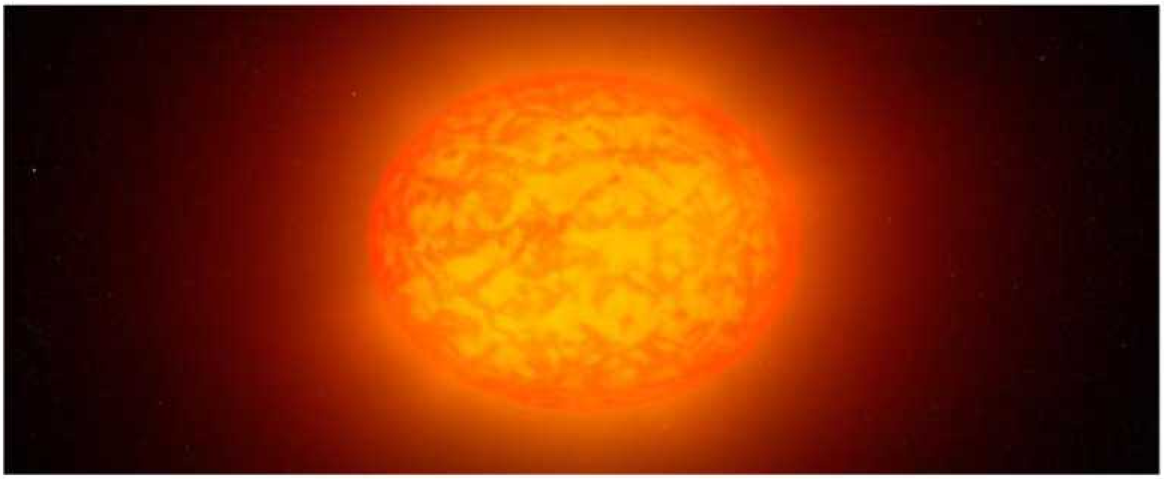
Contact me about my strange universe by visiting **http://skymanbob.com.**



© ERASHOV | DREAMSTIME.COM (STATUE); TONY HALLAS (M78)

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

MAKING JUPITER. Astronomers tested two different ideas about planetary formation for gas giants and showed that the bottom-up method seems more likely, based on temperatures predicted by their simulations and observed in real systems.



JACK-O'-LANTERN. Some stars rotate so fast that they bulge at the equator, earning the name "pumpkin stars." Such is the case with KSw71, which rotates every 5.5 days and is 10.5 times the size of the Sun. NASA

'PUMPKIN STARS' CARVE OUT A NICHE IN THE UNIVERSE

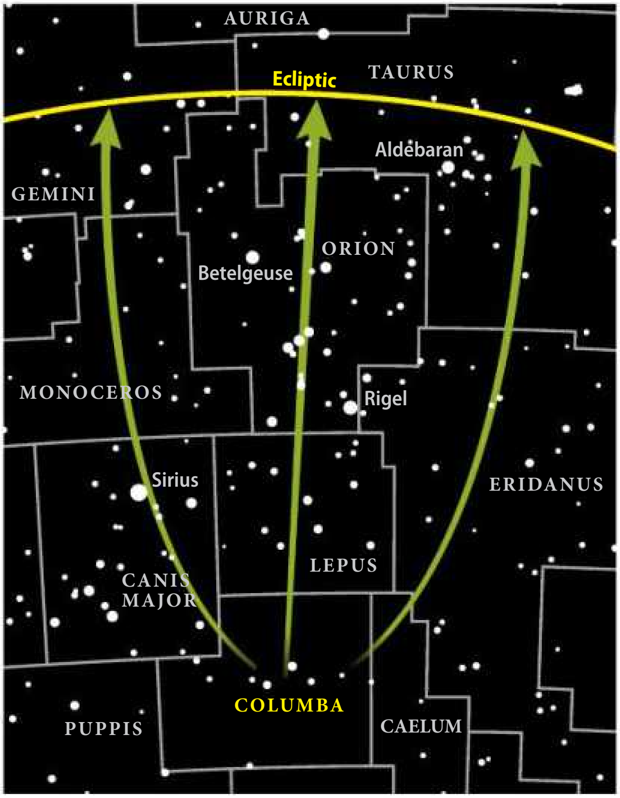
Not all objects are created equally round. Recent observations by NASA's Kepler and Swift space observatories found 18 stars that have taken on the name "pumpkin stars," thanks to their unusual shapes. The findings were published October 25 in *The Astrophysical Journal*.

As it turns out, pumpkin stars take on their oblong shape because of their short periods of rotation. On average, one of these stars rotates on its axis every 5.5 days. (By comparison, the Sun rotates every 24.5 days.) The process creates brilliant X-ray emissions far outstripping the Sun's. At the same time, this rapid spinning affects the shape of the star, causing it to bulge at the equator.

Most of the stars are between 2.5 and 10 times the size of the Sun. Most also seem to be entering their "giant" phase, when hydrogen depletes and the stars expand outward, just as the Sun will do someday.

Current modeling suggests that these stars form when two Sun-like stars are in such a tight orbit around each other that they become one star, destabilizing the rotation in the process. Researchers believe 160 of these pumpkin stars may have been spotted in Kepler observations. — **John Wenz**

THREE DEGREES OF SEPARATION



ASTRONOMY: ROEN KELLY

JIGSAW CONSTELLATIONS. You've heard of six degrees of separation, the theory that everyone on Earth can be connected to anyone else through no more than five intermediaries. Well, how many constellations do you have to traverse to link with one that the ecliptic passes through? Thirteen constellations contain a segment of the ecliptic, 35 lie one constellation away, 31 are separated by two star groups, and just nine have three degrees of separation. The closest of these to the celestial equator is Columba, which has multiple paths to either Gemini or Taurus. — **Rich Talcott**

FAST FACT

Of the nine constellations that require three hops from the ecliptic, only two — Cepheus and Ursa Minor — lie in the northern sky.

BRIEFCASE

JAPAN'S NEUTRINO DETECTOR GETS A BIG UPGRADE

The Kamioka Observatory, run by the University of Tokyo and the Institute for Cosmic Ray Research, recently received a big computing upgrade that could serve as an early detector for supernova. Neutrinos, which are small, weakly interacting particles, are produced by supernovae. Since few supernovae explode per century in Milky Way-like galaxies, an early warning system can help ensure the observatory can spot the elusive particles.

MICROLENSING EVENT HELPS FIND AN UNUSUAL FAILED STAR

Researchers know of plenty of brown dwarfs — a class of objects between gas giants and stars — but seeing one is fairly hard, since they give off only a faint amount of light. But a microlensing event, which curves space-time so that distant objects temporarily appear nearer, led to the discovery of a brown dwarf orbiting a star in an area called the "brown dwarf desert," a distance of 3 astronomical units where no brown dwarfs to date had been found.

SUBARU TELESCOPE CAN NOW LOOK INTO EXOPLANET ATMOSPHERES

Thanks to the addition of the Coronagraphic High Angular Resolution Imaging Spectrograph, the Subaru Telescope atop Mauna Kea, Hawaii, can view nearby exoplanets and characterize their atmospheres, and provide other data about the planets such as refined mass estimates. This could help in the quest to find a truly Earth-like planet. — **J. W.**

RING ORIGINS. Theorists predict that rings around the outer planets are likely due to those worlds capturing Kuiper Belt objects and destroying them, and that such destruction is common in most planetary systems.

Pluto's slushy heart contains a large ocean

The heart-shaped region on Pluto, Sputnik Planum, holds a secret to a violent past: It may have been formed by a head-on collision with a 125-mile-wide object, leaving a slushy liquid ocean behind.

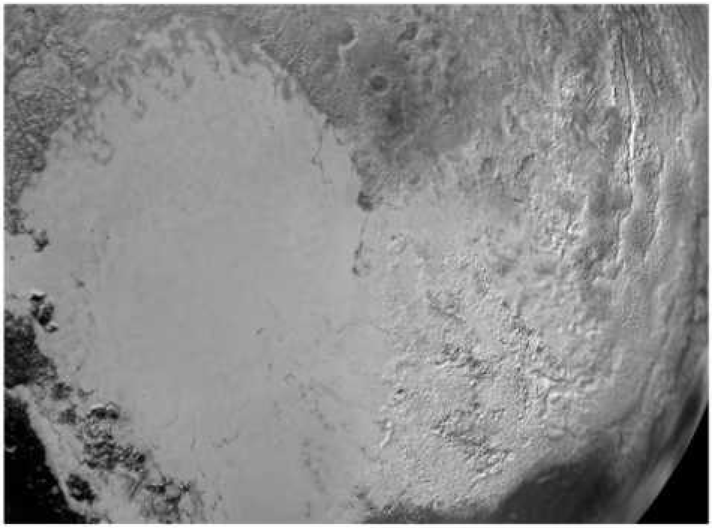
What's more, the incident was so violent that it tilted the dwarf planet, putting the Sputnik Planum area roughly on Pluto's equator. This violent incident may have also shepherded Charon into its strange orbit.

In a paper published November 16 in *Nature*, researchers came close to solving a mystery of Charon's orbit. Prior to the New Horizons mission, Hubble data provided a rough idea of Pluto's surface topography, including a smudgy outline of what we now know as Sputnik Planum. Sputnik Planum lies directly opposite of Charon, since Pluto and Charon are similar enough in size that one side always faces the other.

The presence of the ocean and its effect on Pluto's tilt helps explain this puzzle. The gravitational interaction between Pluto and Charon also may help explain how the ocean stays liquid. The barycenter — the center of mass between the two objects — exists outside either body, creating a sort of middle ground in the space between the two bodies. This is because their sizes are similar enough to each other to create such an effect. Charon's diameter is a little more than half that of Pluto. (The next closest size comparison is the Earth-Moon system, but the Moon is small enough, at about one-quarter the size of its parent body, that the barycenter is within Earth's mantle, about 1,056 miles [1,700 kilometers] below the surface.)

The Sputnik Planum region also goes through consistent cycles of sublimation (solids turning directly into a gas) and refreezing because it's tidally locked to Charon, with the same face facing Charon at all times in its three-day cycle.

The collision of the 125-mile-wide object may have been responsible for the formation of Charon and Pluto's four other small moons, all of which seem to be made mostly of water ice rather than the nitrogen and ammonia ices mixed with water on Pluto. **— J. W.**



PUSH AND PULL. The Sputnik Planum area of Pluto, a nitrogen glacier floating in a slushy water-ammonia ocean, tugs more heavily than the rest of the surface on Charon, Pluto's largest moon. Some astronomers consider Pluto and Charon binary dwarf planets rather than a planet-moon system. NASA/JHUAPL/SwRI

I've got my eye on you, you're everything I see

M. KAUFMAN; B. SAXTON (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO); NASA/ESA HUBBLE SPACE TELESCOPE

LOOKING THROUGH YOU. Long ago and far away, the galaxy IC 2163 merged with portions of another galaxy, NGC 2207, in a fashion similar to storms on Earth. NGC 2207 swept by IC 2163, with the latter object nabbing stars and gas. The materials act like a stellar tsunami, crashing into the galaxy and creating this unique shape. As it slows down, clouds of gas become denser. The galaxies are about 114 million light-years from Earth. **— J. W.**

QUICK TAKES

MOON IMPACTS
The GRAIL lunar mission studied the detailed gravitational environment around Orientale Basin to understand how the enormous impact that formed it affected the local area and deformed the lunar surface in ways normally invisible.

LUNAR ORBIT
A new model for the Moon's violent formation describes both Earth and the Moon taking on strange orbits, which have since smoothed into the partnership present today.

TEST RUN
NASA and the Federal Emergency Management Agency teamed up for an emergency exercise to test preparedness for an asteroid impact. The drill simulated how the agencies would share information and respond to the threat.

BREAKTHROUGH
The Parkes radio telescope in Australia celebrated first light as part of the Breakthrough Listen project to detect alien signals.

CREATED EQUAL
Outbursts from the birth disks around massive stars prove that they form in ways similar to lower-mass stars, reversing some previous ideas.

EARTHLY CLUES
A hot spring in Chile is shedding light on mineral structures found on Mars in 2007. In Chile, the structures arise partly as a result of biological processes, so researchers are questioning whether the same processes are responsible for the martian formations.

FAINT LIGHT
Astronomers found a new record-holder for the faintest dwarf galaxy orbiting the Milky Way: Virgo I. Its discovery hints that more might be lurking unseen.

WATER ON MARS
Mars' Utopia Planitia region has as much water as Lake Superior in an underground deposit, according to recent data collected by the Mars Reconnaissance Orbiter.
— Korey Haynes

IDEAL SPHERE. Most stars are fatter at their equators thanks to the centrifugal force of their spin. Kepler 11145123 rotates so slowly, it is only 1.9 miles (3km) wider than it is tall — a record, as far as astronomers can measure.

The mystery of Beagle 2's failure begins to unravel

We may be one step closer to knowing what happened to the European Space Agency's Beagle 2 lander in 2003, after it failed to check in after separating from the Mars Express Orbiter.

No one knew Beagle 2's fate until NASA's Mars Reconnaissance Orbiter spotted it in 2014 and sent home eight pixelated images from its HiRISE camera. Unfortunately, the images shed little light on what happened.

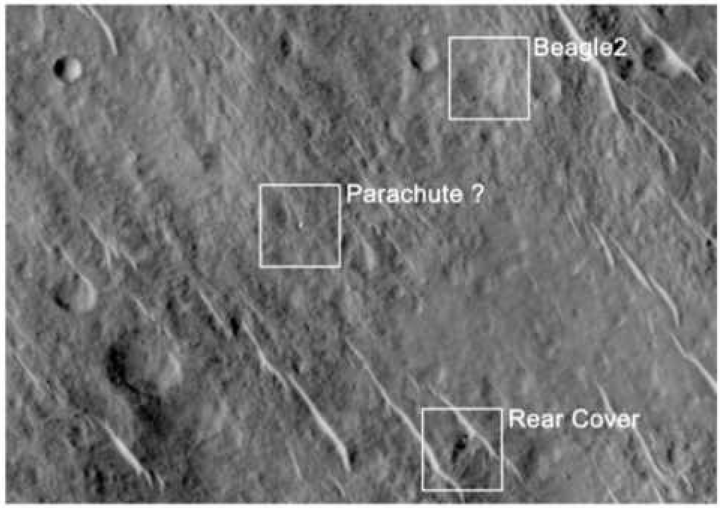
To figure this out, a team led by Nick Higgett, leader of the Digital Research Group at De Montfort University in the U.K., built a 3-D model of Beagle 2 and tried to re-create the HiRISE images. Among the simulated images, two closely matched the real HiRISE images.

It's hard to tell which of the two could be the answer, but both show that everything came agonizingly close to going right for Beagle 2.

While the results don't tell us exactly what happened to the lander, they narrow it down considerably. Knowing that Beagle 2 landed successfully but simply failed to report back to Mars Express — which is the most likely result of the simulations — rules out most of the 180 potential problems.

The team first needs to figure out if the lander's fourth solar panel opened. If it turns out that all four deployed properly, that narrows the list down to just 25 events that could have damaged Beagle 2's electronics or wiring harness.

Understanding what causes models to fail helps researchers make better spacecraft designs, so figuring out what went wrong with Beagle 2 may benefit future missions to Mars. **— Nicole Kiefert**



THE END. Beagle 2 could have been a success for the British space community. Instead, the lander crashed to the martian surface and wasn't heard from again. A team has built a 3-D model of Beagle 2 and tried to re-create NASA images showing the lander's fate. NASA

Mercury is shrinking

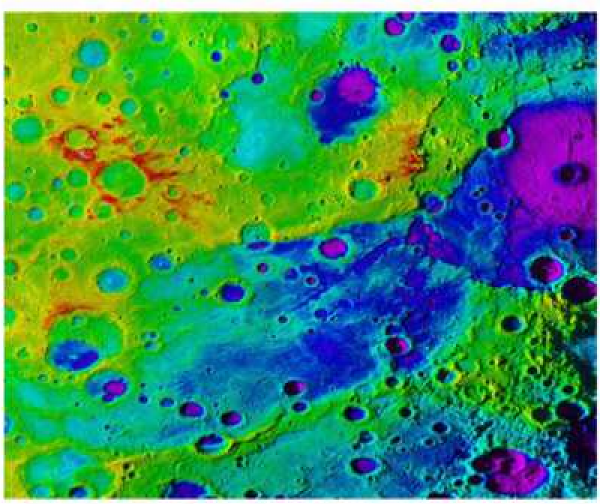
A new study of a mercurian valley bolsters the case for Mercury as a shrinking planet. The study's authors believe the valley likely formed in response to global contraction as the planet's interior core cooled, causing the solitary plate that makes up its lithosphere to contract and bend.

Researchers found the valley using a high-resolution topographic map of Mercury's southern hemisphere, made from images taken by NASA's MESSENGER spacecraft.

The valley is 250 miles (400 kilometers) wide, 600 miles (1,000km) long, and about 2 miles (3km) deep. It extends into the Rembrandt basin, one of the largest basins on the planet. Two large fault scarps surround the valley and, through Mercury's contraction, ended up becoming large cliffs. The floor of the valley lies below the terrain, which scientists believe was lowered by the same method that created the scarps.

Although the outcome is similar, the process of creating canyons and valleys is different between Earth and Mercury. "Unlike Earth's Great Rift Valley in East Africa, Mercury's Great Valley is not caused by the pulling apart of lithospheric plates due to plate tectonics; it is the result of the global contraction of a shrinking one-plate planet," said Thomas R. Watters, senior scientist at the Center for Earth and Planetary Studies at the Smithsonian's National Air and Space Museum and lead author of this study.

Although there are examples of lithospheric buckling on Earth, this is likely the first to occur on Mercury, Watters said. **— N. K.**



THE INCREDIBLE SHRINKING PLANET. Mercury is a weird planet, and it might be the remnants of a much larger planet. As if that weren't enough, this mercurian canyon shows the planet may be contracting, becoming even smaller. NASA

385 million light-years

The length of the newly discovered Vela Supercluster, the largest found to date.

ESO

Planets shape parent disks

SPIRAL SIGNS. Three different research groups using the European Southern Observatory's Very Large Telescope have imaged the planet-making disks around stars in three different systems. These planets, in turn, shape their parent disks, carving out paths in the gas and dust, but astronomers are still working to understand the details. The three systems pictured here include young and old stars, concentric rings, and asymmetric spiral arms. Understanding the differences and similarities between the systems will help researchers understand how planetary systems form. **— K. H.**

ASTRONEWS

SUBSOLAR CYCLE. Astronomers suspect warm, substellar objects called brown dwarfs may undergo magnetic activity cycles similar to the Sun and other stars based on the polarization of flare events flipping every decade.

Fast radio burst tells its travel story

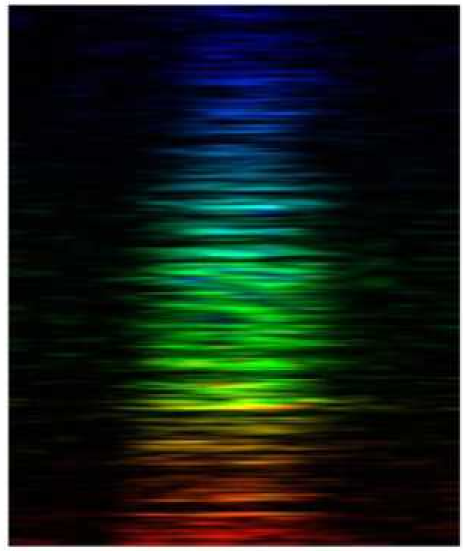
Fast radio bursts (FRBs) are well named: They are short, bright blips of radio emission that appear without warning and disappear within milliseconds. They are also powerful, arriving from billions of light-years away, and this long travel time means they can tell valuable stories about their journey through intergalactic space.

On August 7, 2015, astronomers were using the Parkes radio telescope in Australia to study a pulsar, a rapidly rotating star that gives off radiation in beams like a lighthouse. But in the same region of sky, they happened to catch FRB 150807, the most powerful FRB glimpsed so far. The researchers, led by Vikram Ravi from the California Institute of Technology and Ryan Shannon from Curtin University in Australia, published their finding November 17 in *Science*.

This newest FRB is only the 18th ever discovered, and astronomers still don't know what produces the brilliant outbursts. Most never repeat, leading astronomers to surmise that some cataclysmic event triggers the bursts. And because they appear for so brief a time, even pinpointing where these bursts originate has been tricky. The extraordinary brightness of FRB 150807 helped astronomers determine that it is definitely not a local occurrence — the radio signal traveled for at least 1.5 billion years to reach Earth, putting it far beyond the Milky Way's boundary.

This long journey means that the burst carries imprints of its trip. By studying distortions in the FRB, astronomers can glean information about the terrain it passed through. While most of space is generally empty, there is an enormous amount of matter spread thinly in the space between galaxies. This material is too cool and diffuse to study by normal astronomical methods, and yet it can explain a lot about the overall nature of the universe. So an FRB that tells this story is invaluable.

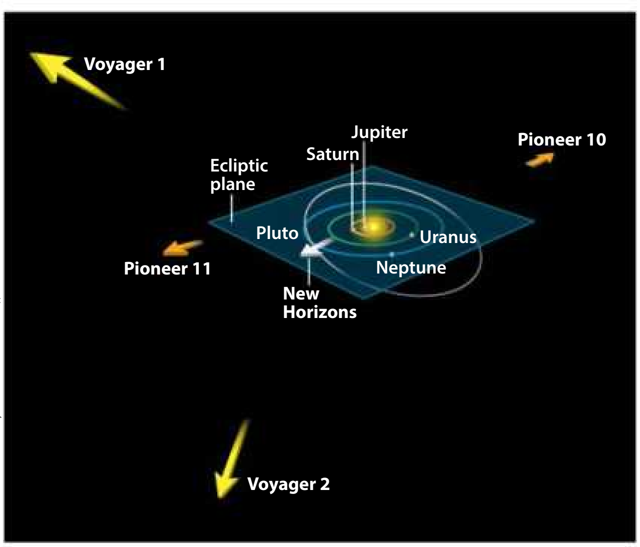
After its trip, the light from FRB 150807 was only weakly distorted, meaning the intergalactic medium it traversed for so long was not very turbulent. This is in line with what astronomers originally predicted for the thin material between galaxies, and puts a firm mark against theories that call for more choppy currents in intergalactic space. The measurements of FRB 150807 also describe a quiet magnetic environment. This rules out some theories that predict FRBs are produced in extreme environments with strong magnetic fields, but otherwise confirms again that the space between galaxies is quiet. **— K. H.**



RADIO TWINKLE. The fast radio burst FRB 150807 shows a range of radio frequencies, shown here by a rainbow of longer (redder) to shorter (bluer) wavelength emission. Time increases from left to right, showing how the burst brightens and then fades. The more detailed structure shows the burst's twinkle as the radio emission encounters turbulence in the intergalactic medium on its way to Earth, much as starlight twinkles thanks to turbulence in Earth's atmosphere. V. RAVI/CALTECH

77 years old — John Glenn's age when he took his second space flight in 1998. Glenn, a veteran and former senator, died December 8, 2016.

SO LONG, SOLAR SYSTEM



ASTRONOMY: ROEN KELLY; FIGURES FROM: HTTPS://THESKYLIVE.COM AND NASA

GET OUT OF HERE. The final stages of Pioneers 10 and 11, Voyagers 1 and 2, and New Horizons are all on escape courses out of the solar system. However, Jonathan McDowell of the Harvard-Smithsonian Center for Astrophysics says that they aren't behind their "home" vehicles in most cases due to correction maneuvers made by the probes after separation, as well as outgassing from the third-stage separation and any residual fuel burns. "There is no tracking data of the separated final stage usually, so these differences are not only significant but unknown," he says. **— J. W.**

Voyager 1
Velocity: 38,610 mph (62,137 km/h)
Distance: 138 AU*
Declination: 11°**
Right ascension: 17h12m 10.0s
Constellation: Ophiuchus
Launch: September 5, 1977
Nearest stellar destination: 1.6 light-years of Gliese 445 in 40,000 years

Voyager 2
Velocity: 35,970 mph (57,888 km/h)
Distance: 114 AU*
Declination: –57°
Right ascension: 20h00m 40.0s
Constellation: Pavo
Launch: August 20, 1977
Nearest stellar destination: 1.7 light-years from Ross 248 in 40,000 years***

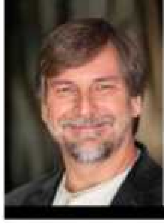
Pioneer 10
Velocity: 26,900 mph (43,291 km/h)
Distance: ~116 AU
Declination: 26°
Right ascension: 05h12m 38.0s
Constellation: Taurus
Launch: March 3, 1972
Nearest stellar destination: Aldebaran system in 2 million years

Pioneer 11
Velocity: 25,450 mph (40,958 km/h)
Distance: ~96 AU
Declination: –8°
Right ascension: 18h50m 21.0s
Constellation: Scutum
Launch: April 6, 1973
Nearest stellar destination: Lambda Aquila in 4 million years

New Horizons
Velocity: 32,055 mph (51,588 km/h)
Distance: 37.2 AU
Declination: –20°
Right ascension: 19h02m 45.0s
Constellation: Sagittarius
Launch: January 19, 2006
Nearest stellar destination: currently unknown

FAST FACT The ashes of Pluto discoverer Clyde Tombaugh are aboard New Horizons.

* As of December 14, 2016
**Degrees above or below the ecliptic in celestial north or south
*** Will be approximately 3 light-years from the Sun at this point



FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Oklahoma skies

To all the amateurs out there, thanks!

OKIE-TEX STAR PARTY

The grounds of the Okie-Tex Star Party near Kenton, Oklahoma, in the state's panhandle, offer a setting just right for camaraderie and sharing the wonders of the sky.

Some years ago I was at a party when a guy introduced himself and said, "Wally told me that you like astronomy!" A mutual friend knew that he was an amateur astronomer and had told him, "You really ought to talk to Jeff Hester."

"Astronomy?" I replied, somewhat puckishly. "I suppose I have some passing interest in the subject."

I recognized the look. My new friend beamed! Maybe he would get to talk about his passion after all, without his family reading him the riot act for killing an otherwise perfectly enjoyable party!

I've been there. My own passion began as a kid when I first looked through a 3-inch dime-store refractor in a friend's backyard. I still recall Steve sitting there proudly in the dark next to his new window on the universe. And the blurry image of Saturn and its rings in the eyepiece of the tiny telescope was just about the coolest thing I had ever seen.

Steve, who was a few years older than me, quickly got serious about the hobby. He built a 6-inch Newtonian reflector and a German mount that we used to explore the sky. I went on to build telescopes as well, and I still have an 8-inch mirror that I ground and polished by hand sitting in my office. But that 6-inch Newtonian is where I cut my teeth as an astronomer.

That is where I got my first experience with astrophotography. Instead of a drive motor, the right ascension axis of the telescope was geared with a crank that had to be turned by hand at one revolution per minute for the telescope to track properly. I have fond memories — or at least memories — of sitting on frozen ground in the wee hours of cold Oklahoma winter nights, holding a watch next to the telescope and turning the crank to match the motion of the second hand. Steve looked through the eyepiece and made minor corrections.

Sometimes Steve played drive motor and I kept the guide star next to the illuminated cross-hairs, but I'll be honest. It was his telescope, and I usually wound up with the grunt work.

So when my new friend at the party began to tell me about his 14-inch Cassegrain, I was honestly enthusiastic. Time was when I would have killed for the setup he was describing! I asked the right sorts of questions and nodded appreciatively as he talked about how far he had gotten on the Messier list, and the darkroom that he had built.

My first darkroom experience came developing Kodak Tri-X film in the sink and making prints using a slide projector as an enlarger. So again, my appreciation was sincere.

I was appreciative on a deeper level as well. I never would have wound up in astronomy without the guidance and encouragement of amateurs. I grew up during the space race, and was all about rockets and astronauts. But what got me seriously hooked on astronomy was a Merit Badge program offered by the Kirkpatrick Planetarium and taught by members of the Oklahoma City Astronomy Club.

That program sparked the interest of our whole troop. We even went on to win top honors at the state Scout-O-Rama for a booth that featured a home-made planetarium, a selection of telescopes, some astrophotography, and a bunch of kids who knew their stuff.

All of that came back to me when I was invited to give a talk at the Okie-Tex Star Party last fall. Amateurs are always a fun group to talk to; it's nice to have an audience that gets your jokes! But mostly I accepted the invitation to hang with a bunch of amateur astronomers under the almost obscenely dark skies of the Oklahoma panhandle to remember my own roots, and to say thanks.

That's the point of this column, as well. Were it not for people like many of the readers of *Astronomy* magazine, my life would have taken a different course. When your clubs go out and put on public events and you let kids look through your telescopes, your enthusiasm shines through. That matters. I know, because it mattered to me.

So there it is. Thank you!

Back to the party: My new friend was clearly enjoying his audience. His swollen chest was almost popping buttons as he confided in me that his setup was the envy of his club! He couldn't quite hide his sense of superiority when he finally asked, "So, what telescope do you use?"

I would like to say that I was gracious at that point. I probably should have thanked him for all that amateur astronomers do and had done for me. But alas, I'm afraid that I just couldn't pass up the opportunity.

"What telescope do I use? Well, mostly I use Hubble …"

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

ASTRO**NEWS** **"NEW" NAMES.** The International Astronomical Union published an official list of 227 common names for stars on November 24. Most of the names have been in use for centuries, such as Altair, Sirius, and Proxima Centauri.

The mysterious orbit of a pulsar and a white dwarf

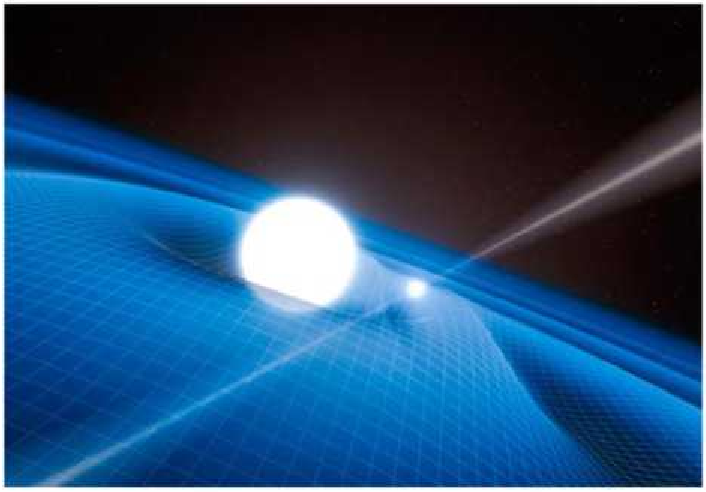
When stars die, they have a few options. Sun-like stars become objects known as white dwarfs: hot, planet-sized balls depleted of hydrogen. But larger stars collapse into city-sized neutron stars or black holes.

A white dwarf orbiting a neutron star isn't unusual. But research published November 2 in *The Astrophysical Journal* found a case that thus far denies explanation: A white dwarf in an eccentric orbit around a pulsar (a type of rapidly spinning neutron star), an astronomical first.

Often, pulsar-white dwarf duos are the remnants of stellar systems that began as binaries and continued on in this fashion. But according to current modeling, this object would need to have begun life as a white dwarf (rather than being the core of a small star), which would have taken 100 billion years.

Three explanations have been put forth. In one scenario, a third body would have destabilized the binary orbit of the white dwarf, making its orbit eccentric instead of roughly circular. In the second, one of the stars would have changed from one state into another. This could be a neutron star becoming a denser, strange quark star (a hypothesized but thus-far-undiscovered kind of star), throwing off the white dwarf companion. Or the pulsar could be a white dwarf that collapsed into a neutron star after accreting enough mass.

Both these explanations seem iffy compared with the third: The pulsar, in the act of stealing the material from the white dwarf, created a disk of materials that gradually changed the nature of the white dwarf's orbit. This scenario is unproven, although researchers believe it to be the mostly likely out of all possible explanations. For now, it remains a weird cosmic mystery waiting for a final answer. — **J. W.**



STRANGE SIBLINGS. A white dwarf and pulsar make a heck of a pair. They are, respectively, the remnants of Sun-like stars and of massive behemoth stars. This illustration shows how each affects the fabric of space-time. ESO/L. CALADA

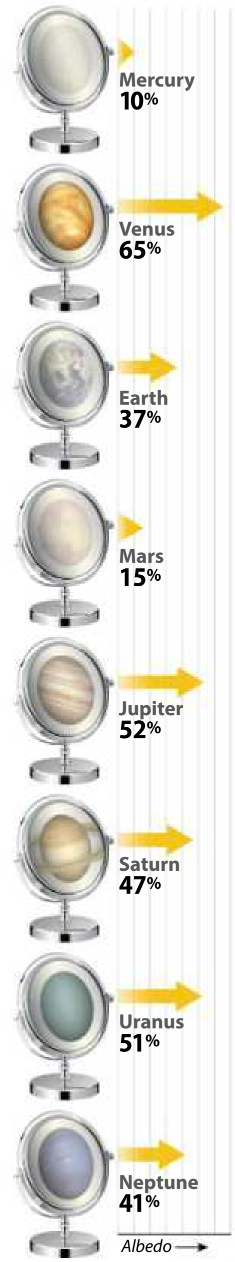
Carina Nebula collapsing

ESO/A. MCLEOD

STELLAR DESTRUCTION. Astronomers studying the Carina Nebula with the European Southern Observatory's Very Large Telescope observed a clear relationship between the pillars of the nebula dissipating and the ionizing radiation from nearby stars. The powerful radiation from the very stars the nebula recently birthed causes a process known as photoevaporation. At an atomic level, the starlight ionizes the gas, stripping off electrons. This process eventually destroys the gas pillars themselves, which can be light-years tall. Astronomers have observed similar destruction in the Eagle Nebula before. — **K. H.**

MIRROR, MIRROR

SPOTLIGHT. Like good and bad mirrors, each planet reflects a percentage of the sunlight that falls on it. Astronomers call that reflectivity albedo. Here's how they compare. **Michael E. Bakich**



ASTRONOMY: ROEN KELLY

FAST FACT: The Moon's albedo is 12 percent, so it reflects about the same amount of light as a pine forest on Earth.

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Twice-setting stars

What causes stars to set, rise, and then set again?

This month's column presents a naked-eye celestial mystery. It's about seeing a bright star that appears to set. OK, nothing so odd about that. Except in this case the star reappears briefly about a second or two later before slipping beneath the western horizon for good. It's a puzzling sight that may have several causes, or combination of causes, none of which I am certain are correct.

I've glimpsed these springing stars on perhaps three occasions over a period of 20-odd years, so it appears to be an uncommon event. The phenomenon always took me by surprise and caused long moments of fruitless pondering. To date I have observed twice-setting stars only over the long slopes of Mauna Loa volcano, as seen from the summit area of neighboring Kilauea volcano when I was living on Hawaii's Big Island.

I found the observations curious for two reasons. First, after seeing the phenomenon, I would wait to see if other setting stars would spring back into view, but none ever did. Second, Mauna Loa's profile (which looks like an overturned plate) covers a few degrees of sky as seen from Kilauea. So the phenomenon does not occur at the horizon where one might expect most weird atmospheric anomalies to happen, but rather some degrees above it.

A mirage of sorts?

In October 2016, I was in Eastbourne, England, experiencing unseasonably hot weather. Ships on the distant horizon appeared irrationally enormous while riding above the water's surface on a cushion of air.

At first glance, it looked as though what I was observing was a classic inferior mirage. In this phenomenon, the ship seemed enormous because an upside-down image of the ship appeared conjoined and beneath the actual ship. Also, the "ships" appear separated from the horizon by a thin band of sky because some of the sky above the real ship is also part of the mirage in its mirror image.

On the Big Island, a temperature inversion (when a layer of cold air becomes trapped beneath a layer of warmer air) is common under trade-wind conditions at heights between 4,000 and 8,000 feet (1,220 and 2,440 meters). Such conditions can lead to superior mirages, ones in which in which an upside down image appears above the original image.

But superior mirages also can make objects from beyond the horizon visible and suspend them in the air. Although rare, city lights normally out of view have appeared floating above the horizon from high northern latitudes — so why not (albeit briefly) light from a bright star that has already set?

Although not at a high northern latitude, Mauna Loa's summit lies 13,679 feet (4,169m) above sea level. It is an active volcano with a dramatically sharp and smooth profile — one shaped by extensive lava flows that soak up the Sun's rays during the day only to reradiate the heat into the atmosphere at night.

Adding to this radiative cooling, the mountain's slopes follow long radial rifts that can in places emit exceedingly hot steam into the cool air above them. It seems possible that either of these thermal effects can affect the density of the surrounding air and set up shifting mirage conditions, which can bend starlight after the star has set and make it briefly jump back into view.

As always, I'd like to hear your own experiences and thoughts. I'd especially appreciate hearing from others who have witnessed this or a similar phenomenon. Send reports to sjomeara31@gmail.com.

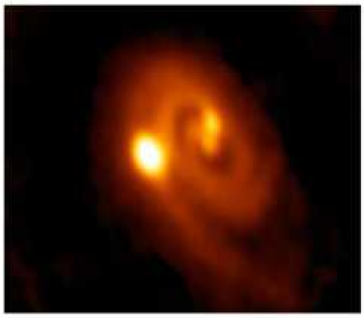
Stephen James O'Meara is a globe-trotting observer who is always looking for the next great celestial event.

This inferior mirage over the English Channel shows an oil tanker with a conjoined mirror image of the ship's tower, exaggerating its height. Note how the more distant front of the ship has all but vanished from view, leaving but a trace of the real ship floating on a mirror image of the sky below it. ALL IMAGES: STEPHEN JAMES O'MEARA

This inferior mirage over the English Channel shows a cargo ship with a conjoined mirror image of the ship and sky seemingly sailing above the sea. Note how the wave crests also seem to form miniature spires above the horizon line.

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

ASTRO**NEWS** **DOWNLOAD COMPLETE.** The New Horizons spacecraft, which buzzed Pluto in July 2015, has finished its data transmissions. It delivered the last of more than 50 gigabits of data October 25.



TRIPLET STARS. ALMA captured this image of the three stars in the L1448 IRS3B system. Two are visible close together near the system's center, separated by 61 times the average Earth-Sun distance. A third star resides farther out, at a distance 183 times the Earth-Sun distance from the center-most star. BILL SAXTON, ALMA (ESO/NAOJ/NRAO), NRAO/AUI/NSF

Radio observatories spy triple-star system

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) and Very Large Array (VLA) radio observatories discovered a triple-star system in its early years. The system is likely less than 150,000 years old and is answering important questions about how multiple-star systems form.

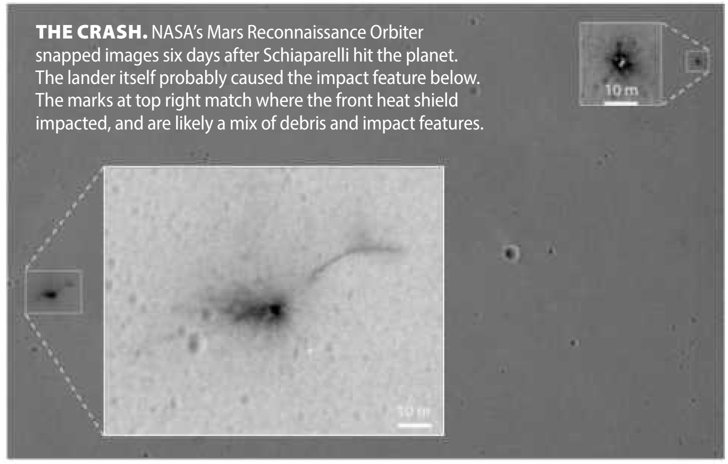
Known as L1448 IRS3B, the system contains two stars bunched closely together, with a third sibling farther away. The disk of gas that enfolds all three stars shows a distinct spiral. That spiral, as well as the spacing of the three stars, sheds valuable light on ideas about how stars in multiple systems form.

All stars form in clouds of nebulous material that slowly condense into a star-sized ball, surrounded by a swirling disk of gas. When it comes to twins and triplets, some systems form with the stars far apart, thousands of times the average Earth-Sun distance. The fraternal twins of the astrophysics world, these stars are born from the same initial cloud and then form their own disks independently.

But astronomers think that stars forming within just a few hundred times the Earth-Sun distance — within a solar system's worth of space, give or take — are more like identical twins: They are part of one initial disk that later fractures into multiple stars because of instabilities. Those instabilities are on display in the L1448 IRS3B system in the form of the obvious spiral in the disk. The multiple stars seem to confirm astronomers' ideas.

The new observations are the first time astronomers have seen such a triplet-star system still embedded in its formation disk. The research team published their results October 27 in *Nature*. — **K. H.**

Hard crash for the ExoMars lander



THE CRASH. NASA's Mars Reconnaissance Orbiter snapped images six days after Schiaparelli hit the planet. The lander itself probably caused the impact feature below. The marks at top right match where the front heat shield impacted, and are likely a mix of debris and impact features. NASA/JPL-CALTECH/UNIV. OF ARIZONA

On October 19, the European Space Agency's (ESA) Schiaparelli lander struck the martian surface at over 180 mph (300 km/h).

ESA later determined the failure was due to a bad reading from the craft's Inertial Measurement Unit, which tricked the craft into believing it was at a lower altitude, instead of 2.3 miles (3.7 kilometers) above the ground. The craft released its parachute at that point and began following other landing procedures, which resulted in total destruction of the lander on impact.

Schiaparelli was meant to be the lander component of the joint ESA-Russian Space Agency ExoMars mission to search for signs of past life on Mars. The Trace Gas Orbiter is still in orbit around Mars. The third component is a rover, set to launch and arrive in 2020.

NASA images revealed the crash site as of October 25, and follow-up images refined the investigation. They clearly showed the deployed parachute, which shifted (likely due to wind) over the course of days. About a mile (1.5km) away, the heat shield, also ejected early, appears to have caused its own impact features. And the crash site for the lander itself shows not only impact scars and signs of debris, but a larger feature to one side. Mission members speculate this might be a sign of where the unspent fuel tanks exploded.

The early stages of Schiaparelli's entry and descent had been progressing smoothly, so the science team has some data with which to work. By studying the information the lander gathered in the atmosphere's upper levels, the mission team can still glean important details about Mars' atmosphere. And by studying what went wrong during descent, the mission team can apply that knowledge toward future landings, like the 2020 rover for ExoMars. — **N. K.**

Astrobabble

From asterisms to Thorne-Żytkow objects, we turn gibberish into English.

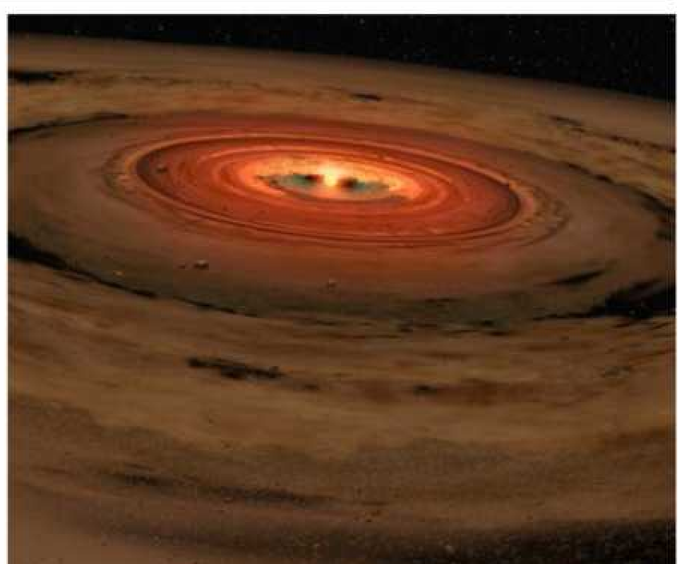
Hydroxyl
A chemical group with one hydrogen atom and one ionically charged oxygen atom. The highly reactive compounds behave similarly to alcohols. It was recently detected on the asteroid (and possible planetary core) 16 Psyche.

Depleted galaxy
A galaxy from which the stars in the galactic nuclei have been expelled. This may occur when two small galaxies merge their supermassive black holes, the turbulence of which ejects many kinds of stars.

Circumstellar disk >>
The area around a young star where planets, moons, comets, and asteroids form. Disk Detective, a NASA program to identify young solar systems in the process of forming planets, recently found a nearby circumstellar disk in AWI0005x3s, just 212 light-years away.

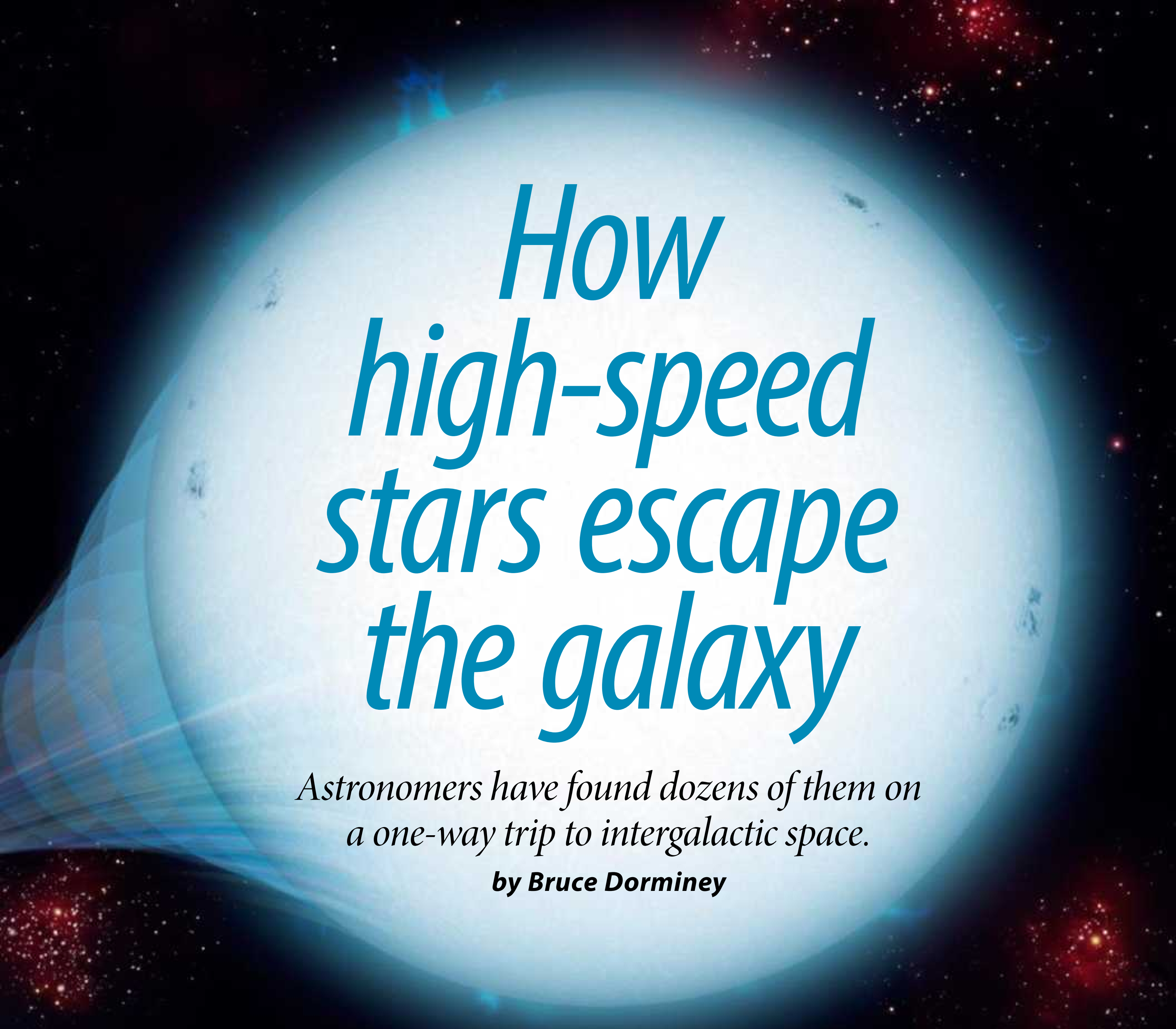
Parsec
A portmanteau of parallax and arcsecond used as an alternative to light-years to measure distance. One parsec equals 3.26 light-years. As it is not a unit of time, Han Solo's bold claims about the *Millennium Falcon*'s speed were lies.

— John Wenz, jargon@astronomy.com



NASA

If a binary star system ventures too close to the supermassive black hole at the center of the Milky Way, the black hole's gravity could capture one of the stars and toss the other into the galaxy's halo at speeds of 1 million mph or more. Astronomers think this scenario explains most of the Milky Way's two dozen or so hypervelocity stars. *ASTRONOMY*: ROEN KELLY



How high-speed stars escape the galaxy

Astronomers have found dozens of them on a one-way trip to intergalactic space.

by Bruce Dorminey

Stars bob and weave in and out of the Milky Way Galaxy's spiral arms like cars speeding through rush-hour traffic. But a snapshot of the nighttime sky makes it appear that these luminaries are as fixed as the great pyramids of Egypt. Of the estimated 200 billion to 400 billion stars that call our galaxy home, however, a tiny fraction of hot, massive ones stand out. Gravitational interactions have revved them up to speeds double or even triple that of the Sun. These so-called hypervelocity stars race through the Milky Way so quickly that they are destined to break free of the galaxy's gravitational embrace.

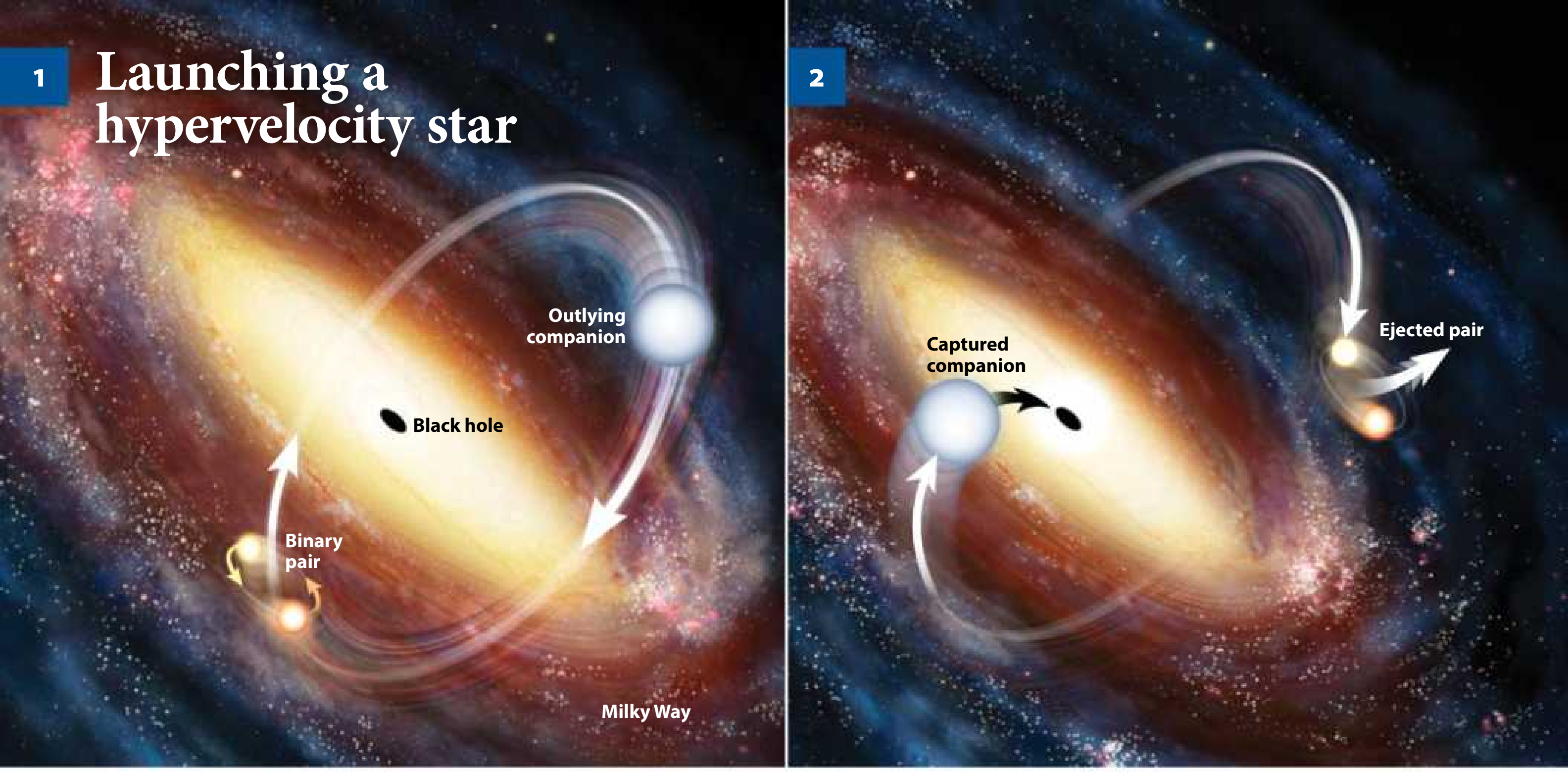
Our local solar neighborhood is in constant motion, participating in a mostly orderly flow shared by the vast majority of the stars revolving around the Milky Way's center. But a small number of fast-moving suns break this overall pattern. Astronomers often find these "runaway stars" fleeing youthful clusters.

Hypervelocity stars take these speeds to a new level. Over the past decade, scientists have discovered a couple of dozen of these speed demons. Nearly all are B-type luminaries with masses between two and five times that of the Sun and surface temperatures above 18,000° F (10,000 kelvins).

Most lie in the Milky Way's outer halo at least 150,000 light-years from the galactic center and move at velocities of more than 700,000 mph (1.1 million km/h). Such a star could zip from Earth to the Moon in barely 20 minutes and could traverse 1,000 light-years in a million years.

And all of them, by definition, have velocities high enough to eventually escape the gravitational clutches of our galaxy. The advent of new

Launching a hypervelocity star



Hypervelocity star HE 0437–5439 could have a complex origin story. Some astronomers think it started as a triple star made up of a tight binary system and an outlying singleton (1). When the trio approached the black hole in the Milky Way's core, the hole captured the outer member and threw out the binary at hypervelocity (2). The ejected pair evolved until one component became a red giant and the two spiraled closer (3). Eventually, the duo merged into a single "blue straggler" (4). *ASTRONOMY*: ROEN KELLY

ground- and space-based technology should soon uncover more hypervelocity stars and give us a closer look at those already known.

The first glimpse

Theorist Jack Hills of the Los Alamos National Laboratory in New Mexico first predicted hypervelocity stars in 1988, but astronomers didn't find one until 2005. Warren Brown of the Harvard-Smithsonian Center for Astrophysics (CfA) and colleagues stumbled upon SDSS J090745.0+024507 while targeting faint blue stars in the galaxy's halo. This particular star lies some 350,000 light-years from the center of the Milky Way and has a radial velocity (its speed directly away from the galaxy's center) of 1.51 million mph (2.42 million km/h). It made its way from the Milky Way's core to the outer galactic halo in only 140 million years.

Theorists think that Sagittarius A* (pronounced "A-star") — the supermassive black hole at the Milky Way's center — accelerates most of these hypervelocity stars, but astronomers also are interested in whether any high-velocity stellar interlopers exist. Such stars could be making their way into the Milky Way in the same way that others are leaving. And other researchers wonder if some hypervelocity stars could be ejected from dense stellar clusters or by supernova explosions.

Gravity accelerates these stars to their phenomenal speeds. The basic explanation is a "three-body exchange" between a binary pair of stars and a black hole, says Brown. The black hole captures one of the stars into a tight orbit and slings the other out of the galaxy.

"This gravitational slingshot could potentially eject stars at a speed that approaches the speed of light," says Avi Loeb, a theoretical astrophysicist at Harvard University. "These stars traverse cosmological distances and are the ultimate hypervelocity stars. They [are] not yet observed, but we made predictions about their abundance as a function of speed."

CfA astronomer Scott Kenyon says it is unclear how many hypervelocity stars exist in our galaxy. He estimates there are probably several hundred of them with three to five times the Sun's mass. "We use spectroscopic techniques to estimate a distance and thus a position in the Milky Way," he says. "We then compare the radial velocity to the velocity needed to escape the galaxy." And all of these stars are on track to exit the Milky Way within a few hundred million to a billion years.

To B or not to B

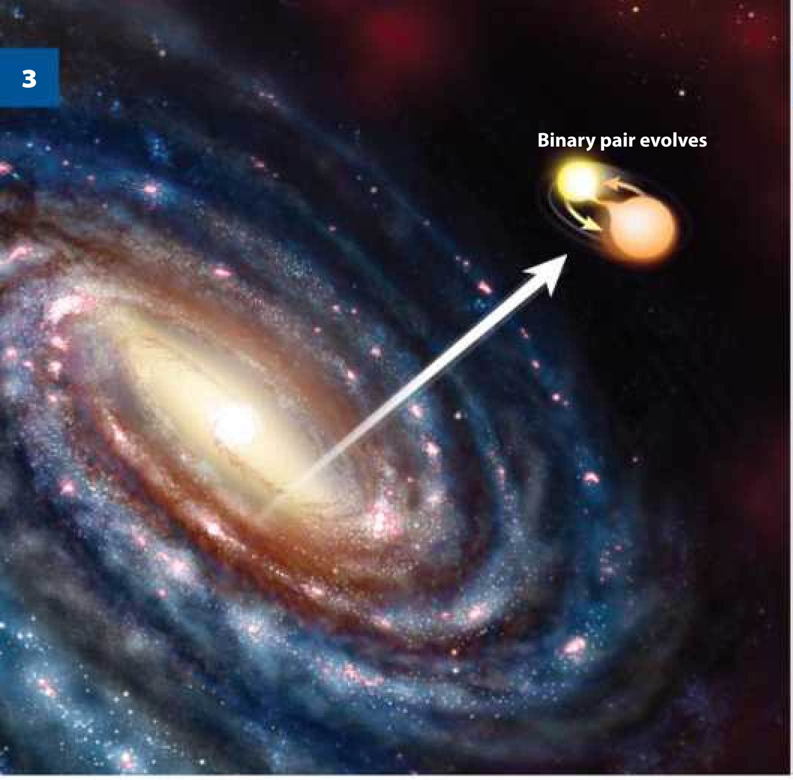
So far, almost all known hypervelocity stars are B-type suns on the main sequence, the period in their lives when they produce energy by fusing hydrogen into helium in their core. Because such stars live no more than several hundred million years, you wouldn't expect to find any on the galaxy's fringes.

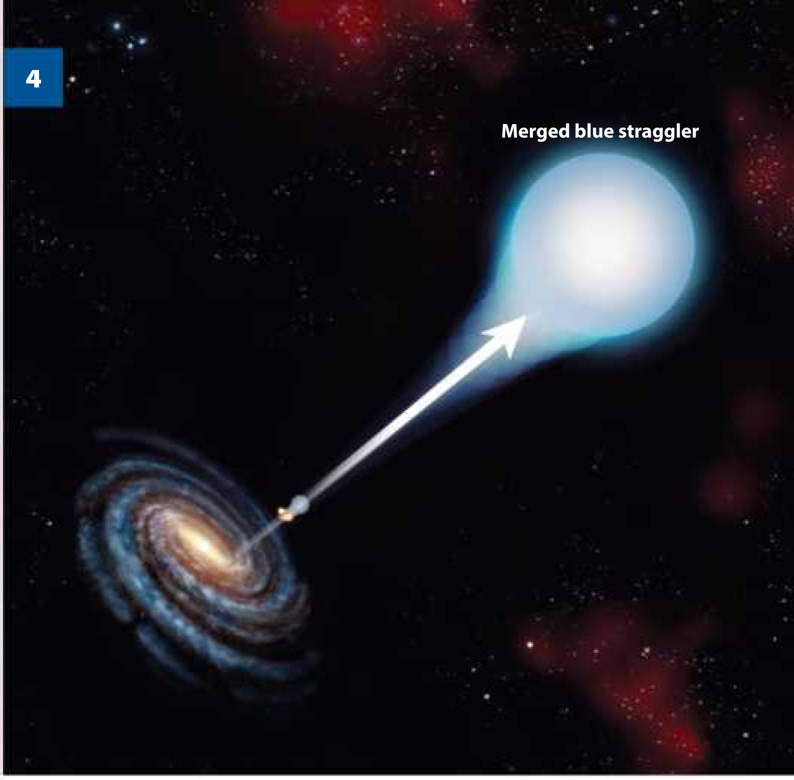
"These B stars should not exist there," says Brown. "There's no star formation in the outer Milky Way halo. It's a dead region — the galaxy's halo contains the galaxy's globular clusters and old, metal-poor, low-mass stars. Unless it was ejected there, you would never expect to see a B star traveling at those speeds in the outer halo."

But there they are. The best explanation for their existence involves a binary star that ventures too close to a massive black hole, says Hagai Perets, an astrophysicist at the Technion – Israel Institute of Technology in Haifa. The black hole captures one star into a highly eccentric orbit and ejects the other as a hypervelocity star.

A decade after Brown and his colleagues discovered the first such star, however, there's still a dearth of data on bona fide hypervelocity stars across the whole sky. Astronomers can measure any given star's radial velocity by examining its spectrum — light spread out into its constituent wavelengths. If an object is moving toward us, its spectral lines shift to shorter wavelengths; if it's moving away, the lines swing to longer wavelengths. The higher the velocity, the greater the shift.

Although this sort of spectral analysis is straightforward for nearby stars, it becomes





far more difficult for distant suns in the Milky Way's outer halo. Even large telescopes can't gather enough of their light. That's why astronomer Ulrich Heber of the University of Erlangen-Nuremberg in Germany thinks there are probably several low-mass hypervelocity stars just waiting to be discovered. Although these diminutive objects live longer than their B-type cousins, they radiate much less light and so can't be seen out to as great a distance. Still, they would be easier to detect than the even fainter white dwarf remnants of any dead B-type star.

On the move

Once astronomers know a star's radial velocity as viewed from Earth, they can calculate how fast it's moving relative to the galaxy's center. But even this tells only half the story. To directly link a wayward star in the galaxy's outer fringes to its theoretical point of origin at the supermassive black hole in the Milky Way's core, observers also must determine the star's motion across our line of sight. This so-called proper motion is even harder to measure precisely than radial velocity.

Astronomers determine proper motion by observing the shift in an object's position relative to more distant objects. For a hypervelocity star, this means measuring its movement in relation to background galaxies or quasars, a process that takes years.

Despite their breakneck speeds, hypervelocity stars have proper motions of less than 1 milliarcsecond per year. (One milliarcsecond equals 0.000000005°, or the angular size of a dime seen from about 2,300 miles [3,700 kilometers] away.)

Ground-based surveys are accurate to only about 5 milliarcseconds per year, so proper-motion studies for hypervelocity stars must be done from space. That's where the European Space Agency's (ESA) Gaia mission comes in. This astrometric observatory — designed to measure precise positions and radial velocities of some 1 billion stars — is yielding proper motions accurate to within 0.1 milliarcsecond per year. In the next year or two, Gaia should provide superb proper motions for known hypervelocity stars and new candidates.

Los Alamos theorist Jack Hills predicted hypervelocity stars in 1988, but astronomers didn't find one until 2005.

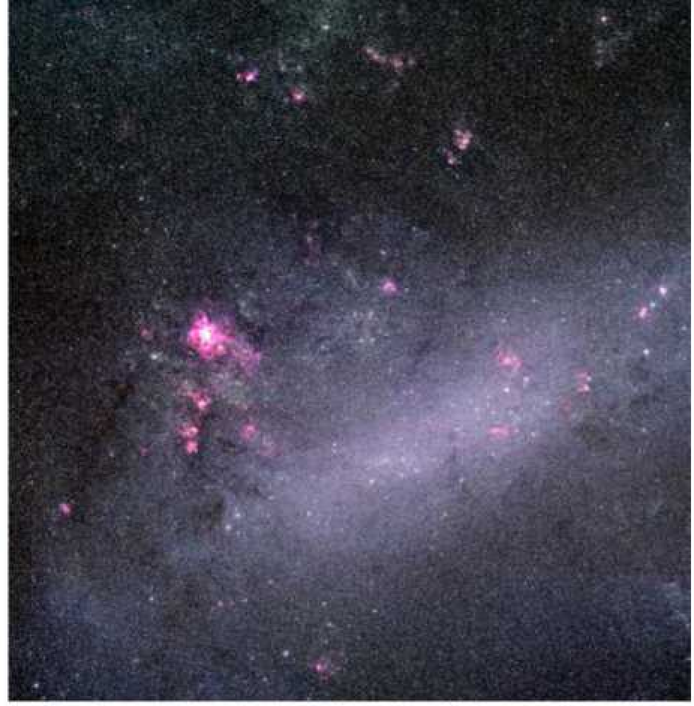
These observations will, in theory, help astronomers determine much more about these stars' points of origin. Although researchers think most originated in interactions with Sagittarius A*, they still debate whether some might be interlopers from outside the galaxy. Perhaps they made their way into the Milky Way's outer halo in a stream of stars from a tidally disrupted dwarf galaxy. Or maybe the Milky Way's satellite galaxy, the Large Magellanic Cloud (LMC), ejected some into our galaxy's halo.

"There's an unbound B star, HE 0437–5439, that's near the Large Magellanic Cloud that could either be from the LMC or the Milky Way," says Brown. "HE 0437–5439 is moving away from us, and we don't know if it's angled our way or to the LMC." If this star originated in the LMC, it might be the smoking gun for a previously undetected intermediate-mass black hole that ejected the star at hypervelocity.

Although the source remains elusive, Brown argues that the star is a remnant of a binary system ejected from the Milky Way. His scenario begins with a trio of stellar companions: a tightly bound binary pair in orbit with a more-distant sun. The three got caught up in the destructive gravity of Sagittarius A* and paid the price. The supermassive black hole captured the system's outlying member and ejected the other two, which remained an intact pair.

As the pair hurtled away from the galactic center, the more massive star eventually evolved into a red giant. As it swelled, the two stars spiraled together and merged into an even bigger "blue straggler." This delayed formation process for HE 0437–5439 is the best way to get a B-type main sequence star to its current position some 200,000 light-years from the Milky Way's center. Otherwise, this

Hypervelocity stars don't tend to be photogenic because they glow dimly due to their distances. The Hubble Space Telescope captured HE 0437–5439 (center), which lies in the constellation Doradus near the Large Magellanic Cloud. NASA/ESA/O. GNEDIN (UNIVERSITY OF MICHIGAN)/W. BROWN (HARVARD-SMITHSONIAN CfA)



The Large Magellanic Cloud, the largest satellite galaxy of the Milky Way, could be the source of hypervelocity star HE 0437–5439. If so, a previously undetected intermediate-mass black hole likely ejected it from a young star cluster. ESO

particular star would have evolved off the main sequence long ago.

"Only Sagittarius A* can explain the fastest B-type hypervelocity stars," says Brown. "Other processes eject different types of stars at different speeds."

The oddball stars

Heber, for one, studies some of these special cases. And he has concluded that nature has found a way to generate hypervelocity stars that doesn't rely solely on interactions with the galaxy's supermassive black hole. He suggests alternatives that include satellite galaxies disrupted by the Milky Way's tidal forces, binary supernovae, and ejections from star clusters.

Heber preferentially targets relatively low-mass stars that have evolved into bloated red giants. Such stars burn helium in their cores rather than hydrogen. "We find that most of our candidates are unlikely to have been launched from the galactic center," says Heber. "We are eagerly awaiting the Gaia astrometric measurements, which will allow us to trace their trajectories back to their place of origin much more accurately, maybe to a stellar stream, a cluster, or a spiral arm."

Right now, says Kenyon, astronomers have two good models for generating hypervelocity stars: disrupting a binary star system that passes too close to a black hole, and disrupting a binary during a supernova explosion. In the second scenario, two stars revolve around each other in a tightly bound orbit. When the higher-mass one reaches the end of its life and its core collapses, it triggers a supernova that can liberate its lower-mass companion. The exploded star's collapsed remnant — either a neutron star or a black hole — and the previously bound main sequence star then go their separate ways. This mechanism will work wherever young stars hang out, including inside youthful star clusters.

The neutron star RX J0822–4300 is a prime example. In 2012, astronomers clocked it moving at 1.5 million mph (2.4 million km/h). The explosion that created Puppis A — a supernova remnant some 7,000 light-years from Earth in the southern constellation Puppis — launched the stellar remnant onto this trajectory. Astronomers think this supernova was a lopsided explosion, and the neutron star headed one way while much of the supernova debris went in the opposite direction.

Trajectories of hypervelocity stars should deviate from a straight line depending on the shape and orientation of the dark matter halo.

Unfortunately, astronomers estimate that they would have to observe some 10,000 normal core-collapse supernovae to find one hypervelocity supernova. Scientists don't think such explosions create all hypervelocity supernovae, however.

A case in point is US 708, the fastest-known hypervelocity star with a speed of 2.7 million mph (4.3 million km/h). This helium-rich star is spectral type O, and one of the hottest stars known in the Milky Way's halo. Judging by its trajectory, it almost certainly did not originate in the galaxy's center.

Astronomers think it was once part of an ultracompact binary system. Its companion was a massive white dwarf near the limit of what these stars can weigh. When US 708 evolved into a red giant, it transferred much of its hydrogen envelope onto the white dwarf, eventually triggering a statistically rarer type Ia supernova that sent US 708 onto a hypervelocity trajectory.

Pride of the Lion

You might think that hypervelocity stars would be spread across the sky randomly, but that's not the case. One of the biggest puzzles surrounding current observations is that half of the B-type hypervelocity stars are clumped around the constellation Leo, Brown says. Heber thinks this could mean that the galactic center ejected them preferentially in a certain direction. He says this could happen if the ejected stars came from a stellar disk surrounding the supermassive black hole.

But the observations of clustering may just reflect a lack of data. "We do not have a complete survey of the entire sky," says Kenyon, "so maybe we are seeing a statistical fluke." Surveys of the southern sky should clarify this issue. In particular, they will allow astronomers to study north-south asymmetries and see whether similar numbers of hypervelocity stars reside in Aquarius, the constellation opposite Leo.

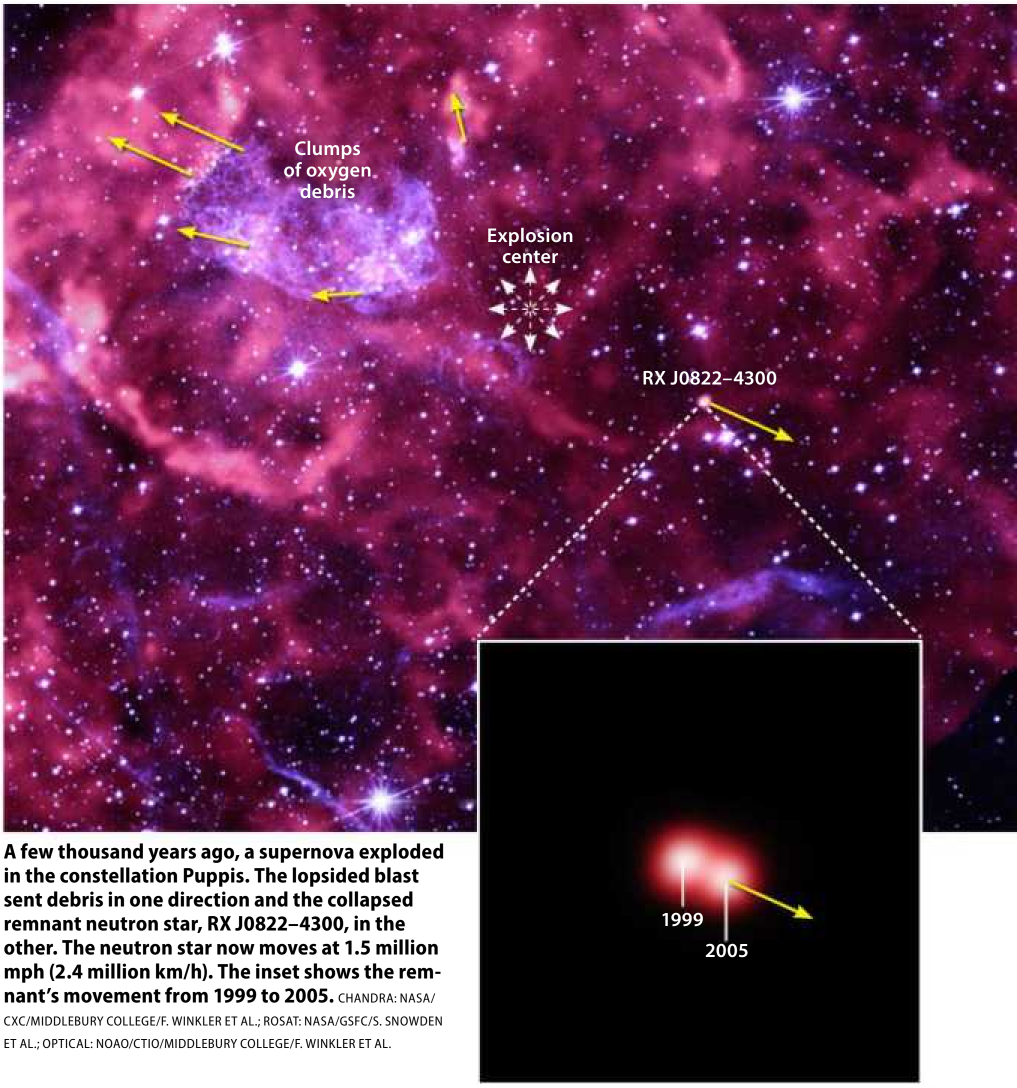
New surveys with the 1.35-meter SkyMapper robotic telescope in Australia, the European Southern Observatory's 2.6-meter VLT Survey Telescope in Chile, and the 8.4-meter Large Synoptic Survey Telescope (LSST) currently under construction in Chile will complete the search for hypervelocity stars in the southern sky.

Once these surveys are finished, astronomers can start using hypervelocity stars to study other features of the Milky Way. "Because [B-type] hypervelocity stars originate from the galactic center, their trajectories should be a straight line outward," says Brown. "However, theorists believe that the Milky Way is surrounded by a triaxial [football-shaped] distribution of dark matter."

This means the present trajectories of the hypervelocity stars should deviate from a straight line as they feel the gravitational pull of this unseen matter, he says. How much the trajectories deviate, and in what direction they do so, depend on the shape and orientation of the dark matter halo.

If astronomers can find 200 or so hypervelocity stars distributed all across the sky, says Kenyon, then measuring their precise trajectories could tell us how they decelerate as they travel from the galactic center into the halo. Scientists then could use these deceleration measurements as a function of position on the sky to learn whether the shape of the dark matter halo is more spherical or if it is flatter at the galaxy's poles.

In principle, Kenyon says, if hypervelocity stars spread out nonuniformly on the sky, the degree of their asymmetry can tell us about asymmetries in the distribution of matter in the galactic center and inner bulge.



A few thousand years ago, a supernova exploded in the constellation Puppis. The lopsided blast sent debris in one direction and the collapsed remnant neutron star, RX J0822–4300, in the other. The neutron star now moves at 1.5 million mph (2.4 million km/h). The inset shows the remnant's movement from 1999 to 2005. CHANDRA: NASA/CXC/MIDDLEBURY COLLEGE/F. WINKLER ET AL.; ROSAT: NASA/GSFC/S. SNOWDEN ET AL.; OPTICAL: NOAO/CTIO/MIDDLEBURY COLLEGE/F. WINKLER ET AL.

Into the future

Still, current technology limits observations to only the brightest and thus most massive hypervelocity stars. Astronomers identify candidates based on their brightness and color and then they take spectra to see if they are moving at high velocities. To extend their reach to smaller and dimmer solar-type stars, scientists will need the LSST to select hypervelocity candidates based on color and then target these suns with the next generation of extremely large telescopes to get spectra. Finally, the Gaia mission will provide precise astrometric data to verify their place of origin and determine whether they hail from the galaxy's center, stellar streams, or elsewhere.

These solar-type stars become visible once they evolve off the hydrogen-burning main sequence and become red giants. Such stars shine brightly enough to be visible throughout the Milky Way's halo — and perhaps beyond. Future all-sky infrared surveys conducted from space, such as NASA's Wide Field Infrared Survey Telescope and ESA's Euclid spacecraft, should be able to detect these aged hypervelocity stars.

Hundreds of billions of years in the future, hypervelocity stars may be the only objects beyond the galaxy we'll be able to observe. At that stage of cosmic evolution, all the galaxies in our Local Group will have merged into a single megagalaxy. And, assuming that the Hubble expansion of the universe continues to accelerate under the relentless push of dark energy, all the galaxies outside the Local Group will disappear beyond our cosmic horizon.

As Brown has written, "The only extragalactic sources of light in the observable cosmic volume will be hypervelocity stars ejected from our galaxy. Thus, hypervelocity stars may become the primary tool for measuring the Hubble expansion." And our window on the cosmos at large will be reduced to those few hypervelocity stars that ply space-time wholly unimpeded by the gravitational bonds of their original host galaxy.

Science journalist **Bruce Dorminey** *is author of* Distant Wanderers: The Search for Planets Beyond the Solar System *(Springer, 2001). Follow him on twitter: @bdorminey.*


SUPER

NOVA 1987A 30 years later

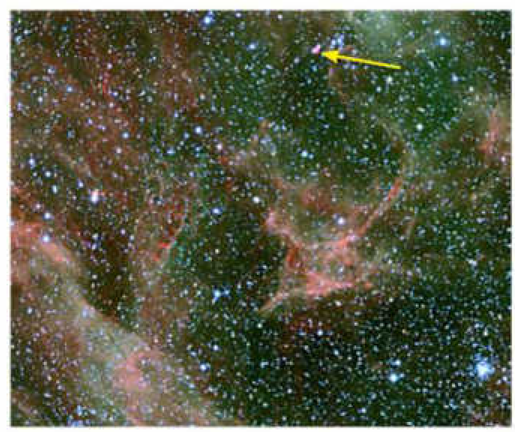
When a blue supergiant star lit up the southern sky, astronomers used it to learn how massive stars explode. **by Liz Kruesi**

Astronomy doesn't adhere to humans and their timescales. Cosmic objects typically take thousands, millions, or even billions of years to evolve. But every so often, the universe gifts us an exception. A brilliant explosion that appeared in our sky 30 years ago is one such present.

This cosmic object, Supernova 1987A, marked the death of a massive star. The glowing ember lies 160,000 light-years from Earth in the Milky Way's largest satellite galaxy, the Large Magellanic Cloud (LMC). In astronomical terms, that's next door. This proximity means that our telescopes can resolve small changes in the evolving supernova remnant, changes that would be invisible if the object lay millions of light-years away.

"It changes on human timescales," says Penn State University astrophysicist Kari Frank. That uniqueness is what keeps she and the hundreds of other astronomers who study SN 1987A interested in this object.

Supernovae happen on average once per century in a galaxy the size of the Milky Way, although our galaxy is long overdue. So we welcome our galactic neighbor's gift. With observations tracking every step of this supernova's evolution as it transitions from blast to remnant, astronomers are piecing together details of the explosion itself and the star that gave birth to it.



The tiny purplish splotch (arrow) at the top of this image marks the site of Supernova 1987A and its expanding debris in 2006. The intricate folds of the Honeycomb Nebula appear at center left. ESO

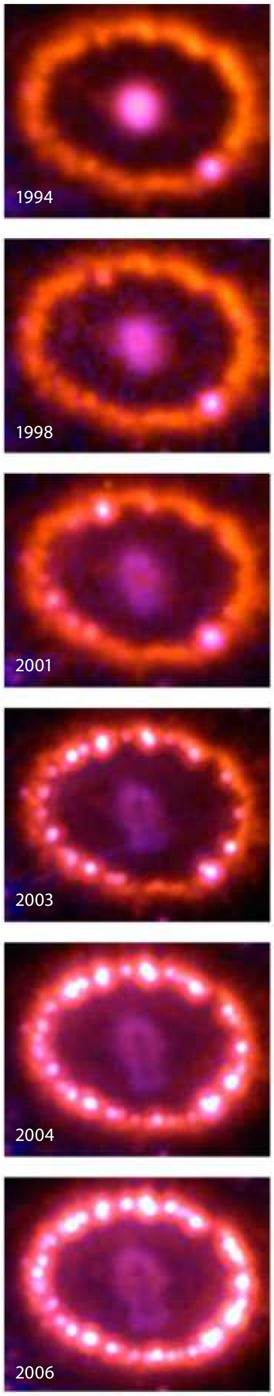
Scientists can't obtain these types of details for any other supernova, which makes SN 1987A not just an exciting cosmic object but also one that reveals characteristics of an entire class.

After watching the continually evolving glow of SN 1987A in every type of light for three decades, this is what we now know.

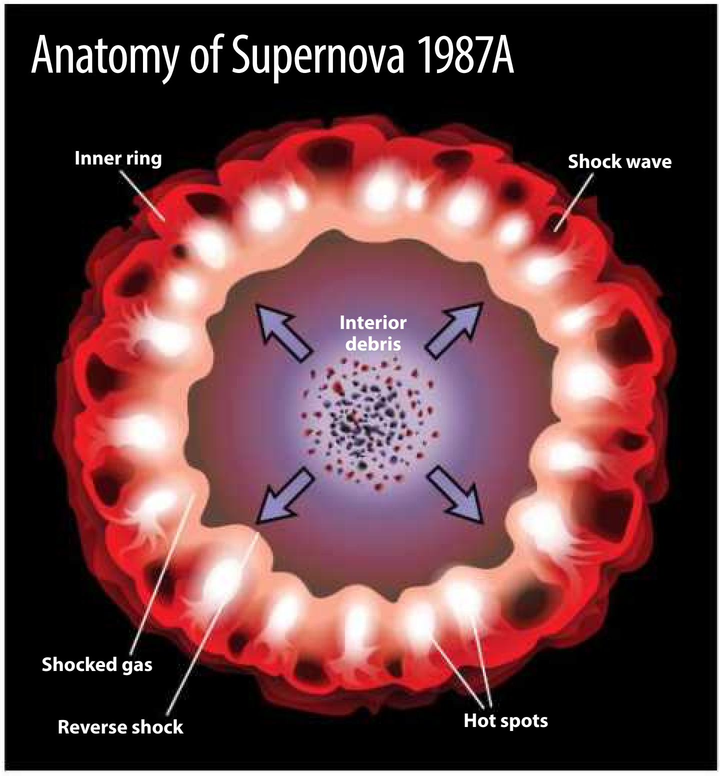
The historic explosion

SN 1987A burst onto the scene February 23, 1987, when it shone as a brilliant new star in the

The first naked-eye supernova in nearly 400 years lit up the southern skies in February 1987. The blast occurred in the Large Magellanic Cloud, a Milky Way satellite galaxy, not far from the massive Tarantula Nebula to its upper left. ESO



Supernova 1987A's ring comes alive with hot spots over a 12-year period. The ring, composed of material ejected from the progenitor star some 20,000 years before the blast, lights up as the supernova's shock wave heats knots of dense gas.
NASA/ESA/P. CHALLIS AND R. KIRSHNER (CfA)



This snapshot shows SN 1987A's structure from a few years ago to coincide with images of the inner ring looking like pearls on a necklace. The pearls are dense gas pockets excited by the supernova's shock wave, which since has started moving beyond the ring. The shock's collision with the ring created a reverse shock that is now heading back toward the center.
ASTRONOMY: ROEN KELLY

southern sky. Many astronomers at first didn't believe the news of a supernova so close to the Milky Way, thinking that colleagues might be playing some sort of cruel joke. But over the next few days, researchers across the globe scrambled to observe this beacon and confirmed that it lay in the nearby LMC. Its location couldn't have been much better — almost any Milky Way supernova would have been heavily obscured by intervening dust.

By comparing photographs of SN 1987A's region taken before and after the explosion, astronomers soon pinned down which star had detonated. It was a supergiant star cataloged as Sanduleak –69°202 that held the mass of several Suns and burned so hot that its surface appeared blue. At this star's core, just like in all stellar cores, the temperatures and pressures were high enough to fuse atomic nuclei into heavier elements.

Once the star that led to SN 1987A developed a heart of iron, it could no longer create heavier elements. Its core then began to collapse, and the star's outer layers fell toward the imploding interior. When the core reached the density of an atomic nucleus, it abruptly stiffened and generated a shock wave that blew off the gaseous outer layers. Astronomers have not yet seen evidence of this collapsed core — either a neutron star or a black hole — making the missing cinder the biggest remaining mystery of SN 1987A.

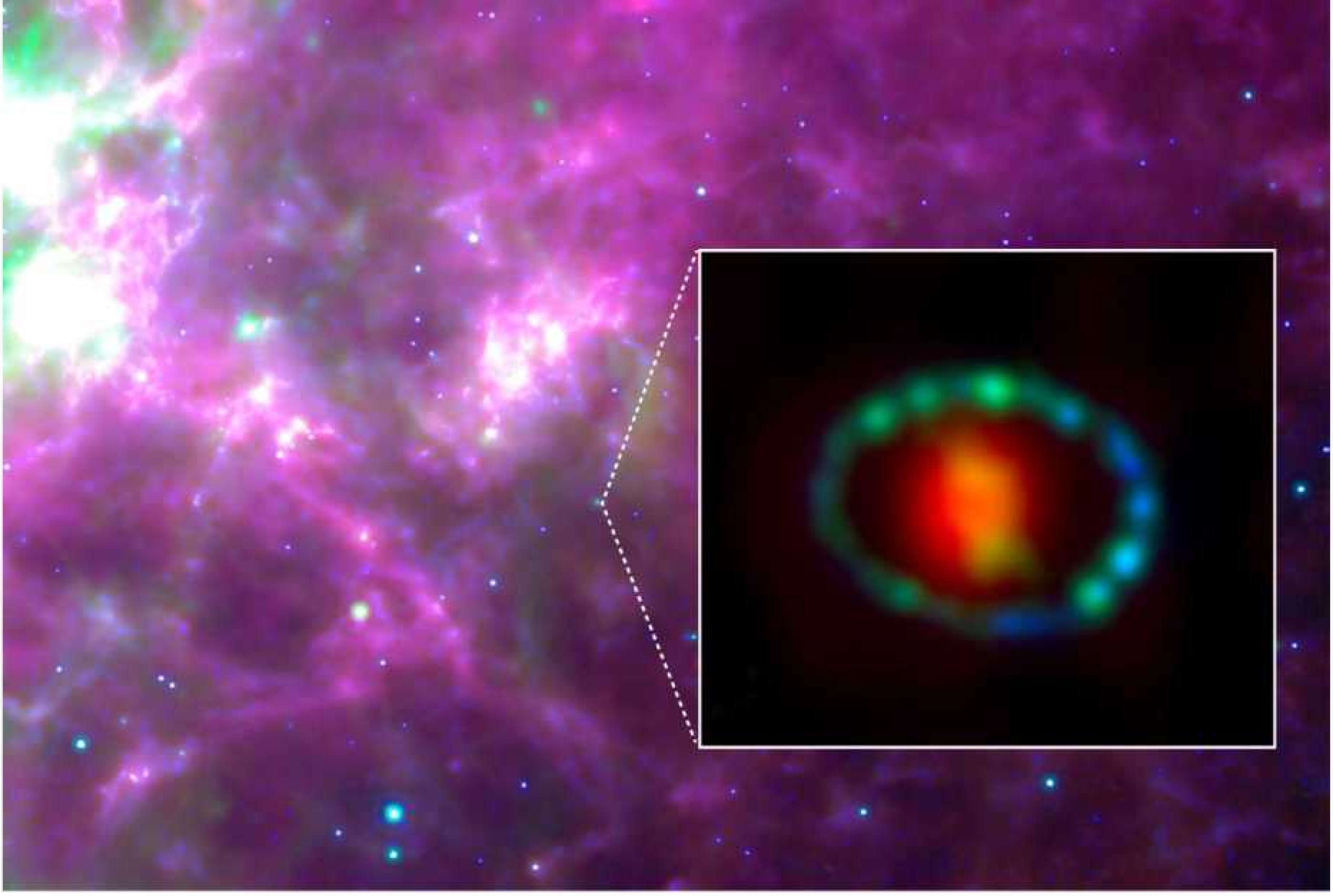
Although Contributing Editor **Liz Kruesi** *was alive for SN 1987A's February 1987 appearance, she wasn't yet old enough for her interest in astronomy to have kicked in.*

The exploded layers of gas rushed away from the blast site at varying speeds, the fastest moving at about one-tenth the speed of light. For a couple of years afterward, the supernova glowed thanks to radioactive elements created in the explosion that were scattered throughout the debris. These elements decayed naturally, emitting energy in the process that heated the gas. But by 1990, SN 1987A's radioactive elements no longer powered the growing remnant. So, the gaseous leftovers cooled and dimmed.

By 1997, though, SN 1987A's remains had started brightening again — but not because of radioactive materials. Instead, the high-speed gaseous shock front that had rushed away from the explosion site had slammed into surrounding interstellar gas. The collision heated knots in the newfound material. The heated gas, however, wasn't keen on this fresh influx of energy, so it released light in an effort to shed some of the excess. Astronomers first saw this emission, appearing like glowing pearls on a necklace, in wavelengths of optical light in 1997 using the Hubble Space Telescope.

Then, in July 1999, the Chandra X-ray Observatory launched. Three months later, astronomers obtained their first X-ray view of SN 1987A. Roughly every six months since then, Penn State astronomer David Burrows has captured images of the remnant using this telescope. The X-ray emission appears as a ring — Chandra doesn't have the angular resolution to make out the individual "pearls" — of hot gas glowing at roughly 1 million kelvins.

Astronomers now know where this ring of material comes from: Sanduleak –69°202 shed this gas some 20,000 years before the blast. But they don't agree on what process led the star to cast off a few solar masses' worth of star stuff. Either the star was rotating so fast that it launched a dense wind of material from around its equator, or two massive stars merged all those thousands of years ago and flung off the gas.



The Spitzer Space Telescope and Herschel Space Observatory show infrared radiation from stars and dust in SN 1987A's vicinity. Inset: ALMA reveals the glow from cold carbon monoxide molecules (red) at the blast site's center, while Hubble captures hot gas in the surrounding ring. ESA/NASA/HERSCHEL/SPITZER/STScI/ESO/ALMA

That discarded matter moved more slowly than the explosion's shock front, so when the blast wave hit this pre-existing ring, those clumps glowed. The knots brightened in Hubble image after Hubble image, starting in 1997 and ending just recently.

Illuminating inside and out

Now it seems as though the blast wave is moving beyond the ring. Swedish astronomers Claes Fransson and Josefin Larsson have led the recent Hubble Space Telescope observations of the ring, and the images show the pearls growing fainter and losing their luster. New clumps of matter outside of the main ring have started to appear. The farther away from the blast site that astronomers look, the further back in time they can see. That means that as the shock front moves into this new region, it's telling scientists about what Sanduleak –69°202 shed before the 20,000-year-old ring of material. "As this shock wave continues to evolve, we'll see more and more of the mass-loss history of the progenitor star," says Larsson.

While Chandra doesn't have the resolution to pick out individual clumps in the X-ray emission, its data also show that the brightness has plateaued. "The shock wave is moving past the ring into something else. And that's exciting because we don't know what's there," says Frank, who works with Burrows on the Chandra data.

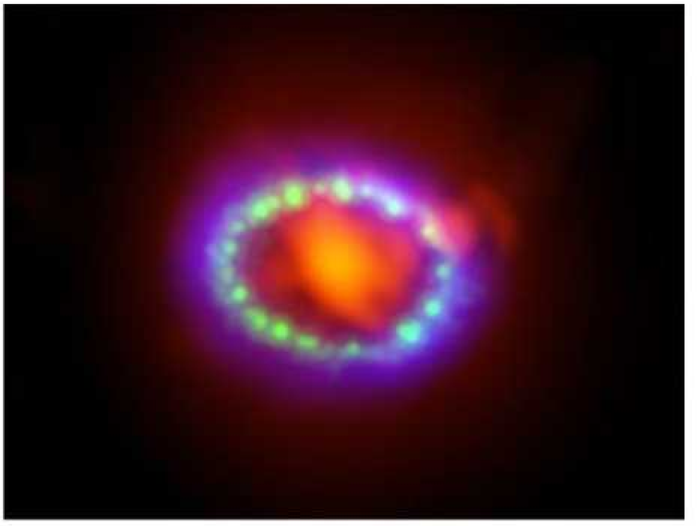
The ring's radiation has overwhelmed any less-intense X-ray light from other regions of the remnant. But soon the ring should dim, and Frank and Burrows expect other regions to start becoming visible in X-rays. Specifically, they're looking for material compressed by a secondary front. When the blast wave slammed into the ring's inner edge, most of it passed through and heated the material to ignite the known ring, says Burrows, but part of that shock would have reflected off the ring's inner edge and is now moving back toward the remnant's interior. "That's called the reverse shock," he says.

Supercomputer simulations by Salvatore Orlando of Italy's Osservatorio Astronomico di Palermo and colleagues predict the reverse shock should begin encountering the star's exploded debris — the ejecta — in five to seven years.

Cool things down

Supernova explosions release an immense amount of energy and drive temperatures sky high. Even today, SN 1987A's ring glows in optical and X-ray light because the blast wave has excited the atoms there to temperatures of a million degrees. With so much of the focus during the past three decades on the ring, it's easy to think that the whole supernova remnant must remain hot. But the ring is the exception — the rest of the remnant is frigid.

Because astronomers haven't yet seen a central neutron star in SN 1987A, they can put limits on how bright — or rather, faint — it must be: It's probably 1,000 times fainter than the Crab Nebula's neutron star.



Above: ALMA captured radiation from newly formed cold dust (red) in the interior of the SN 1987A remnant. Visible-light and X-ray emission imaged by Hubble and Chandra, respectively, reveal where the expanding shock wave slams into surrounding gas. R. INDEBETOUW ET AL./A. ANGELICH (NRAO/AUI/NSF); NASA/STScI/CfA/R. KIRSHNER; NASA/CXC/SAO/PSU/D. BURROWS ET AL.

Left: A three-ring circus gathers tightly around the site of SN 1987A while wispy tendrils of unrelated gas frame the scene in this composite view from 1994, 1996, and 1997. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

For Mikako Matsuura and her colleagues' next observing project, they are using ALMA to study whether dust and molecules mirror each other in the SN 1987A remnant. Most scientists think they should, but the universe sometimes surprises us.

At the center of the explosion's site, material has long expanded away, radiating energy and thus heat in the process. In fact, the remnant's center is now cool enough for atoms to have combined into molecules, and some of those molecules to have conglomerated into dust particles. The temperatures here range between 20 and 100 kelvins. (Remember that water on Earth freezes at 273 K.) To study material at these cool temperatures, astronomers turn to less-energetic light and the instruments that collect it: infrared telescopes and submillimeter arrays.

The most crucial tool in this work has been the Atacama Large Millimeter/submillimeter Array (ALMA) in northern Chile. ALMA can separate details just 0.05" from one another on the sky, which is better resolution even than what Hubble can achieve. To study SN 1987A's dust, which radiates at these cold temperatures, Mikako Matsuura (then at University College London) and her colleagues combined 2013 observations using a still-incomplete ALMA with 2012 infrared data from the European Space Agency's Herschel Space Observatory. They found that the remnant houses an enormous amount of dust — about one-half of the Sun's mass.

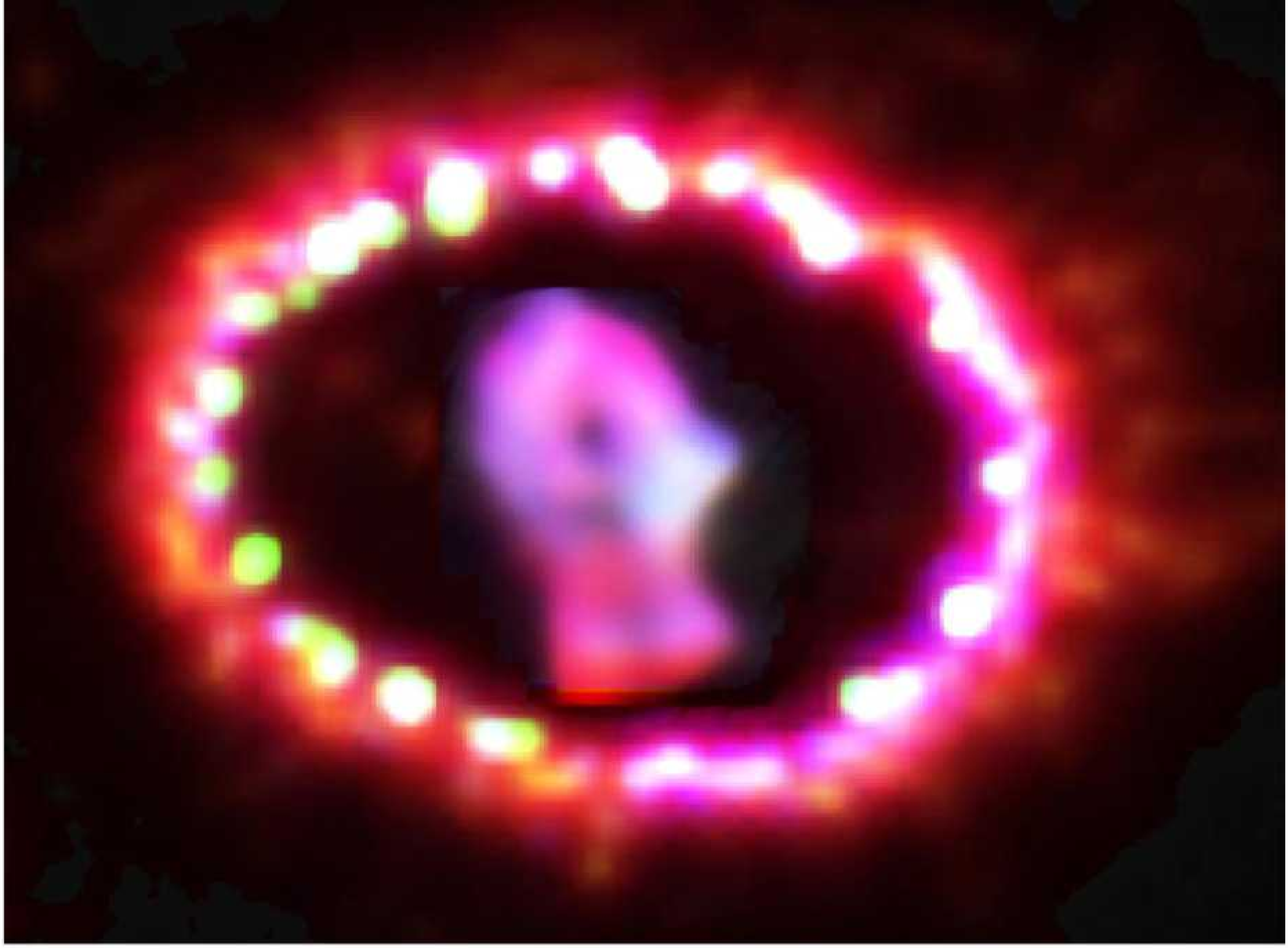
The dust that astronomers talk about isn't like the dust that whips around after you drive along a dirt road. Instead, it's similar to the texture of smoke. Cosmic dust can range in size from a few molecules up to 0.1 millimeter across, and it radiates at temperatures of only about 20 kelvins.

Because astronomers can't put the dust lurking in SN 1987A's center on a scale to weigh it, Matsuura's team turned to the same tool scientists have used for decades: the collected light. They knew the material's temperature from the type of light it emitted (submillimeter and far-infrared), and they knew that a brighter signal equated to more material. "So the total brightness from the object can give the total mass," says Matsuura. "It's simple physics." What isn't so simple, however, is understanding the process that creates all that dust — or what processes could destroy it.

Mapping the star's guts

The same group of astronomers also is using ALMA and infrared instruments to observe molecules in the remnant's ejecta. Whereas studying dust gives scientists limited information, such as what type of object can create the tiny particles, molecules give more insight into the physics of what's going on. Each type of molecule is made up of a unique combination of elements and emits light of specific colors, or wavelengths. This means that astronomers can figure out what molecule they're detecting by measuring the wavelengths of light their instruments see. And they can gather an array of additional information from the detected molecules: the direction and speed of motion (toward and away from the telescope), temperature (because certain molecules exist only at certain temperatures), and the amount of the molecule. With all these details, they can begin to piece together information about the exploded star's innards.

However, it isn't only cold molecules that astronomers can use to peer inside the ancient progenitor star.



SN 1987A has now evolved into a supernova remnant. The proof came in this 2011 Hubble image showing a fish-shaped central structure of expanding supernova debris. This material has started to brighten as it basks in the X-ray glow from the surrounding ring of pre-supernova material. NASA/ESA/P. CHALLIS (CFA)

A specific wavelength of high-energy X-ray radiation traces a radioactive element that scientists know must have been produced in the supernova blast. Using data collected by NASA's NuSTAR X-ray observatory between 2012 and 2014, researchers studied the distribution of titanium-44. How this element is scattered across the remnant can reveal how turbulent the motions inside the progenitor star were during the blast. And it also can show how asymmetrical the explosion was. It turns out that SN 1987A was very lopsided.

Larsson, in addition to her Hubble studies of the optical pearl necklace, also has worked on mapping the motions of different elements and molecules in the remnant. She's used Hubble and the Very Large Telescope in Chile to get at these values with a goal of teasing out ever more details of the explosion from its ejecta.

Specifically, Larsson is measuring each gas cloud's movement toward or away from Earth, and from that value she can calculate how far away it lies. "We'll build up a more detailed view of the three-dimensional distribution of different elements and molecules," she says. Combining these data with the molecular information from ALMA observations will lead, she says, to a detailed 3-D map of the explosion. So far, Larsson and her colleagues have mapped hydrogen, iron, silicon, calcium, magnesium, and oxygen — and these elements are not distributed symmetrically.

With multiple pieces of evidence showing that the SN 1987A blast was asymmetric, perhaps astronomers will be able to find out more about how the explosion happened. Most computer models fail to produce supernovae — they stall out during the blast and can't explode the star. But supernovae occur across the cosmos and spew their ejecta into the interstellar environment. SN 1987A and its resulting remnant make for the best constraints that scientists have to compare computer models against.

Astronomers have big goals for their studies of SN 1987A and its remnant, and they'll need to continue observing the blast site to reach those goals. It's a rare opportunity to watch in detail as a cosmic object evolves, and scientists aren't taking this next-door explosion for granted. Until the universe provides us with another nearby supernova to study with modern tools, SN 1987A will remain the best target. "We need to watch it while we can," says Frank. "It may be our only chance for a long time."

DEFINING THE TRANSITION

Even though we still call the object "Supernova" 1987A, most astronomers accept that this is a remnant now, and not a supernova. The phrasing is important, and it relates to a crucial transition period that scientists don't know much about. That's because the transition isn't something they can test in a laboratory or see anywhere else in the sky. They need to make out the structural details of a supernova evolving into a remnant — and that's possible only with SN 1987A. — *L. K.*

PLANET NINE EFFECT?

Q: COULD THE IRREGULARITIES ASTRONOMERS DETECTED IN NEPTUNE'S ORBIT HAVE BEEN CAUSED BY "PLANET NINE"?

***Robert B. Ellis,** Tucson, Arizona*

A: Many people are familiar with the fantastic story of the discovery of Neptune. Based on the observation that Uranus' orbit was not as expected, French astronomer Urbain Le Verrier (and, independently, English astronomer John Couch Adams) predicted Neptune's existence in 1845.

Le Verrier wrote to German astronomer Johann Galle at the Berlin Observatory, who discovered Neptune the night Le Verrier's letter arrived (September 23, 1846), within 1° of his prediction. That angle is about half the apparent width of a finger at the end of an outstretched arm seen against the sky.

Pluto's discovery was much more by chance. There were many predictions of Pluto's orbit prior to its discovery, most of which were not even close to giving Pluto's actual position. Several well-known astronomers contributed predictions, including, most famously, Americans Edward Charles Pickering and Percival Lowell. Lowell's prediction, made in 1914, was remarkably close to Pluto's actual orbit, although his estimate of the planet's mass was a few thousand times too large at 6.6 Earth masses.

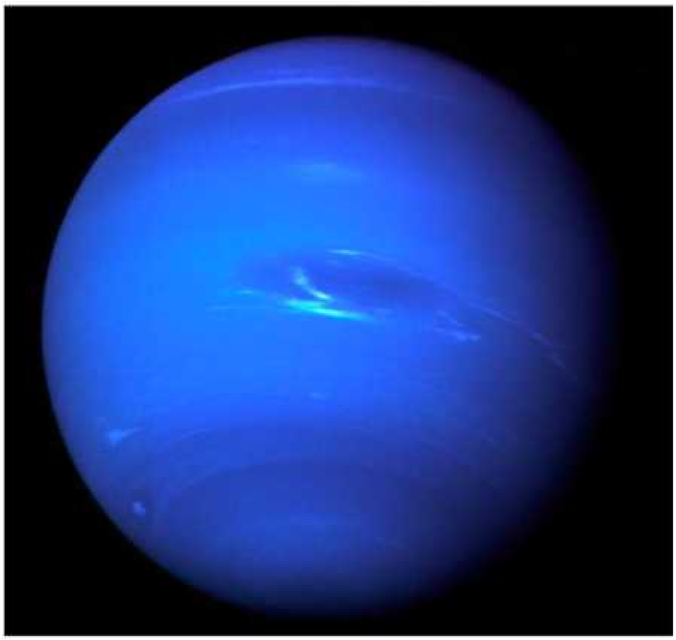
Today, we think those early predictions were based on the incorrectly known mass of Neptune. After Voyager 2's encounter with Neptune in 1989, researchers used telemetry data to revise Neptune's mass, after which there were no longer any observed discrepancies in Uranus' or Neptune's orbit. So, unfortunately, the answer to your question is "No," because today we see no perceptible irregularities in Neptune's orbit.

I say "unfortunately" because many astronomers, including me, do think there is some evidence for an undiscovered planet in the outer regions of our solar system. The orbits of many of the most distant trans-Neptunian minor planets, as well as the dwarf planets Sedna and 2012 VP_{113}, are curiously aligned. One possible explanation for this alignment is the action of an as-yet undiscovered planet much more massive than Earth in the outer regions of the solar system. Only future discoveries (or lack thereof) will show whether the predictions of this hypothesized planet are like the many incorrect predictions made about Pluto prior to its discovery, or whether they are more like Le Verrier's astonishingly accurate prediction of Neptune.

Chad Trujillo
Assistant Professor
Department of Physics and Astronomy
Northern Arizona University

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.



Once the Voyager 2 spacecraft passed Neptune in 1989 and planetary scientists were able to accurately measure its mass, all irregularities in the distant world's orbit vanished. NASA

Q: I AM PLANNING TO PHOTOGRAPH THE 2017 TOTAL SOLAR ECLIPSE THROUGH A HYDROGEN-ALPHA FILTER. IF I WERE TO ATTEMPT THIS DURING TOTALITY, WOULD THE CORONA BE VISIBLE IN THE H-ALPHA WAVELENGTH? MY CAMERA HAS A VARIETY OF ISO SETTINGS AVAILABLE AND MANY EXPOSURE SETTINGS.

David A. Cater
Siloam Springs, Arkansas

A: The solar corona — our star's outer atmosphere — is visible only during the total phase of a solar eclipse. The reason is a contrast effect, really. The Sun's photosphere (its visible face) is so brilliant that its light completely swamps the faint illumination (along with all the delicate details) of the corona.

In fact, the corona glows with only one-millionth of the brightness of the photosphere. Believe it or not, that output is more than you might think. What else shines with a similar illumination? The Full Moon. Indeed, if you want to experience the level of illumination eclipse watchers will experience during totality, head outdoors some night when the Full Moon is in the sky.

A Hydrogen-alpha (Hα) filter normally is a great way to observe the Sun. Because it only passes light with a wavelength of 656 nanometers, the normally dangerous brilliance of our star falls to a safe level. In doing so, the Hα filter acts the same as a visual solar filter, like a #14 welder's filter or the cardboard and Mylar eclipse glasses manufacturers currently are producing by the millions.

Unfortunately, if you try to view or photograph the much fainter corona, the result will be the same as trying to view it through eclipse glasses: You'll see nothing. So, you can take as many Hα images during the partial phases of the eclipse (when the photosphere is still visible) as you want, but during totality, you'll need to use a camera with no filter.

Michael E. Bakich
Senior Editor

Q: WHAT ARE THE ACCEPTED PROOFS THAT EARTH REVOLVES AROUND THE SUN? WHEN DID THIS REALIZATION TAKE PLACE?

Bob James
Las Vegas

A: We had no direct view of Earth until the dawn of the Space Age. Finding physical evidence that our planet revolves around the Sun took some clever thinking to prove that this heliocentric model of our solar system represents reality.

The idea is ancient. Around 230 B.C., the Greek philosopher Aristarchus suggested that this was the case. He was an outstanding observer and based this idea on careful observations. Still, without direct proof that Earth moves, Aristotle's Earth-centered universe remained the dominant model for centuries.

In 1610, Galileo turned his new telescope toward Venus. To his amazement, he saw the planet pass through phases just like the Moon. Galileo correctly surmised that this could happen only if Venus had an orbit closer to the Sun than Earth's orbit.

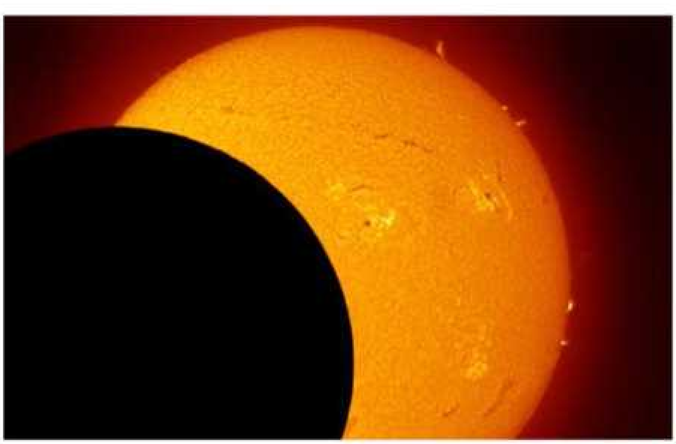
With improved telescopes, astronomers started looking for another proof of Earth's motion around the Sun, stellar parallax. Earth's orbit is huge — some 186 million miles (300,000 kilometers) in diameter. If an astronomer measures the position of a nearby star, and then measures it again six months later, the star's apparent position against the background of more distant stars should shift a tiny amount.

Observing this would prove that Earth in fact is not stationary. It wasn't until 1838 that an astronomer finally detected this shift. That year, German astronomer Friedrich Wilhelm Bessel successfully measured the parallax of the star 61 Cygni.

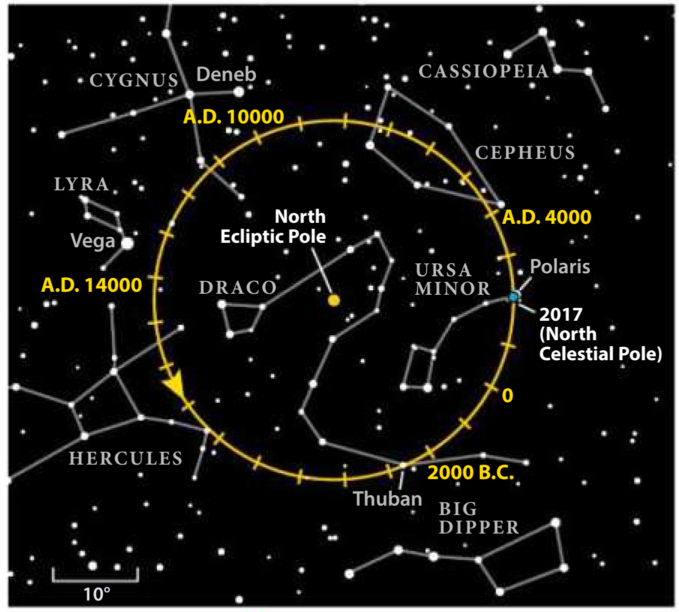
And there's yet another proof. Imagine standing still with rain coming straight down. To stay dry, you just hold your umbrella directly over your head. As you begin to walk, however, you need to tilt the umbrella "into" the rain, even though the rain is coming straight down. The faster you walk, the greater the tilt needs to be.

As Earth orbits the Sun, we can detect a "tilt" of incoming starlight. English astronomer James Bradley discovered this phenomenon in 1725 by accident — while he was searching for stellar parallax! This aberration of starlight, as it is called, is a result of light having a finite speed and Earth's motion around the Sun.

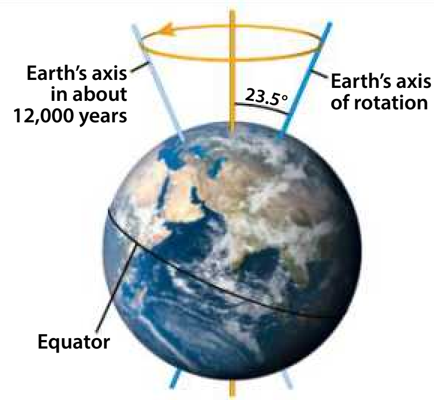
Raymond Shubinski
Contributing Editor



You can photograph the partial phases of a total solar eclipse through a Hydrogen-alpha filter, but you'll need to remove it if you want to capture the Sun's faint corona. JIM LAFFERTY



HOLLEY Y. BAKICH/ASTRONOMY: ROEN KELLY



One of the long-term effects of precession is to change our North Star. Currently Polaris (Alpha [α] Ursae Minoris) occupies that spot. Around A.D. 14000, however, Vega (Alpha Lyrae) will be the closest bright star to the North Celestial Pole.

Q: EARTH'S AXIS IS TILTED 23.5° WITH RESPECT TO THE EARTH-SUN PLANE. WHAT FACTORS CONTRIBUTE TO ITS "WOBBLE" OVER EXTENDED PERIODS?

Robert Feingold
Highlands Ranch, Colorado

A: Astronomers call the wobble of Earth's axis precession. While most of us are familiar with our planet's primary motions — rotation (spinning once a day) and revolution (orbiting the Sun once a year) — few are aware of precession. To see this characteristic vividly demonstrated, observe a spinning top or gyroscope. Its tilted axis of rotation gyrates in a circular motion, sweeping out a cone-shaped area in the process.

You can cause a top or gyroscope to precess by gently tapping it while it's spinning. The "tap" that causes Earth's axis to precess is the gravitational pull from the Sun, the Moon, and, to a much lesser extent, the planets. Gravity alone, however, won't do the trick. But it just so happens that Earth has a slight equatorial bulge, and it's this bulge that gets the gravitational tug. In other words, if our planet were a perfect sphere, there would be no precession.

While a top or gyroscope might precess several times each second, a single precession of Earth's axis takes nearly 26,000 years (25,772 years, to be exact). The effects — changes in our "pole" stars, a shift in the celestial coordinates of right ascension and declination, and a westward drift of the solstices and equinoxes — are so gradual that most changes take decades to be noticed. No wonder precession is one of Earth's "unknown" motions.

Glenn Chaple
Contributing Editor

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

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

March 2017: The Moon hides Aldebaran

A waxing crescent Moon appeared just east (left) of Aldebaran on April 10, 2016, moments after our satellite passed in front of the 1st-magnitude star. A fatter crescent Moon occults Aldebaran on March 4. PHILIPPE MOUSSETTE

This month opens with a stunning view of Venus suspended beneath a crescent Moon in evening twilight. Mars and Uranus join these brilliant objects in the western sky after sunset, but the more distant worlds pale in comparison. The waxing Moon visits Aldebaran on March 4, blocking the 1st-magnitude star from view across most of the United States. And Mercury begins its best evening appearance of 2017 in late March.

Jupiter climbs into view later in the evening, and it remains a fine sight until dawn. It shares the early morning sky with beautiful Saturn and, in the month's final days, Venus on a return visit after having passed between the Sun and Earth.

Our night sky tour begins after sundown March 1. Although the crescent Moon will grab your attention first, you can't help but see **Venus**, too. The brilliant "evening star" shines at magnitude –4.8 and shows up easily within a half-hour after sunset. It remains on view until about 8:30 P.M. local time, offering more than an hour of observing time after twilight ends.

Venus doesn't stick around all month, however. The inner planet's orbit is carrying it closer to a line joining the Sun and Earth, so it loses altitude each day. On March 1, it stands 20° high an hour after sunset. That drops to 13° a week later and just 4° a week after that. It's still visible because it shines so brightly (at magnitude –4.4 on the 15th), but you might need an observing site that affords an unobstructed view to the west.

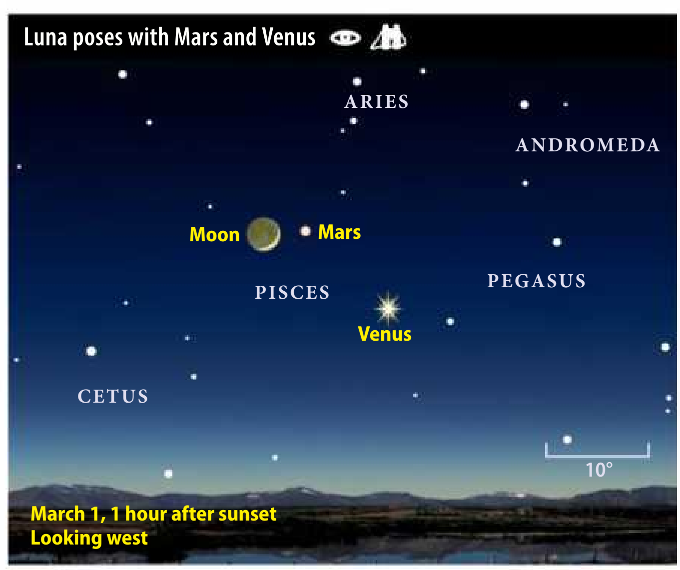
The planet's telescopic appearance changes in tandem with its orbital movement. As Venus approaches Earth, its apparent size swells and its phase dwindles to a thin crescent as the hemisphere lit by the Sun turns away from us. And these changes happen quickly. On March 1, the inner world spans 48" and appears 16 percent lit.

One week later, Venus measures 53" across and shows a 10-percent-lit phase. And the week after that (on the 15th), the disk appears 57" across while the Sun illuminates only 4 percent of its Earth-facing hemisphere. By this stage, you should be able to discern its large crescent through steadily held binoculars.

Venus reaches inferior conjunction March 25, when it passes most nearly between the Sun and Earth. The inner planet then shoots into the predawn sky, where it becomes visible by month's end.

Mercury gives an almost mirror-image performance to Venus. The innermost world passes on the far side of the Sun from our perspective (a configuration known as superior conjunction) March 6 before climbing into view after sunset. You can start looking for it around the 20th, when it lies 6° above the western horizon a half-hour after sunset. Mercury shines at magnitude –1.2, bright enough to pierce the twilight glow even at this low altitude, though binoculars can help you to spot it. A telescope reveals the planet's 5.7"-diameter disk, which appears nearly 85 percent lit.

Observing conditions improve quickly. On the 25th, Mercury stands 10° high at the same post-sunset time. Although it glows fainter then, at magnitude –0.9, the added



A waxing crescent Moon stands near brilliant Venus and ruddy Mars as darkness falls March 1. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

RISING**MOON**

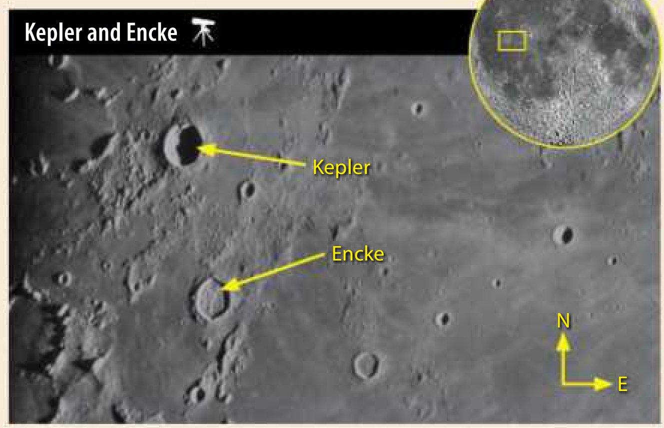
Young and old provide a vivid contrast

It's hard to hide the lunar crater Kepler. This youthful impact scar stands out near the Moon's equator, near the eastern shores of the vast Oceanus Procellarum. The deep, 20-mile-wide bowl is round and sharply defined — a smaller version of prominent Copernicus to its east.

Kepler appears half-lit the evening of March 8. The low Sun angle highlights the roughness of the debris ejected during the impact event that formed the crater. Look a bit to its south for the similarly sized Encke. This crater's rim appears softer and shows the effects from eons of bombardment. Debris from the Kepler impact fills its bowl.

If you return to Kepler a couple of evenings later, you'll see how the higher Sun angle transforms the roughness and shadows into a bright apron with rays. Procellarum's dark lava is thinner here, and that allowed the impact to gouge out lighter-hued rock from below. While Kepler appears more prominent thanks to its rays, Encke has all but disappeared. Typically, older craters fade into the background under a high Sun.

Kepler celebrates the German astronomer who developed the laws of planetary motion in the 17th century. Encke honors the 19th-century German astronomer who first calculated the orbit of a short-period comet. Coincidentally, Comet 2P/Encke lies 10° high in the west an hour after sunset in early March.



As the Sun rises above Kepler's sharp rim, compare it with the softer features of neighboring Encke. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

altitude makes it easier to see. A telescope shows a disk 6.4" across and two-thirds lit.

On March's final evening, the diminutive world stands 12° above the horizon a half-hour after sunset and is still 7° high under a much darker sky 30 minutes after that. The magnitude –0.2 planet appears 7.5" across and 43 percent illuminated when viewed through a telescope. Mercury will reach the peak of this apparition — its best of 2017 — April 1.

The early evening sky's other two planets, **Mars** and **Uranus**, put on more-subdued shows. The two pair up in the western sky March 1, when the Red Planet lies 2° northeast of its neighbor and the crescent Moon stands 4° southeast of Mars. All three objects appear in the same field of view through 7x50 or 10x50 binoculars. Place the Moon on the field's left side, find magnitude 1.3 Mars to its right, and then search for Uranus 2° directly below the ruddy world. Uranus glows at magnitude 5.9 and should show up easily if you have a transparent sky.

Mars remains an evening fixture throughout March. It crosses from Pisces into Aries on the 8th and traverses more than half the latter constellation by month's end. This rapid eastward motion keeps Mars well ahead of the Sun and visible long after darkness falls throughout March. A crescent Moon returns to its vicinity on the 30th.

Uranus does not fare as well. It dips into the twilight glow after midmonth and won't return to view until mornings in late spring.

The Moon calls attention to several planets as it parades through the evening sky in March. But our satellite also heralds a few noteworthy stars. On the 1st, attentive observers in North America's eastern half will see the Moon pass in front of (astronomers say "occult") magnitude 4.4 Nu (ν) Piscium shortly after 8:30 P.M. EST.

But this is just a prelude to the main event March 4.

— *Continued on page 42*

METEORWATCH

Great views of the elusive zodiacal light

Late winter and early spring are the best times for Northern Hemisphere observers to spot the zodiacal light after sunset. Viewing conditions peak when the ecliptic — the Sun's apparent path across the sky — makes a steep angle to the western horizon.

This soft light comes from sunlight reflecting off tiny dust particles in the inner solar system; they concentrate heavily along the ecliptic. It appears somewhat dimmer than the Milky Way, so look for it from a dark site when the Moon is out of the sky (March 14–28 this year) and twilight has faded away. The cone-shaped glow stretches from the horizon up through Taurus.

The zodiacal light appears as a softly glowing pyramid in the west after twilight fades away in late March. STEVE CULLEN

OBSERVING HIGHLIGHT Venus' telescopic look changes radically. On March 1, it appears 48" across and 16 percent lit. On the 15th, it spans 57" and is 4 percent lit.

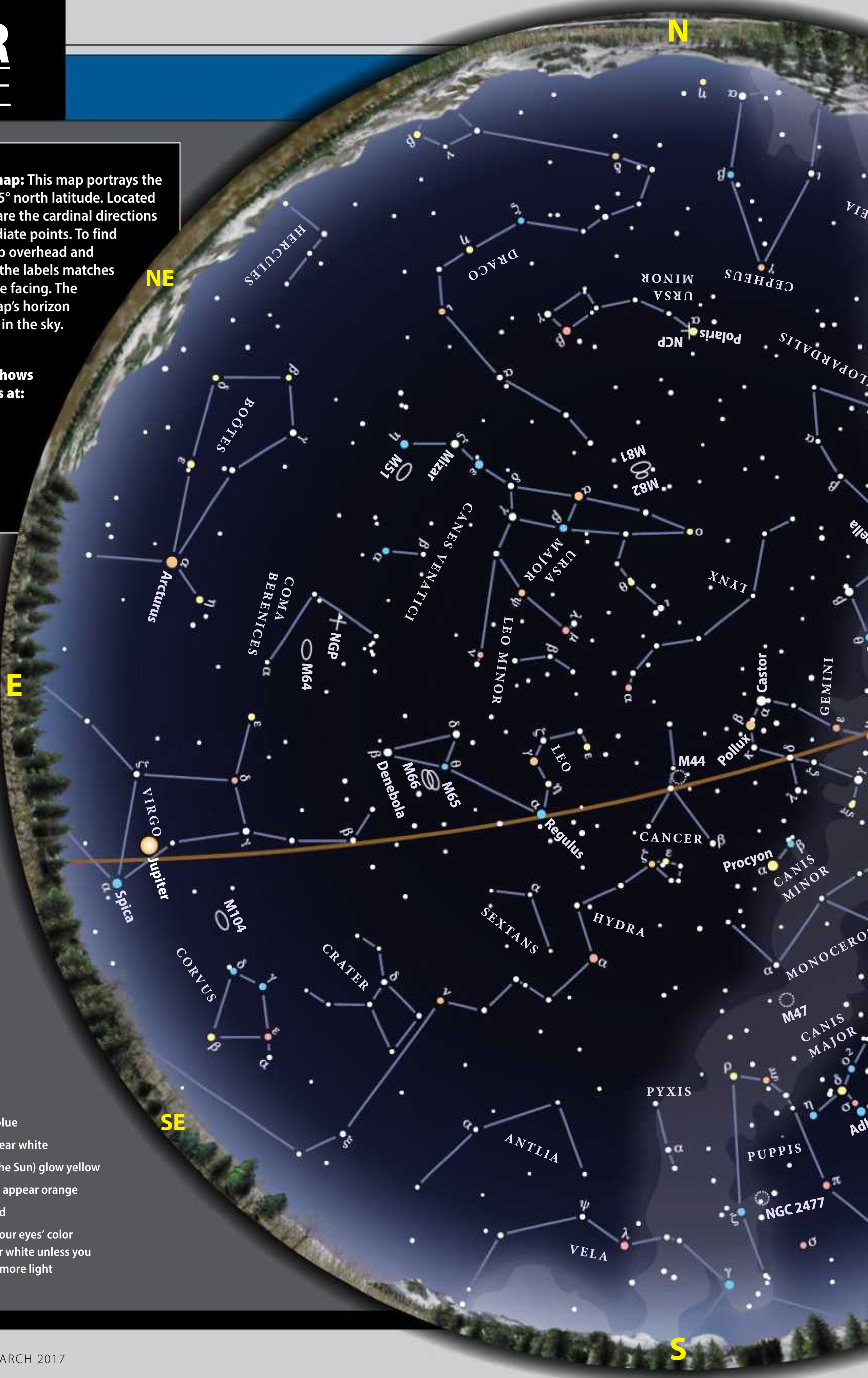
STAR DOME

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

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

10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth



STAR MAGNITUDES

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

STAR COLORS

A star's color depends on its surface temperature.

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

MAP SYMBOLS

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

MARCH 2017

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

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 The Moon passes 4° south of Uranus, 11 A.M. EST

The Moon passes 4° south of Mars, 2 P.M. EST

Neptune is in conjunction with the Sun, 10 P.M. EST

2 Venus is stationary, 9 A.M. EST

The Moon passes 0.8° south of dwarf planet Ceres, 4 P.M. EST

3 The Moon is at perigee (229,325 miles from Earth), 2:33 A.M. EST

Asteroid Amphitrite is at opposition, 7 A.M. EST

4 The Moon passes 0.2° north of Aldebaran, 10 P.M. EST

SPECIAL OBSERVING DATE

4 Observers across most of the United States will see a nearly First Quarter Moon occult Aldebaran.

5 First Quarter Moon occurs at 6:32 A.M. EST

6 Mercury is in superior conjunction, 7 P.M. EST

Asteroid Vesta is stationary, 10 P.M. EST

8 Asteroid Daphne is at opposition, 2 A.M. EST

10 The Moon passes 0.8° south of Regulus, 6 P.M. EST

12 Full Moon occurs at 10:54 A.M. EDT

14 The Moon passes 2° north of Jupiter, 4 P.M. EDT

Asteroid Pallas is in conjunction with the Sun, 11 P.M. EDT

18 The Moon is at apogee (251,438 miles from Earth), 1:25 P.M. EDT

20 The Moon passes 3° north of Saturn, 6 A.M. EDT

Vernal equinox occurs at 6:29 A.M. EDT

Last Quarter Moon occurs at 11:58 A.M. EDT

25 Venus is in inferior conjunction, 6 A.M. EDT

26 The Moon passes 0.005° south of Neptune, 4 A.M. EDT

27 New Moon occurs at 10:57 P.M. EDT

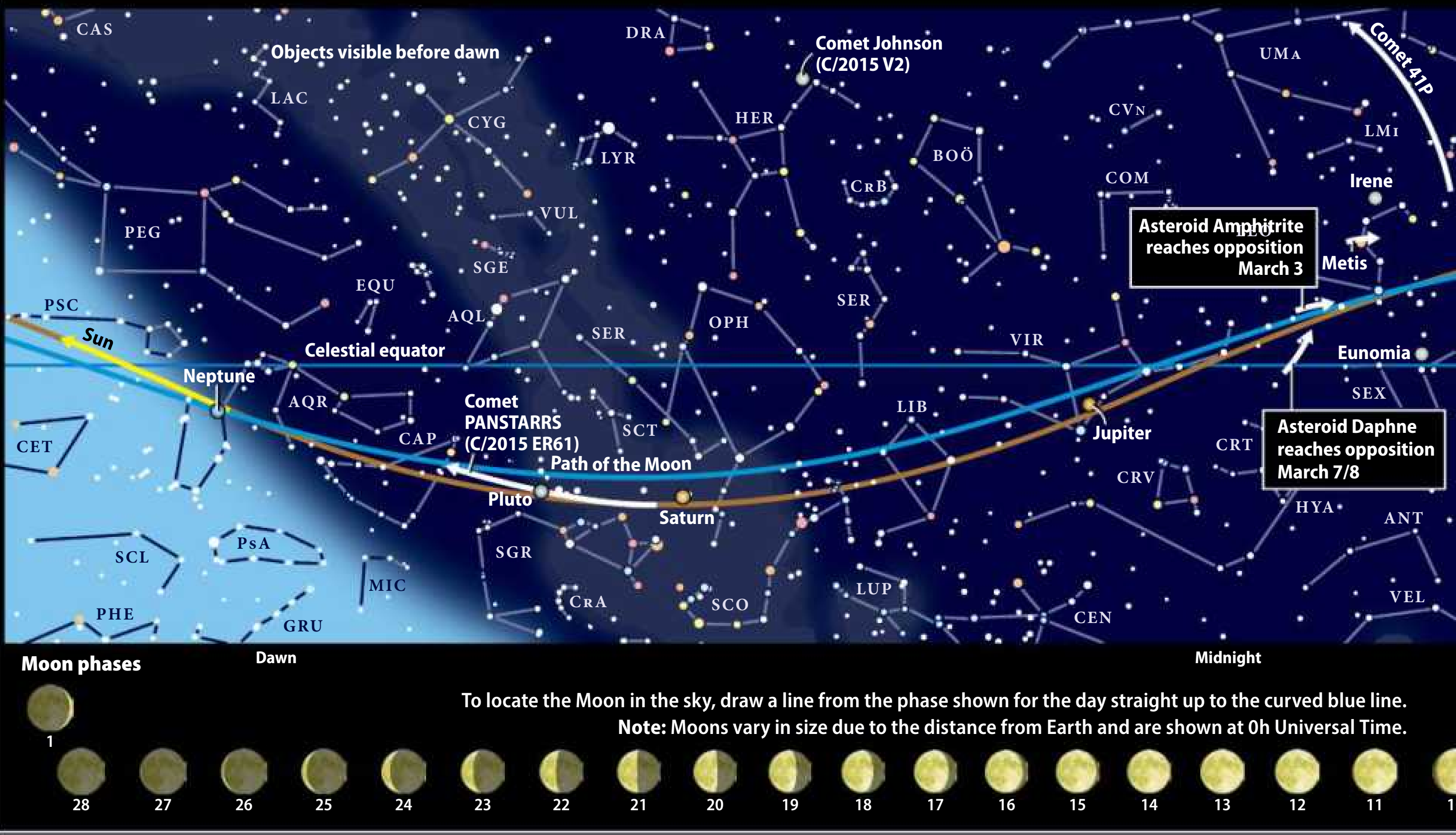
29 The Moon passes 7° south of Mercury, 3 A.M. EDT

30 The Moon is at perigee (226,088 miles from Earth), 8:32 A.M. EDT

The Moon passes 5° south of Mars, 9 A.M. EDT

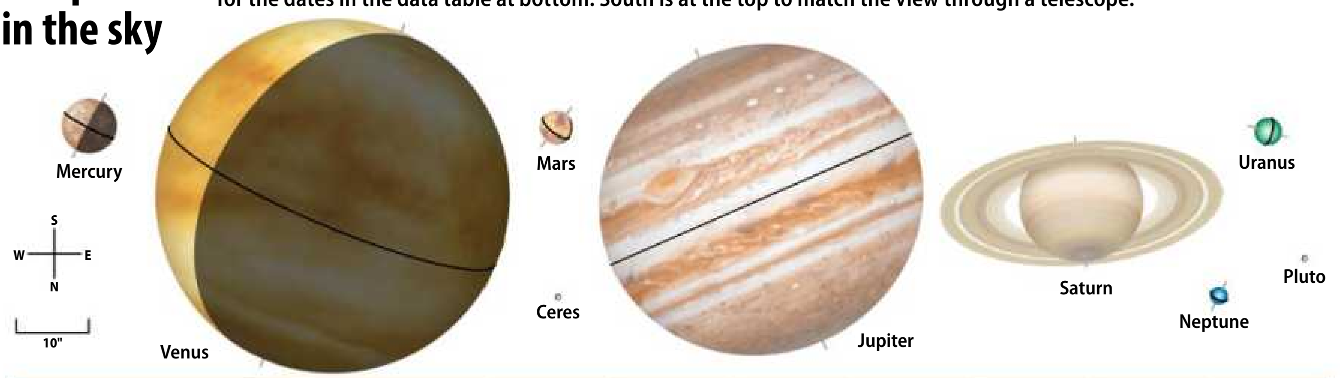
BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

The planets in March 2017

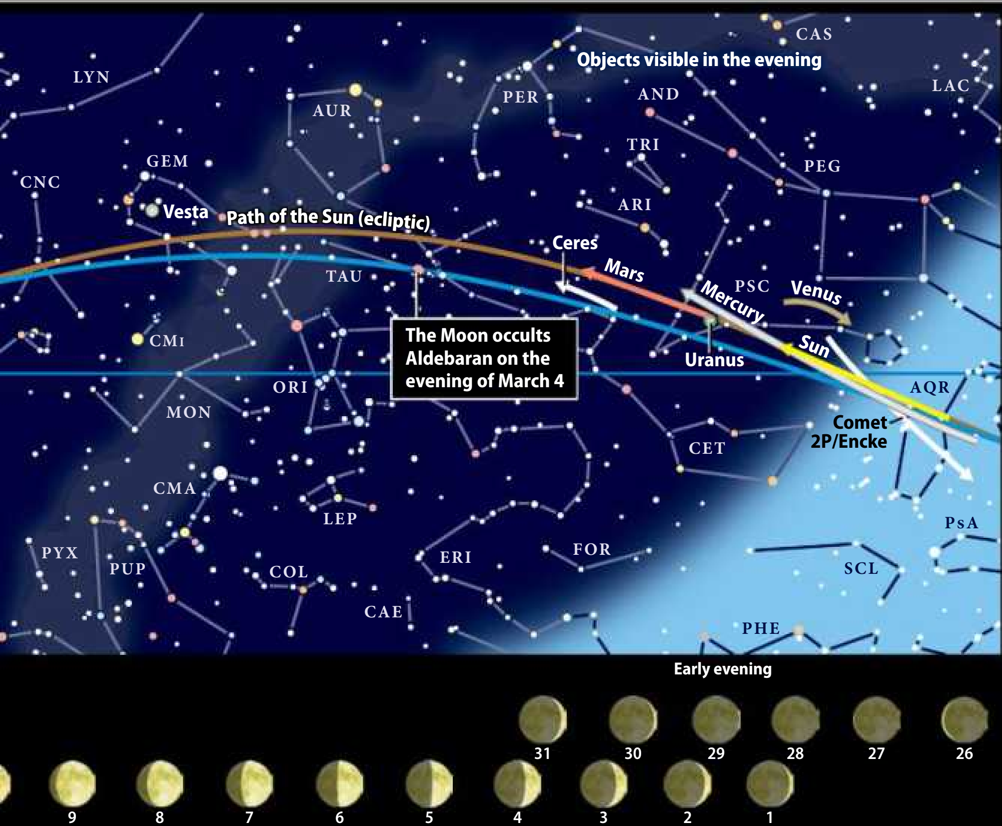


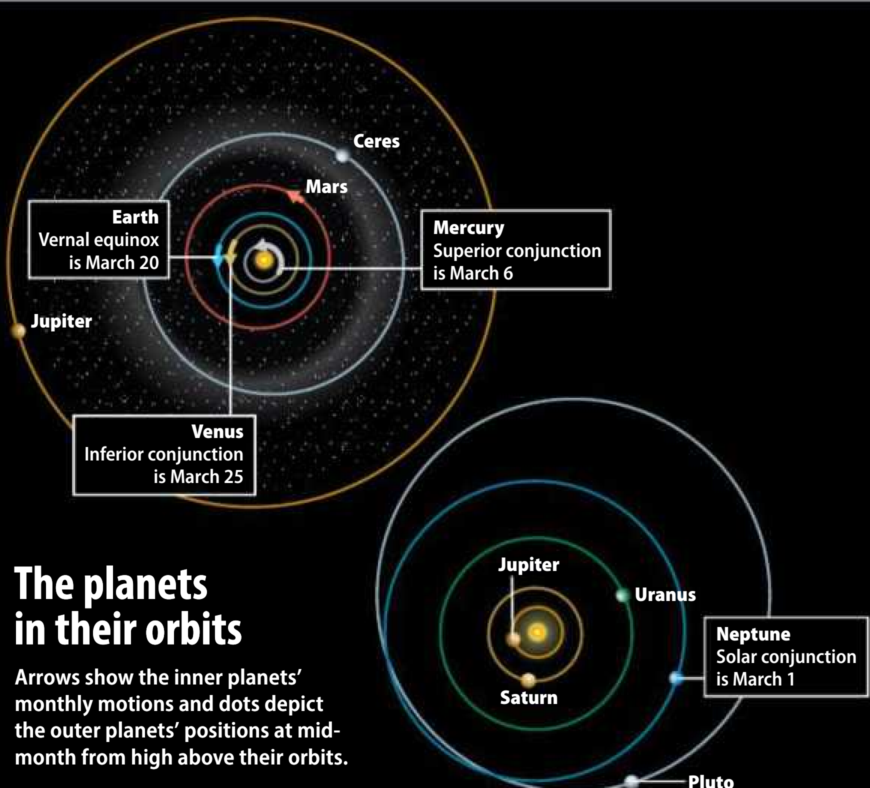
The planets in the sky

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



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	March 31	March 1	March 15	March 15	March 15	March 15	March 15	March 15	March 15
Magnitude	–0.4	–4.8	1.4	9.1	–2.4	0.5	5.9	8.0	14.2
Angular size	7.3"	46.9"	4.4"	0.4"	43.3"	16.5"	3.4"	2.2"	0.1"
Illumination	47%	17%	95%	98%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.925	0.356	2.126	3.343	4.549	10.052	20.804	30.921	33.689
Distance (AU) from Sun	0.324	0.719	1.491	2.774	5.456	10.053	19.933	29.950	33.289
Right ascension (2000.0)	1h44.3m	0h36.6m	2h04.2m	2h42.8m	13h19.5m	17h47.7m	1h24.3m	22h54.8m	19h21.0m
Declination (2000.0)	13°19'	10°53'	12°49'	12°11'	–6°42'	–22°05'	8°15'	–7°52'	–21°12'



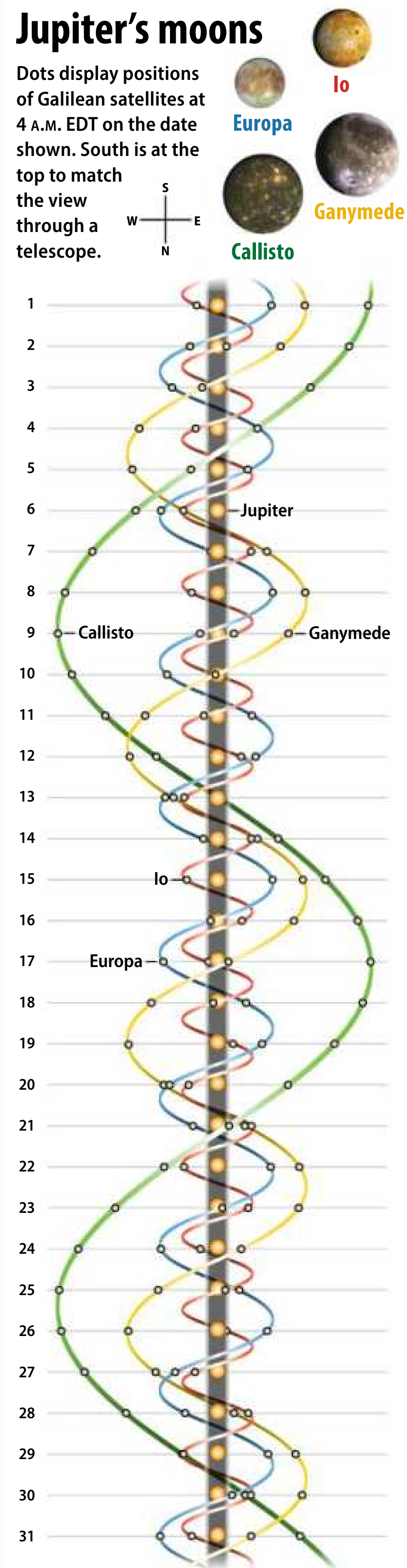


The planets in their orbits

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

Jupiter's moons

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



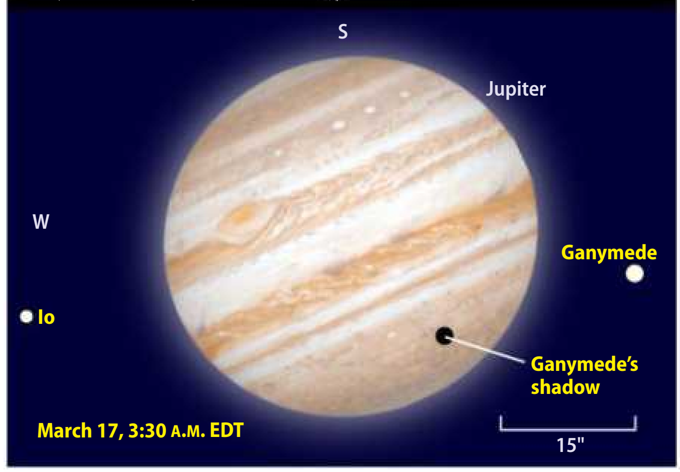
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (west)	Jupiter (southeast)	Venus (east)
Venus (west)		Jupiter (southwest)
Mars (west)		Saturn (south)
Uranus (west)		

Ganymede casts a giant shadow



The solar system's largest moon appears off Jupiter's eastern limb while its large shadow darkens the planet's north polar region March 17.

That evening, our satellite occults the 1st-magnitude star Aldebaran in Taurus the Bull. Observers across most of the United States, except for those within shouting distance of the Canadian border or in the northern half of New York and New England, can see this event. With Aldebaran bright and the Moon only about 45 percent lit, binoculars will deliver nice views. Of course, a telescope's more-stable platform yields the best looks.

The occultation begins after 11 P.M. EST on the East Coast and after 7 P.M. PST on the West Coast. Exact times depend on your location (visit www.lunar-occultations.com/iota/iotandx to get accurate predictions). With a telescope, center your field of view on Aldebaran. You probably won't see the Moon's dark limb lurking just west of the star. But as Luna's orbital motion carries our satellite to its stellar rendezvous, Aldebaran will vanish suddenly. It will remain hidden for up to an hour or more (again, it depends on your location) before snapping back into view. The star returns at the bright limb, which makes the reappearance much harder to view.

Jupiter pokes above the eastern horizon around 9 P.M. local time in early March and during evening twilight by month's end. This early rising time foreshadows the planet's imminent arrival at opposition, the peak of its yearlong apparition, which will occur in April's first week. And this means our view of the gas giant in March is close to perfection.

Jupiter brightens from magnitude –2.3 to –2.5 during March. Only the Moon and Venus outshine the solar system's largest planet. Jupiter appears against the backdrop of Virgo the Maiden, approximately 5° from 1st-magnitude Spica. The constellation's brightest star pales in comparison, however, appearing less than 5 percent as bright as the planet.

The approach of opposition also means that Jupiter is pulling closer to Earth and thus looming larger when viewed through a telescope. The planet's equatorial diameter swells from 42" to 44" this month. Its polar diameter is 6 percent smaller, however, a

COMETSEARCH

A close pass by a small (but bright) comet

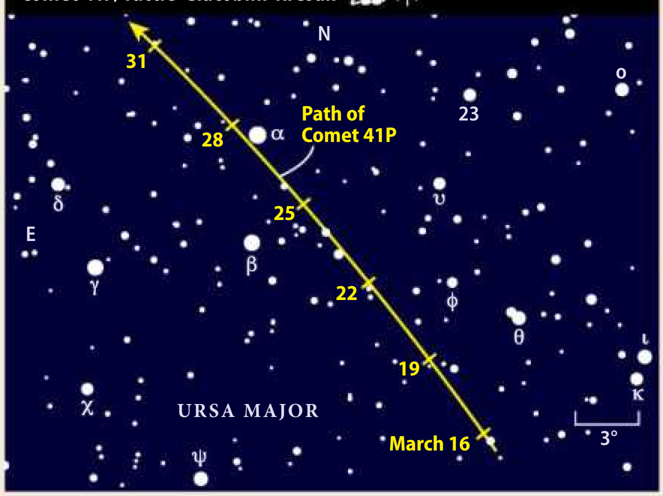
By the end of March, Comet 41P/Tuttle-Giacobini-Kresak should be a decent sight through binoculars and might even grow bright enough to see with the naked eye. Observers typically aren't so fortunate. It was a faint object when American astronomer Horace Tuttle first saw it in 1858. After that apparition, it remained hidden until French observer Michel Giacobini spotted it in 1907. But it soon disappeared, and wasn't recovered until Slovakian astronomer Lubos Kresak stumbled upon it in 1951.

Astronomers were able to pin down its orbit and realized that it revolves around the Sun once every 5.4 years. And yet, people saw it during only three apparitions in nearly a century.

But 2017 looks particularly promising. The comet swings within 13 million miles of Earth in late March, its closest approach yet. And it treks through Ursa Major, so it rides high in the sky for much of the night. The best views should come late in the month when the Moon is out of the sky. The comet then lies near the bowl of the Big Dipper, passing within 1° of magnitude 1.8 Dubhe (Alpha [α] Ursae Majoris) on the evening of the 27th. If predictions hold, it could reach 5th or 6th magnitude.

And we may experience a dramatic outburst. At its 1973 appearance, 41P brightened by 10 magnitudes in one week. It had a five-magnitude outburst during its 2001 return.

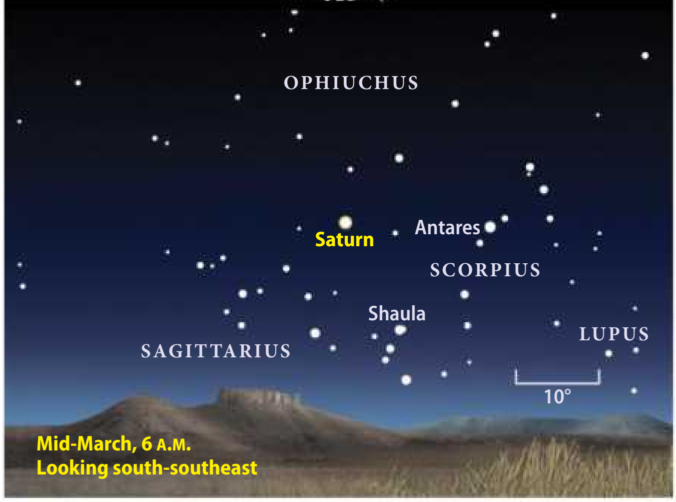
Comet 41P/Tuttle-Giacobini-Kresak



This periodic visitor should glow brightly this month as it comes closer to Earth than at any time since its discovery nearly 160 years ago.

Astroimagers should keep an eye on Comet PANSTARRS (C/2015 ER61) as well. On March 1, the 7th-magnitude object sits between the Lagoon and Trifid nebulae in Sagittarius. And on the 8th, it passes 1° north of the bright globular cluster M22.

Saturn returns before dawn



The ringed planet becomes a tempting target for all observers this month as it climbs higher in the morning sky around the onset of twilight.

difference noticeable even through small instruments.

But the first thing you'll notice as you focus on Jupiter is its richly detailed atmosphere. The planet's cloud tops resolve into a series of alternating bright zones and darker belts. Turbulence at the edges of these bands triggers more-subtle features. They show up under good observing conditions, typically after Jupiter climbs 30° above the horizon some three hours after it rises. You get sharper views then because the light travels through less of Earth's atmosphere.

Whenever you have Jupiter centered in the field, you can't help but notice up to four pinpricks of light hovering nearby. These are the Galilean satellites: Io, Europa, Ganymede, and Callisto, in order of their orbital distances. Because they circle the planet at different rates, their relative positions change constantly.

The moons' common orbital plane tilts nearly edge-on to our line of sight, so an individual satellite spends most of its time either east or west of the planet. The three inner ones, however, pass in front of the planet once each orbit and cast a dark shadow on the jovian cloud tops. Half an orbit later, the moon disappears behind the planet.

Innermost Io orbits fastest and thus delivers the most events. All North American observers can see it and its shadow transit the mornings of March 2, 9, 16, and 25. Europa gives a similar show the nights of March 15/16 and 22/23, and again the morning of March 30. For Ganymede, the biggest satellite and the one with the largest shadow, the best-timed events occur the nights of March 9/10 and 16/17. During the latter one, the shadow touches Jupiter's cloud tops at 2:36 A.M. EDT. The moon itself starts to transit at 4:53 A.M., just 12 minutes before the shadow lifts back into space.

Callisto orbits far enough from Jupiter that it currently doesn't pass in front of or behind the giant's disk. The morning of March 13 provides a rare opportunity to see the moon due south of the planet.

While Jupiter dominates the predawn sky during most of March, don't pass on the opportunity to view **Saturn**. The ringed planet lies in Sagittarius and rises around 2:30 A.M. local time on the 1st. All month, early rises will be greeted to spectacular binocular views of Saturn among the Milky Way's rich star fields, with the Lagoon and Trifid nebulae (M8 and M20, respectively) and open star cluster M23 less than 5° away. Saturn stands among them shining at magnitude 0.5.

Predawn views of Saturn and its ring system through a telescope are sublime. The planet's disk spans 17" at midmonth while the rings span 38" and tilt 26° to our line of sight. The rings now protrude above the planet's north pole, and the planet's shadow falls on the western side of the rings behind Saturn.

Venus returns to view in the eastern sky before dawn following its March 25 inferior conjunction. By the 31st, the inner planet rises an hour before the Sun and shines brilliantly at magnitude –4.1. When viewed through a telescope, it shows a beautiful 2-percent-lit crescent that spans 58".

LOCATING**ASTEROIDS**

Pollux points the way to Vesta

March offers asteroid hunting at its easiest. Simply walk outside, point your binoculars at 1st-magnitude Pollux, slide half a field of view to the southwest (lower right), and the second-brightest dot near the field's center will be 4 Vesta. You can watch the asteroid shift positions relative to the background stars every few nights without having to set up a telescope.

Use the StarDome map at the magazine's center to locate Gemini's twin stars, Castor and Pollux. On evenings at this time of year, Pollux lies to its celestial twin's left. Hold your binoculars steady by leaning against a wall or propping your elbows on the roof of your car. Then, use the trio of 4th-magnitude stars Kappa (κ), Upsilon (υ), and Iota (ι) Geminorum to orient yourself and triangulate to Vesta's position. The asteroid won't move much in the first half of March but picks up speed later in the month.

The 325-mile-wide space rock fades from magnitude 7.1 to 7.6 during March, but that's still brighter than anything in its vicinity except for Kappa, Upsilon, and 5th-magnitude 76 Gem. A telescope shows Vesta more easily, but don't expect to see any details.

The celestial Twins harbor the brightest asteroid

Seventh-magnitude Vesta shows up quite easily this month southwest of Pollux in a region with a few bright guide stars and not much else.

The past, present, ASTRONOM

A rich tradition keeps Japanese astronomy on a path to pioneering new eras. **by Ilima Loomis**

Even though we've spent the past half-hour discussing his research on ancient galaxies, at this moment, it feels like the most technically challenging subject I've broached with Dr. Masanori Iye today just might be lunch.

Iye is one of many astronomers working in Japan; a country that, as we'll soon see, is emerging as an astronomical powerhouse.

Trying to quiet my grumbling stomach, I've happily accepted Iye's offer to join him at Cosmos Lodge, the cafeteria of the National Astronomical Observatory of Japan (NAOJ). But the plan hits a snag when I find myself face to face with the cafeteria's vending machine-style ordering system. Seeing my confusion at the panel of mysterious buttons and kanji, Iye helps me deposit some yen and order noodle soup. Together, we bring our tickets to the lunch counter, where we are rewarded with steaming bowls of salty, meaty broth.

From imaging exoplanets to solving a solar mystery, mapping dark matter to investigating the origins of the universe, NAOJ scientists are taking on some of the hottest questions in astronomy today. And few would make a better lunchtime companion than Iye, whose discovery in 2006 of the most distant galaxy found at that time gave scientists a picture of the universe as it appeared nearly 12.9 billion years ago. He broke his own record with the discovery of an even more distant galaxy in 2012.

and future of
Y IN JAPAN

The Atacama Large Millimeter/submillimeter Array is one of the most powerful radio observatories in the world. The National Astronomical Observatory of Japan helped push the array into the submillimeter spectrum, allowing it to even more finely tune in to the cosmos. ESO/S. BRUNIER

"Now I've been defeated by another group," he says with a chuckle. "But it's OK. It's a very interesting competition."

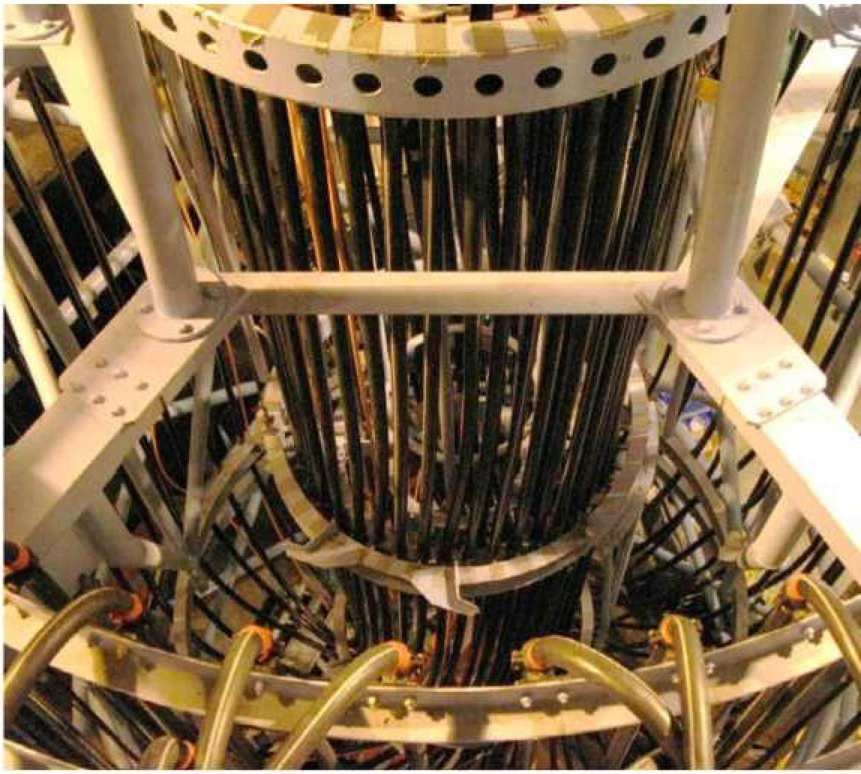
Iye's breakthrough came in developing narrow-band filters to detect Lyman-alpha photons from galaxies at the outer reaches of the universe. Using these filters with Japan's Subaru Telescope in Hawaii, his team completed a detailed survey of primordial galaxies. Their finding that galaxy density decreases significantly between 12.8 billion and 12.9 billion years ago, pinpointing the start of the cosmic dawn, earned Iye the 2013 Japan Academy Prize.

"We are just like archaeologists mining fossils to study the history of the Earth," he says. "We are using telescopes to mine past galaxies to study the history of the universe."

You might trace the origins of modern-day astronomy in Japan to the year 1782, when the tenmonkata, or official astronomer, was installed by the shogun at Asakusa Observatory. An observatory was later built for students at the University of Tokyo, and the Tokyo Astronomical Observatory was founded in 1888, with the mission to establish latitude and longitude, and keep the correct date and time by observing the stars. The observatory was moved in 1924 to its current site at Mitaka, a city on the outskirts of Tokyo, and it was reorganized as the National Astronomical Observatory of Japan in 1988.

Today, NAOJ still keeps Japan's official time and calendar. But with observatories located around Japan, as well as tools like Subaru, the Hinode space telescope, the Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope in Chile, and the "ATERUI" supercomputer, NAOJ scientists are also investigating some of the universe's biggest mysteries.

Above: The Subaru Telescope, shown above the cloud line on Mauna Kea, Hawaii, sits at 13,580 feet (4139 meters) altitude. NAOJ



Right: The arrangement of cable wraps within the telescope allows the azimuth to move freely. DAIGO TOMONO

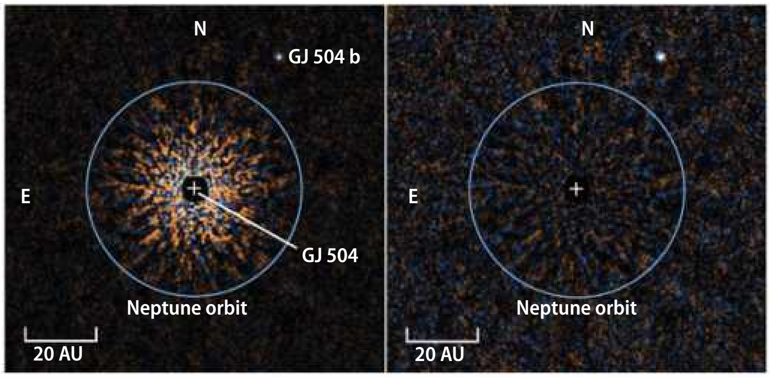
Direct observation of distant worlds

For Motohide Tamura, it wasn't enough just to know an exoplanet was out there. He wanted to actually see it.

But even though nearly 2,000 exoplanets have been discovered with tools like the Kepler Space Telescope, images of these distant worlds have remained elusive, with just a handful of extrasolar planets observed through direct detection to date. Tamura hoped to fill that gap with SEEDS, Strategic Explorations of Exoplanets and Disks with Subaru. The five-year, direct-detection survey of giant planets and circumstellar disks — dust clouds around young stars from which planets form — around 500 nearby stars concluded in January 2015, resulting in the direct imaging of four planets, three brown dwarfs, and more than 30 protoplanetary disks, says Tamura, the principal investigator on the project.

Other extrasolar planet surveys rely on indirect detection methods, such as spotting the flicker of light that results when a planet passes in front of its star. "For statistical studies, those methods are very useful, and to some extent, they can characterize the planet, but eventually we'd like to see the planet itself," Tamura says.

SEEDS measured thermal emissions from planets and disks to create an image of the objects. The technique paves the way for astronomers to learn more about these worlds than is revealed through indirect detection, which typically tells scientists little more about a planet than its location and possible mass. "Most important for direct imaging, we can measure the color of the planet, and eventually we can do spectroscopy of the planet itself," Tamura notes.

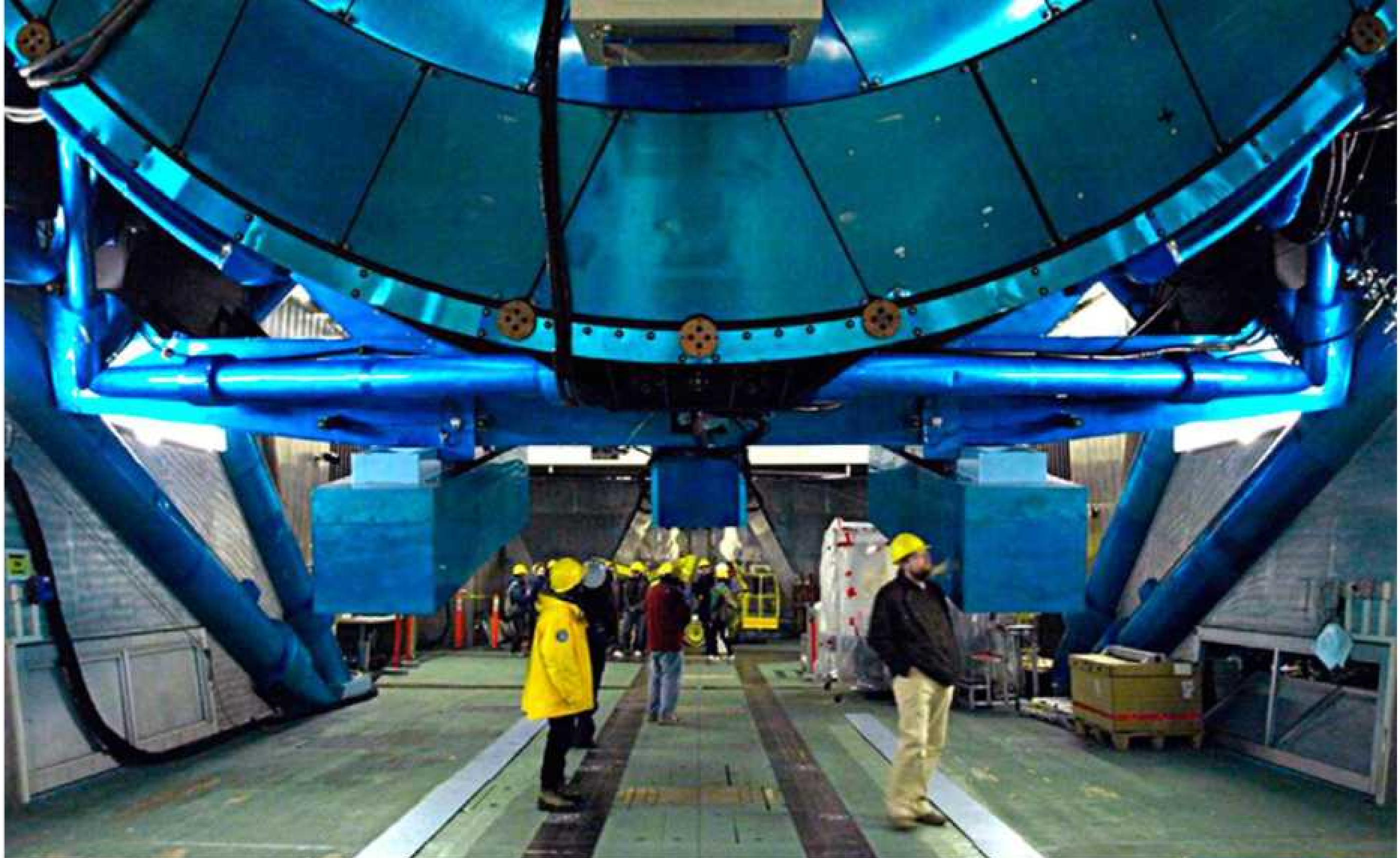


The SEEDS instrument on board the Subaru Telescope directly imaged this planet around the star Gliese 504. The planet is marked GJ504b, with Neptune's orbital distance shown to give an idea of its distance from the star. NASA GODDARD SPACE FLIGHT CENTER/NAOJ

Discoveries included a Jupiter-like planet orbiting 40 astronomical units from its star (an AU is the average distance between Earth and the Sun) — one of the lowest-mass planets with one of the closest orbits yet observed. "It has a blue color, compared to the other directly imaged planets, which means … the upper atmosphere is relatively clean or free of dust, and the temperature of the atmosphere is very cold," says Tamura. Scientists also detected the signature for methane in the planet's atmosphere.

The survey's observations offered astronomers a chance to study circumstellar disks as well, including the chance to observe gaps and tendrils Tamura calls "signatures of an unseen planet" within the disk structure.

SEEDS isn't the only program offering new insights into planetary formation. Misato Fukagawa is among the NAOJ astronomers tapping ALMA at NAOJ's Chile observatory to study protoplanetary disks. The powerful radio telescope allows astronomers to look beyond a disk's dusty outer surface to see the larger masses and structures within. One disk Fukagawa studied



The primary mirror cell is visible from the bottom of the Subaru Telescope when it is tilted. Temperatures there average 50° F (10° C) during the day and 32° F (0° C) at night. DAIGO TOMONO

had the appearance of "two bananas" encircling a central star when observed in infrared. But when she looked at the same object with ALMA, it had more of a horseshoe shape.

"We think that what we saw in infrared is light scattered by the solid particles in the upper surface of the disk. But with ALMA, we think we can see the density structure in the midplane of the disk," she says. "From this structure, we think a little bit of growing material is distributed in this shape."

"Numerical exploration of the universe"

Astronomer Eiichiro Kokubo was also fascinated by planetary science, but it led him down a different path. Kokubo wanted to watch a solar system actually taking shape. For that, he turned to a supercomputer.

"It's very difficult to investigate the formation of planets by telescope because the timescale is very long, and the planets are very small and far away," he says. "But what we can do is a numerical experiment. We can see how a protoplanetary disk evolves with time, or how the planets form. We can do this only with numerical simulations because we cannot see them directly."

Today, Kokubo is director of NAOJ's Center for Computational Astrophysics (CfCA), which operates the Cray XC30 supercomputer ATERUI, the most powerful supercomputer in the world dedicated exclusively to astronomy. Alongside observational and theoretical astronomy, Kokubo calls simulation astronomy "the third way of astronomical research."

"The solar system was formed 4.6 billion years ago. We cannot see it. But we can set up a virtual universe in the computer, using laws of physics," he says. "We often say supercomputers are a kind of theoretical telescope to see unseen things."

The center's role as a branch within NAOJ gives it a unique position to work closely with observational and theoretical astronomers, Kokubo notes. Computing time is available not only to native and foreign astronomers in Japan, but also to Japanese astronomers working abroad.

CfCA completed a major upgrade of ATERUI last year, increasing performance from 502 teraflops to 1.058 petaflops, giving it the capability to perform 1,000 trillion calculations per second. The added speed will allow ATERUI to serve more researchers, as well as to take on even more complex simulations, Kokubo says.

An early achievement for CfCA was its work on a project that simulated the so-called "giant impact scenario," showing how a massive collision with Earth created a disk of rock and debris that quickly formed the Moon. The process had been theorized in the 1970s as a model, but had never been tested. "From this simulation, we could understand how the Moon is formed from the impact-generated disk, and also why we have only one moon," Kokubo says.

More recently, ATERUI was used to create a high-resolution simulation of a supernova. "This is the most inner part of a supernova explosion, which we cannot see from observation," he says. The simulation was so complex, it required the use of the entire supercomputer at once, something

Ilima Loomis *is a science writer based in Hawaii. She previously covered near-Earth object characterization for* Astronomy.

Above: Chodayu Nishiura built the 20cm aperture telescope observatory in 1921 based on a design from Tokyo Imperial University. The aptly named 20-cm Telescope Dome is primarily used for sunspot observations. NAOJ

Right: The Subaru Telescope captured this gorgeous image of the Trifid Nebula in 2013. The nebula is believed to be only 300,000 years old and is 9,000 light-years away in Sagittarius. SUBARU TELESCOPE (NAOJ), HUBBLE SPACE TELESCOPE, MARTIN PUGH; PROCESSING: ROBERT GENDLERE

CfCA schedules for large projects about once a month.

Kokubo says working with simulations has allowed him to fulfill not only his scientific ambitions, but also a childhood dream. "When I was an elementary student, I thought I wanted to be an explorer," he says. "When I'm looking at the solar system, I can't physically be an explorer, but I can do it with supercomputers. It's a numerical exploration of the universe."

Solving a solar mystery

Like many other solar physicists, Patrick Antolin wanted to figure out why the Sun's corona was so hot. While the solar surface is a relatively cool 6,000° C (about 11,000° F), the Sun's atmosphere rises to more than a million degrees Celsius. Now Antolin and other NAOJ scientists working with the Hinode spacecraft may be helping to solve the mystery, in partnership with NASA's IRIS mission and the ATERUI supercomputer.

In August, the team published a paper in *The Astrophysical Journal*, offering new evidence supporting the theory that the heating comes from magnetic waves in the form of resonant absorption, a process in which two different magnetic waves resonate with each other, causing one to get stronger.

The process had been theorized but never directly observed, Antolin says. "This work shows it for the first time in a direct way," he says. "It's the first evidence of a coronal heating mechanism in action."

To get the results, the team used Hinode to measure the waves' side-to-side motion and combined the data with IRIS' observations of the waves' twisting motion to get a three-dimensional picture. By running the results through a simulation in ATERUI, they were able to show how the movement resulted in an unusual form of turbulence not seen on Earth that released energy into the atmosphere.

Antolin compares the turbulence to a spoon as it stirs milk into a cup of coffee. Ordinarily, the spoon creates a small wake that would curl back in a half-circle, and when the spoon stops, so does the turbulence. But the magnetic turbulence they observed was different: When a magnetic field line stops moving, the plasma around it moves at maximum speed in the opposite direction.

The finding "was an essential part of the puzzle," he says. "Large quantities of energy can pass from the magnetic field into the plasma due to this turbulence."

The team observed the phenomenon in a solar prominence, but Antolin says there's no reason to believe it would not be found in other structures of the Sun, and current research will investigate whether it occurs in spicules, which are small jets of gas emitted by stars.

"I think this is already very strong evidence that this is happening all the time," he says.

Mapping dark matter

Physicist Satoshi Miyazaki still hopes to understand the nature of dark matter someday. But for

The ATERUI supercomputer is the National Astronomical Observatory of Japan's central hub for running complex modeling of the cosmos and sifting through large volumes of data. MAKOTO SHIZUGAMI (VERA/CFCA, NAOJ)

the time being, he's using the little that's known about dark matter to help crack an even bigger mystery: dark energy.

Miyazaki heads the NAOJ project that uses a powerful new camera to make a comprehensive study of how dark matter is distributed across the universe. The so-called "dark matter map" will offer scientists important clues about how the universe expanded, which in turn will help explain the role of dark energy.

"We sort of use dark matter as a tool to probe dark energy," he says. "Although dark matter itself is still a mystery, we only need a global feature of dark matter, which is basically the mass."

To detect the presence of dark matter and measure its mass, Satoshi and his team designed a high-resolution, wide-field camera for the Subaru Telescope in Hawaii. With the Hyper-Suprime Cam, they are able to create a survey of galaxies across a broad section of the sky, capturing extremely precise images of even very faint, distant objects.

Although dark matter itself is invisible, the gravity created by its mass bends the light passing through it, like the lens of a magnifying glass. "Suppose there's a dark matter concentration somewhere between us, the observer, and a far, faint galaxy," Miyazaki says. "The shape of the background faint galaxy is warped by the dark matter concentration through gravitational lensing. If we can measure the pattern of the warp of the galaxy, then that pattern tells us how much dark matter is between the galaxy and us, and how it's distributed, and where."

The five-year dark matter survey, which began in January 2012, will eventually observe 1,400 square degrees of sky over 300 observing nights, he says.

The project will run parallel with the five-year Dark Energy Survey, which launched in 2013, he notes. But while the U.S.-led project will survey a wider field of sky, 5,000 square degrees, Miyazaki says NAOJ's survey has an advantage in the superior sensitivity of the Hyper-Suprime Cam, which can detect fainter, more distant galaxies. "If we have a larger number of galaxies, we can get a higher-resolution dark matter map," he says.

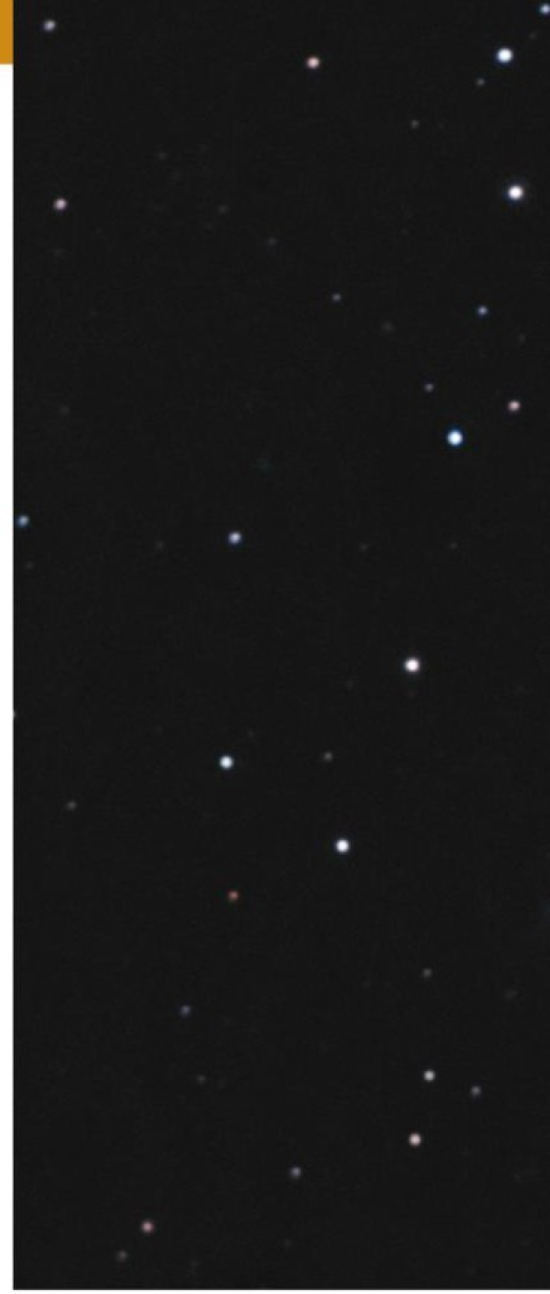
While the survey's goal is to shed light on the mystery of dark energy, Miyazaki says his passion has always been to understand dark matter itself. Now that the survey is underway, he plans to take a closer look at some of the large dark matter clusters being detected, to study how mass is distributed within the cluster itself. "If we have a much deeper and much finer image of the dark matter cluster, that tells us about the nature of dark matter," he says. "That's my next target."

With access to powerful observatories like Subaru and ALMA, not to mention the world's most powerful astronomical supercomputer, it's clear Japanese scientists are poised to play a role in some of the 21st century's most significant astronomical discoveries. From exoplanets and ancient galaxies, to solar physics and the mysteries of dark energy and dark matter, NAOJ astronomers are investigating the hottest questions in the universe today.

Observing on the edge

Galaxies showing their edges expose dust lanes, central hubs, and other intriguing details you can view through a scope.

text and images by Rod Pommier



Edwin Hubble's work on galaxies is legendary. In 1923 the astronomer, working at Mount Wilson Observatory in California, proved that M31, the "spiral nebula" in Andromeda, was another galaxy. In one blow he vastly increased the scale of the universe. If that wasn't the achievement of a lifetime, he subsequently showed that the farther away a galaxy is, the faster it recedes from us, providing the first direct observational evidence of the Big Bang.

And Hubble made another major contribution for which we deep-sky observers will be forever in his debt: a classification system for galaxies.

The Hubble classification

Hubble published the most widely used version of his system in 1936, a decade after his first draft. The system is simple to learn, following a two-pronged "tuning fork" model. The handle and each prong represent one of three classes of galaxies: ellipticals, spirals, and barred spirals.

Elliptical galaxies, designated by the letter E, form the handle. As their name suggests, these galaxies are roughly elliptical in shape, but they are further classified by how stretched and squashed they appear. Spherical galaxies are designated E0, slightly elongated ellipticals are E1, and so on, with cigar-shaped ellipticals designated as E7. Elliptical galaxies are featureless patches of light without spiral arms or dust lanes, and they have no active star-forming regions.

Spiral galaxies, designated by the letter S, form the upper prong of the tuning fork. They have two major features: a central bulge containing old stars surrounded by a flat disk with spiral arms actively forming new stars. Hubble further classified them into three groups: Sa, Sb, and Sc, based on the openness of the spiral arms and the relative size of the central bulge. Class Sa shows tightly wound, almost circular spiral arms and a large central bulge that occupies a majority of the disk, whereas class Sc has multiple open spiral arms, and the central bulge is small and inconspicuous. Those that fall between the two extremes are designated as Sb galaxies, which have definite spiral arms and a central bulge that occupies a minor, but still obvious, portion of the disk.

Barred spirals, designated SB, form the lower prong of the tuning fork. They have a bar of stars crossing the central bulge. Spiral arms extend from each end of the bar like streamers from the ends of a bicycle handlebar. Barred spirals also have three subclasses, SBa, SBb, and SBc, using the same scheme as the classic spirals. (Our own Milky Way is a barred spiral, probably an SBb in Hubble's scheme.)

At the dividing point in the tuning fork

Rod Pommier *is a surgical oncologist in Oregon and a longtime, experienced deep-sky observer. He is a frequent contributor to* Astronomy.

NGC 4565 is a bright, almost perfectly edge-on galaxy in Coma Berenices. Its central bulge occupies about one-sixth the diameter of its disk, so it is a Hubble class Sb.

exists a special class of galaxies known as lenticulars (lens-shaped), designated S0. These galaxies have a large central bulge surrounded by an extended disk-like structure. However, the disk lacks visible spiral arms and is not actively forming any significant quantity of new stars. S0 galaxies are considered a transitional form between the ellipticals and the two classes of spirals. Their addition to the system was one of the revisions Hubble made in 1936. Hubble postulated their existence prior to that, but the overexposed bright centers of lenticular galaxies on earlier, small-scale glass photographic plates overwhelmed their extended disks, rendering them indistinguishable from ellipticals.

Hubble exiled a fourth, nonconformist class of galaxies from the tuning fork. Known as irregular galaxies and designated Irr, they appear disrupted and exhibit neither elliptical nor disk-like structures.

Familiarity with this system can be extremely valuable while observing galaxies. If you know the Hubble classification of a galaxy you are observing, then you can search for certain structural features characteristic of that class and confirm their presence. On the other hand, when you don't know a galaxy's class, you can hunt for clues that might reveal the class, and if you find them, the entire view will suddenly make sense to you. You will gradually learn to systematically check every galaxy for certain structural details you might have otherwise overlooked, making you a better observer.

Professional astronomers have added to Hubble's scheme, using a more complex version developed by French-American astronomer Gerard de Vaucouleurs in the 1950s and onward. For backyard observing purposes, however, the Hubble scheme works well because the de Vaucouleurs scheme introduces many more complexities that are not visible through telescopes.

Observing on the edge

I recommend you begin trying to classify spiral galaxies by observing "on the edge" — that is, seeking galaxies that present us with an edge-on view. With oblique and face-on galaxies, a bright nucleus marks the central bulge, but it's difficult to discern the full extent of the galaxy's disk. A galaxy's disk is hundreds to thousands of times fainter than the nucleus, and while the human eye can detect tremendous differences in brightness, only the brightest central portions of the disk will be visible.

The sky contains many galaxies with diverse shapes, such as those in this portion of Markarian's Chain in Virgo. M86, the large elliptical galaxy at lower right, is Hubble class E3 because it is slightly elongated rather than spherical. Also shown are NGC 4438 and NGC 4435, "The Eyes," on the left side of the image, and NGC 4402, at upper right.

These factors make it difficult to judge the size ratio between central bulge and disk. To make matters worse, only a handful of the nearest galaxies have discernible spiral arms that permit us to judge how tightly wound they are. The final blow is that SB galaxies, in which a bar is visible, are somewhat rare.

With edge-on galaxies, circumstances are much more favorable. The light from the disk and central bulge integrates into a single plane, making them brighter and including nearly the full extent of the disk. The relative sizes of the central bulge and the disk are readily apparent, permitting easy classification. The bar in SB galaxies cannot be seen in profile, and so becomes irrelevant. The nucleus usually can be seen within the central bulge, so these objects offer good opportunities to learn how to estimate the size of a galaxy's central bulge based on the size of its nucleus. This will help you eventually classify oblique spirals.

Most of all, edge-on galaxies are simply beautiful to behold. Their symmetry is striking. Dark dust lanes silhouetted against the equator of a bright edge-on galaxy provide a striking visual contrast. And if you want to observe galaxies that actually resemble their appearance in photographs, then edge-on galaxies are your best bet.

Ellipticals

The central, dominant galaxy in the Virgo Cluster is M87, a giant E0 galaxy. It's easy to see this galaxy as perfectly round. As a challenge, look slightly to the west at **M86**. Even a small scope will show it definitely is not perfectly round. The mild eccentricity of this galaxy, which is featureless even through large apertures, earns it a classification of E3.

One of the satellite galaxies of the Andromeda Galaxy (M31), **NGC 205**, is a large bright E5. It is so elliptical that it is twice as long as it is wide, measuring 10' by 5'. Visually, it brightens gradually toward a much brighter center, and larger scopes show a non-stellar nucleus.

Lenticulars

Having covered the handle of the tuning fork, we arrive at the branch point, occupied by S0 galaxies. A splendid example is **NGC 5866** in Draco.

This galaxy is small at 6.5' by 3', but it is so bright it's hard to imagine Charles Messier could have neglected it. Many observers think it may be his so-called M102, an entry that originally caused confusion in the famous Messier catalog; it's now often referred to as a "missing" object. An 8-inch scope shows an ellipse with a bright center and short pointed tips. Larger scopes reveal longer extensions projecting from the ends of the ellipse. The center contains a bright, non-stellar nucleus. They will also reveal our first equatorial dust lane, which is remarkable for its extreme narrowness, visible only across the center.

Edge-on spirals

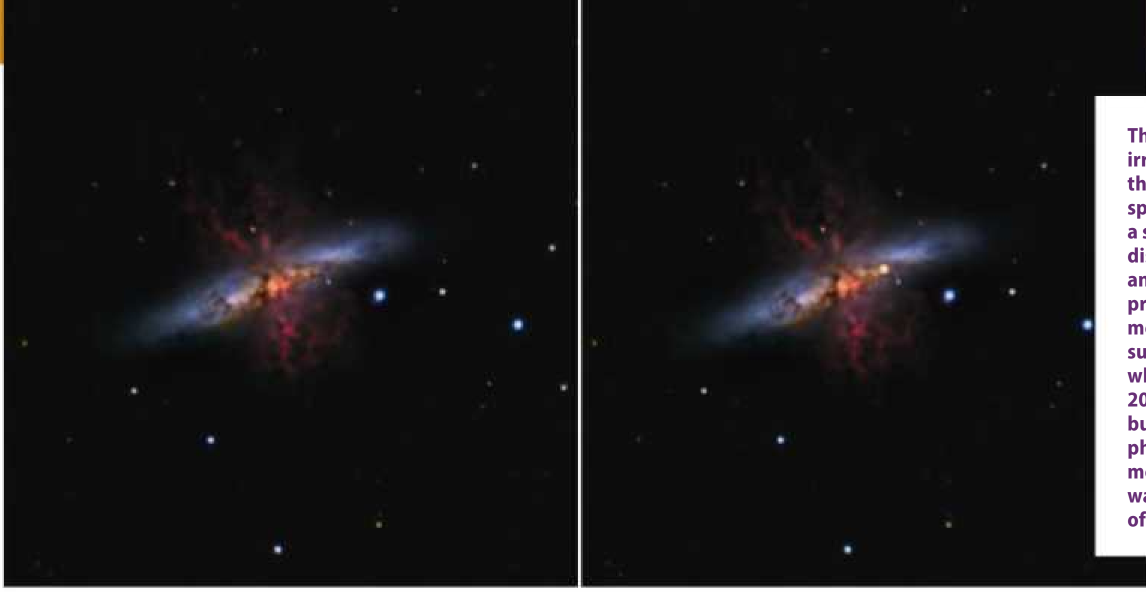
NGC 7814, known as the Little Sombrero Galaxy because of its similarity to M104 in Virgo, is an edge-on Sa galaxy in Pegasus. It is small, measuring 5.5' by 4.3', and has a large football-shaped central bulge that occupies most of the diameter of its disk, which continues as thin, dim projections on either side visible with averted vision in an 8-inch scope.

Through large scopes, a thin, dark dust lane splits the central bulge perfectly and extends into the disk. The dust lane almost disappears at its midpoint where it bisects and is nearly overwhelmed by a nucleus that is brighter on the north side.

The sky offers two splendid, but contrasting, edge-on Sb galaxies. **NGC 891** lies 3.5° east of the beautiful double star Almach (Gamma [γ] Andromedae). Through small scopes it appears as a faint discus of light measuring 15' by 3.8' floating in a sea of foreground stars that provides a stunning 3-D effect. The central bulge occupies one-third the diameter of the disk and tapers gradually toward the tips. NGC 891 has no visible nucleus because it is obscured by its perfectly centered dust lane. An 8-inch scope and dark skies are required to spot the subtle but fairly wide dust lane against the slightly brighter central bulge. Larger apertures will show the dust lane extending farther into the disk on either side.

NGC 891 appears faint mainly because it lies close to the Milky Way's equatorial plane. That means our galaxy's disk of dust blocks and scatters a considerable amount

NGC 205, one of the two bright satellite galaxies of the Andromeda Galaxy (M31), is twice as long as it is wide, earning it a Hubble class E5.



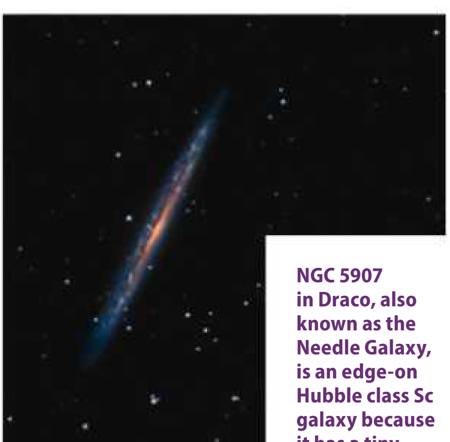
The Cigar Galaxy (M82) is an irregular galaxy, not fitting the criteria for elliptical or spiral galaxies. It is considered a starburst galaxy heavily disrupted by star formation and frequent supernovae, probably triggered by a recent merger. The most recent supernova was SN 2014J, which appeared in January 2014 in the photo on the right, but was not visible in the photo on the left, taken a few months earlier. The supernova was reddish due to scattering of light by the galaxy's dust.

of its light. By contrast, the Sb galaxy **NGC 4565** marks the Milky Way's North Galactic Pole, just as Polaris marks the North Celestial Pole. We view it perpendicular to the dust plane, providing a view virtually unimpeded by dust. So, even though the galaxies are similar in size and lie at roughly the same distance, NGC 4565 appears twice as bright.

NGC 4565 lies 1.5° due east of the star 17 Comae Berenices and measures a large 20' by 3.6'. Through the telescope, it is a beautiful sight, appearing as a long, thin sword of light with a central bulge occupying only one-sixth the diameter of the disk. It resembles a flying saucer in science-fiction movies or two fried eggs placed back to back. Even medium-sized telescopes reveal the dark dust lane dividing the central bulge almost equally. A bright stellar nucleus beams out from the north side of the dust lane.

NGC 5907 is a splendid example of an edge-on Sc galaxy. The combination of its tiny, inconspicuous central bulge and a disk that is flatter than NGC 4565's makes it look like a mere splinter of light and hence its nickname, the Needle Galaxy. Through the telescope, you'll see a galaxy that is amazingly nine times longer than it is wide, measuring 12.7' by 1.4'. Scopes 8 inches and larger show an elongated nucleus and subtle mottling from equatorial dust lanes.

NGC 891 is an edge-on class Sb galaxy in Andromeda with a central bulge occupying about one-third the diameter of its disk. It lies near the plane of the Milky Way's disk of dust, which scatters much of its light. That, and the lack of a nucleus that is obscured by its equatorial dust lane, contribute to its faintness through telescopes.



NGC 5907 in Draco, also known as the Needle Galaxy, is an edge-on Hubble class Sc galaxy because it has a tiny, inconspicuous central bulge.

Irregulars

M82 is emblematic of an irregular galaxy. Its nickname, the Cigar Galaxy, suggests an E7 elliptical, but this object is rich in dust clouds and bright areas of star formation. It also appears discoid, but it lacks defined spiral arms. M82 is a system in a burst of star formation, probably as a result of a galaxy merger. Numerous supernovae, the most recent of which was visible through amateur scopes in early 2014, have created superheated winds of plasma that flow out perpendicular to its long axis on either side. A 6-inch scope shows a cigar of light with a wedge-shaped, dark dust cloud intruding from the south side. Larger scopes show three more dark lanes toward the east end, mottling on the west side, and bright knots near the center.

Go observing!

The deep sky is filled with galaxies of diverse shapes, but they all fit into the Hubble classification scheme. Now that you know the system, use your scope to observe more elliptical and edge-on galaxies and try to classify them. Check your conclusions against databases and hone your skills. Then take your skills to the next level by trying to classify galaxies. You will start noticing more details than you thought possible and enjoy observing galaxies more than ever before.

How to care for your telescope

It only takes a little time now and then to ensure your window to the universe is working at its best. **by Phil Harrington**

When it was operational, Everstar Observatory, nestled in a backyard in Olathe, Kansas, was a great example of a well-designed space in which to store a telescope. MARK ABRAHAM

Unlike so many products in our throwaway society, where built-in obsolescence seems the rule, telescopes often outlast their owners. They require little care and attention and cost nothing to keep. With a little common sense on your part, a telescope will return a lifetime of fascination. But if neglected or abused, your telescope may not make it to the next New Moon.

If the mirror in your reflector looks like this, cleaning it will enable it to gather more light. It will also scatter less of the light it collects and perform much better. ROB HAWLEY

Storing your scope

Nothing affects a telescope's life span more than how and where you store it when you're not using it. A good storage place should be dry, dust-free, secure, and large enough to get the telescope in and out easily. Ideally, you should keep your telescope at or near the temperature outside. Doing so reduces the cooling (or warming) time required when you set up at night.

Without a doubt, the best place to keep a telescope is in an observatory, which offers a controlled environment and easy access to the night sky. Of course, not everyone can build an observatory, nor is one always warranted or desired.

Closets in unheated garages and wooden toolsheds share many of the advantages of an observatory, although you may have to vent them to the outside so air can circulate. Metal, vinyl, or plastic sheds are not as good because such materials trap heat more than wooden enclosures.

How about an unheated basement? Basements certainly are secure and large enough to qualify. They also provide easy access if a door leads directly to the outside. While these considerations weigh in their favor, most basements fail when it comes to being dry and free of dust. If a basement is your only option, invest in a dehumidifier.

Regardless of where you store your scope, always cover the optics. Usually, this is simply a matter of putting a dust cap over the front of the tube and plugging the focuser or covering it with a small plastic bag. Do this diligently. If the telescope did not come with a dust cap, or if it has been lost over time, a plastic shower cap often makes a great substitute.

If your telescope or binoculars came with a case, use it. Not only will a case add a second seal against dust, it also will protect the instrument against accidental bumps.

A dark, damp telescope tube is the perfect breeding ground for mold and mildew. To avoid the risk of your scope becoming a petri dish, be sure all of its parts are dry before you store it. Tilt the tube horizontally to ensure that no water puddles on the lens, mirror, or corrector plate.

Cleaning your scope

No matter how careful you are, dust will contaminate your optics eventually. A moderate amount, surprisingly, has little effect on a telescope's performance. But if there's a lot of it, or if the optics have a coating of mildew, images will appear dimmer and lack clarity.

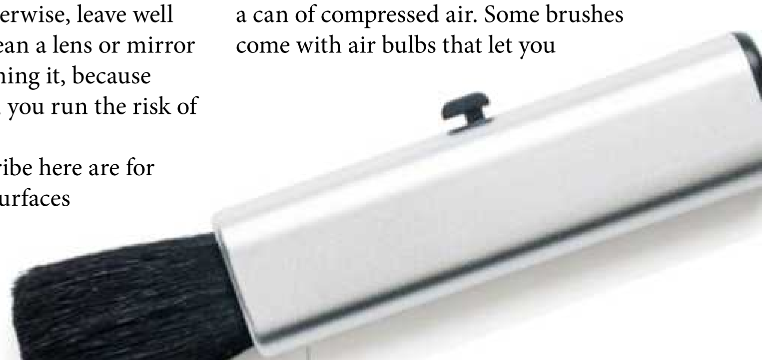
Consider cleaning an optic only when stains are apparent; otherwise, leave well enough alone. Never clean a lens or mirror just for the sake of cleaning it, because every time you touch it, you run the risk of damaging it.

The methods I describe here are for cleaning outer optical surfaces only. Unless you really know what you're doing, I strongly advise against dismantling sealed telescopes (such as refractors and catadioptrics), binoculars, and eyepieces. Dirt and dust will never enter a sealed tube if you store and protect it properly.

If an interior lens or mirror surface in a sealed telescope becomes tainted by film or mildew, take or send it to a qualified professional for disassembly and cleaning. Attempt this yourself, and you may discover that the telescope is much easier to take apart than to put back together. Contact the instrument's manufacturer for its recommendations.

Cleaning lenses and correctors

Begin the process by removing all particles that have found their way onto the surface. This does not mean blowing across the lens with your mouth; you'll only spit all over it. Instead, use either a camel hair brush or a can of compressed air. Some brushes come with air bulbs that let you



A camel hair brush is the tool of choice for most amateur astronomers who wish to quickly eliminate visible particles on lenses or mirrors. Be sure to flick the brush clean after each stroke to prevent dragging anything across your optics. ALL PRODUCT PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

Expect to use a lot of distilled water, especially when you're cleaning a mirror. It's not expensive, so use it liberally. Mix it with dish soap and high-purity isopropyl alcohol for a safe and effective cleaning solution.

Pay particular attention to the bulk cotton or cotton balls you use to clean your optics. The package must be labeled "sterile." Use a new piece of cotton after each cleaning stroke.

blow and sweep at the same time. If a brush is your choice, lightly whisk the surface of the lens in one direction only, flicking the brush free of any accumulated dust particles at the end of each stroke.

Many amateur astronomers prefer to use compressed air instead of a brush because nothing touches the surface. Hold the can upright with the nozzle away from the lens at least as far as recommended by the manufacturer. If the can is too close or tilted, some of the propellant could strike the glass surface and stain it. Also, best results come with several short spurts of air instead of one long gust.

After removing the dust, you'll want a gentle cleaning solution for fingerprints, skin oils, stains, and other residue. You can brew one of the best lens-cleaning fluids right at home: In a clean container, mix 3 cups of distilled water, ½ cup of 99 percent (or as pure as you can get) isopropyl alcohol, and two or three drops of a mild liquid dishwashing soap.

Dampen a piece of sterile surgical cotton or lens tissue with the solution. Don't use most off-the-shelf cotton balls, bathroom tissue, or facial tissue. They're rougher than you might think.

Squeeze the cotton or lens tissue until it's damp, not dripping, and gently blot the lens. Never use elbow grease to get out a stubborn stain — the only pressure should be from the weight of the cotton wad or lens tissue. Then use a dry piece of lens tissue to blot up any moisture.

The steps for cleaning the corrector plate of a catadioptric telescope are pretty much the same. The only difference is in the blotting direction. Begin with the damp cotton or tissue at the secondary mirror holder, and move out toward the edge. You might want to point the telescope straight up when cleaning it. Doing so allows you to channel the excess liquid toward the corrector's edge.

Follow a spoke-like pattern around the plate, using a new piece of cotton or tissue with each pass. As you clean, turn the cotton or tissue in a backward rolling motion to carry any grit away from the surface before it has a chance to be rubbed against the optical surface. Overlap the strokes until the entire surface is clean. Again, gently blot dry if necessary.

Cleaning mirrors

When you clean a mirror, take special care not to damage the fine optical surface. The mirror's thin coating of aluminum is extremely soft, especially when compared to abrasive dirt, and you can gouge it easily.

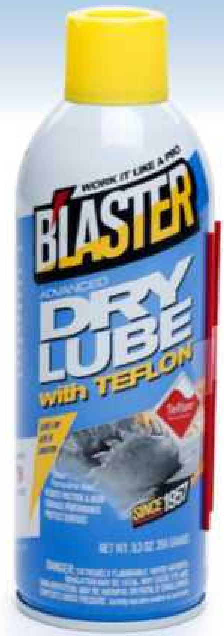
Cleaning a telescope's primary or secondary mirror typically requires you to remove it and the cell that holds it in place from the telescope. Consult your owner's manual for specific instructions.

With the mirror lying on a table, use compressed air to begin the cleaning. Don't use a brush for this step, to avoid any possibility of damage.

Next, inspect the mirror's coating for pinholes and scratches. A good coating can last 10 years or longer if the mirror has been well cared for. To check it, hold the mirror, reflective side toward you, in front of a light. It's not unusual to see a faint bluish image of the light through the mirror if the source is bright, but its image should appear the same across the entire mirror. If not, there may be thin, uneven spots in the coating.

With the mirror lying on a table, use compressed air to begin the cleaning. Don't use a brush for this step, to avoid any possibility of damage.

If your scope didn't come with a cover like the one on the left (or if you lost it), a shower cap can serve as an effective shield against dust. It may not be pretty, but your lens or mirror will thank you by providing better images.



For squeaky or binding telescope parts, nothing beats a tiny bit of Teflon lubricant.

Manufacturers sometimes make Dobsonian mounts that allow wood-to-wood, wood-to-Formica, or other friction contacts. If they bind, applying car wax (be sure to buff it dry) often will make surfaces move smoothly again.

Any scratches or pinholes in the coating will become immediately obvious, as well. You can live with a few, but if scratches or pinholes abound, or if you detect an uneven coating, you'll want to send the mirror out for recoating.

If the coating is acceptable, bring the mirror to a sink. Be sure to clean the sink first and lay a folded towel in it as a cushion just in case the mirror slips. Gently run lukewarm tap water across the reflective surface. This should lift off any stubborn dirt particles that refused to dislodge themselves under the compressed air.

Next, fill the sink with enough tepid tap water to immerse the mirror and add to it a few drops of gentle liquid dish soap. Carefully lower the mirror into the soapy water and let it sit for a minute or two.

With a big, clean wad of surgical cotton, sweep across the mirror's surface ever so gently with the backward rolling motion I described earlier, being careful not to bear down. Roll the cotton a half-turn backward, discard it, and use a new piece. If stains remain after this step, let the mirror soak in the water for five to 10 minutes and repeat the sweeping with more new cotton.

With the surface cleaned, drain the sink. Run tepid tap water on the mirror and its holder for a while to rinse away all soap. Then turn off the tap and pour room-temperature distilled water across the surface for a final rinse.

Finally, rest the mirror on a towel and let it dry. I usually rest it against a pillow on my bed. Tilt the mirror at a fairly steep angle (greater than 45°), its edge resting on the soft towel to let any remaining water droplets roll off without leaving spots. When it's dry, insert it into the telescope, collimate the optics, and you're done!

More tips

Other telescope parts also require occasional attention. For instance, some focusers tend to bind if you don't lubricate them occasionally. To prevent this from happening, use a little Teflon lubricant on the focuser's small pinion gear or roller. Loosen the screws (typically two) that connect the plate to the side of the focuser's housing. Squirt a tiny bit of lubricant on the pinion teeth, tighten the cover plate, and wipe off any drips, as required.

If a metal telescope mount starts to bind, lubricate the axes' bearing points. Some manufacturers recommend this be done at specific intervals, while others make no mention of it at all. If the latter is true, then do it once a year.

The Formica and Teflon materials in most Dobsonian mounts require little in the way of maintenance. But if your Dob doesn't move freely, take the mount apart and apply a little furniture polish or car wax to the contact surfaces. Buff, reassemble the mounting, and try it. You should notice the difference immediately. If not, consider replacing the pads with furniture slides, available at most hardware stores.

Some drives also need an occasional check to keep them happy. Carefully remove the protective housing and put a little light grease between the two meshing gears. While the drive is open, put a drop or two of thin oil on the motor's shaft, as well. Then reassemble the drive, turn it on, and listen for any noises.

Most clock drives hum as they slowly turn. If yours seems unusually loud or if grinding noises are coming from it, turn it off immediately and contact the manufacturer for recommendations.

The bottom line

Even after lots of use, caring for your telescope doesn't take much effort. If you show it even a little love by storing it correctly and performing periodic maintenance, it will happily show you the wonders of the universe for years to come.

Phil Harrington *is a contributing editor for* Astronomy. *He still enjoys using the Criterion RV-8 reflector he got for Christmas in 1971.*

Turn your smartphone astro-

MOON: PHILIPPE MOUSSETTE; TELESCOPE/CELL: ASTRONOMY: WILLIAM ZUBACK

We've all seen the pictures on social media: lunar and planetary photos taken with a smartphone that seem to rival what the best amateurs used to achieve with dedicated (and expensive) equipment just a few years back. There's no denying that smartphones are revolutionizing casual astrophotography and simplifying outreach. Unfortunately, I've never been lucky with handheld cellphone/telescope pictures. My handheld attempts tend to come out looking like they were taken by a potato, with a potato, and of a potato. And all rotten potatoes at that.

It does not have to be this way.

Although the camera sensor in modern smartphones does not hold a candle to a dedicated astro-camera, it's possible — and easy — to take photos and video of the Moon, Sun, planets, and even a few bright deep-sky objects with some proper planning.

The most important piece of this puzzle is the smartphone-to-telescope adapter. Smartphone adapters allow for afocal astrophotography, a type of photography that uses the eyepiece to help focus the image. For lunar and planetary imagers, this is a definite plus because it allows you to vary your magnification simply by changing to an eyepiece with a different focal length. A few years back, if you wanted to find a way to couple your smartphone to your telescope, you went the homebrew route. My attempts typically lacked both elegance and functionality. Fortunately, multiple commercial options are now available.

When choosing an adapter, be certain that it attaches firmly to both your telescope eyepiece and your smartphone. Aside from making sure you have an acceptable image, watching your expensive smartphone hit the ground is probably something that's not on your to-do list for the night's observing session.

You'll also want to look for an adapter that's easily adjustable or designed for a specific eyepiece and/or camera setup. The adapter needs to be strong enough to prevent sag in the system. With afocal projection, you have to ensure that the image is formed directly on the sensor, and exact positioning can be a little tricky.

Other points to consider: You may have had your telescope and eyepiece collection for years, but the lifetime of a typical smartphone is a magnitude of order shorter. An adjustable bracket ensures that you'll be able to use your smartphone adapter with your next smartphone. And pay attention to both the maximum dimensions of the adapter and your phone. Many have an issue with large tablet-style phones.

Here are a few options for you to try.

Tom Trusock *is an* Astronomy *contributor who often reviews equipment.*

1

Magnifi

$39.99–$79.99

Manufacturer: Arcturus Labs
Website: www.arcturuslabs.com
Phone compatibility: iPhone 4, 4S, 5, 5S, SE
Eyepiece compatibility: 25–38mm, must be at least 1 inch (25mm) deep so the adapter can slide on far enough

The Magnifi is designed for specific iPhones. If you happen to have one, a system like this has a lot to recommend it. While admittedly not future-proof, it does allow for quick and repeatable positioning while ensuring the phone is firmly locked into the adapter.

into an

You don't need a pricey rig to capture the cosmos. All you need is your cellphone and some inexpensive equipment. **by Tom Trusock**

-camera

iOptron Universal Smartphone Eyepiece Adapter

$58

Manufacturer: iOptron
Website: www.ioptron.com
Phone compatibility: Universal
Eyepiece compatibility: Included 12.5mm Plössl

This unit has all-metal construction and fits smartphones 2.28 to 3.77 inches (58mm to 96mm) wide and up to 0.55 inch (14mm) thick. With the iOptron adapter, a 12.5mm eyepiece is part of the setup, making that portion of the connection secure. While this makes things a bit more rigid, it limits your adjustment options somewhat and, of course, your eyepiece (and thereby magnification) choices.

Manufacturer: Celestron
Website: www.celestron.com
Phone compatibility: iPhone 4, 4S, 5, 5S; Samsung Galaxy S4
Eyepiece compatibility: X-Cel LX or Ultima Duo

These adapters from Celestron take a slightly different tack. While most adapters in this roundup are generic, these are specific to particular smartphones and particular eyepieces. While you're out of luck if you don't have the exact model phone and/or eyepiece, this type of a design allows for a more complete optical setup and ensures you easily get your optical train aligned. Sadly, because they are phone and eyepiece specific, when you move on, there's no taking it with you. In addition, this product has been discontinued, so you may need to search for this one on eBay or Amazon.

$59.95

Celestron Smartphone Adapter

HookUpz Universal

$44.69

Manufacturer: Carson
Website: www.carson.com
Phone compatibility: All popular models except for larger phones, such as the iPhone 6 Plus and Galaxy Note series.
Eyepiece compatibility: 20–58mm and a depth of at least 14mm

Carson's HookUpz is a lightweight, plastic mount designed to connect most smartphones to nearly any optical device in seconds. The company touts that the adapter is designed for use in telescopes, binoculars, monoculars, microscopes, night vision scopes, borescopes, and slit lamps. It's also the only one in the roundup with glow-in-the-dark rubber (for increased visibility at night). It comes with a case.

Explore Scientific Smartphone Adapter

$14.99

Manufacturer: Explore Scientific
Website: www.explorescientificusa.com
Phone compatibility: Universal
Eyepiece compatibility: 1¼"

The least expensive adapter in this roundup, it will (in theory) fit any size smartphone. Rather than rely on an adjustable clamp as many of the other adapters do, the Explore Scientific adapter uses a pad of soft silicone suction cups to secure the phone to the adapter.

Manufacturer: Modern Photonics
Website: www.telescopeadapters.com
Phone compatibility: iPhone 5, 5S, 5C, 6, 6S, 6 Plus, 6S Plus; Samsung Galaxy S4, S5, S6, S6 Edge, S6 Edge Plus, S7, S7 Edge Plus, Note 4, Note 5. A generic model is also available.
Eyepiece compatibility: 1¼" and 2" eyepieces (separate adapters)

Modern Photonics takes the prize for smartphone-specific adapters. If you have almost any of the recent Apple or main Samsung smartphones, they've got an adapter for you. Additionally, they sell a generic adapter that works within the same system and are one of the few companies that can offer the flexibility to work with 2" as well as 1¼" eyepieces.

$79–$99

Modern Photonics Smart Phone Adapter

SteadyPix Universal Smartphone Telescope Photo Mount

$39.99

Manufacturer: Orion
Website: www.telescope.com
Phone compatibility: Universal
Eyepiece compatibility: 1¼"

An all-steel and padded solution, this adapter fits phones up to 3.4 inches (87mm) wide, allowing its use with large phones like the iPhone 7 Plus.

Manufacturer: Snapzoom
Website: www.snapzooms.com
Phone compatibility: Any phone up to 3.67 inches (93mm) wide and 0.91 inch (23mm) thick.
Eyepiece compatibility: 23–55mm outside diameter, with 1 inch (25.4mm) of room to fit the eyepiece.

Mainly a binocular adapter (in that it will attach to both eyepieces), the Snapzoom can be used with spotting scopes and telescopes in conjunction with the supplied counterweight kit. It's specifically designed to hold the phone in landscape mode to facilitate viewing photos and video after shooting. Snapzoom's website contains detailed troubleshooting instructions along with helpful tips and tricks.

$74.95

Snapzoom Universal Digiscoping Adapter

← 8

9

FoneMate

$95

Manufacturer: Tele Vue
Website: www.televue.com
Phone compatibility: Universal
Eyepiece compatibility: Dioptrix-compatible eyepiece required

The FoneMate is a well-designed system that uses the Tele Vue Dioptrix mounting system to quickly, easily, and securely attach your smartphone to any Dioptrix-capable eyepiece. In addition, the company's new Delos and DeLite eyepieces offer exceptional performance and correction for afocal projection. Tele Vue makes the system as easy to use as possible, providing in-depth instructions and eyepiece recommendations (see the website) to minimize vignetting and maximize image quality. If you already have an investment in Tele Vue eyepieces or are looking to start one, the FoneMate is the hands-down best choice. Of the adapters I've seen, this is one of the more polished systems.

10

SteadyPix Pro Universal Camera/Smartphone Mount

$59.99

Manufacturer: Orion
Website: www.telescope.com
Phone compatibility: Universal
Eyepiece compatibility: 1¼"

An aluminum and ABS constructed solution — not only for cellphones, but point-and-shoot cameras as well (though not DSLRs) — the heavy-duty bracket is compatible with 1¼" eyepieces with housing diameters between 28mm and 45mm. The smartphone bracket will fit phones up to 3.15 inches (80mm) wide. Length is not a consideration. As a bonus, it allows for direct attachment to photo tripods, as well.

11

SteadyPix EZ Smartphone Adapter

$89.99

Manufacturer: Orion
Website: www.telescope.com
Phone compatibility: Universal
Eyepiece compatibility: 1¼"

The latest and greatest from Orion, this adapter fits smartphones as small as 4.7 by 2.4 inches (119 by 61mm) and as large as 8.3 by 4.7 inches (210 by 119mm), large enough for even the biggest phones on the market. The eyepiece mount is adjustable and can be used with eyepieces with 31–55mm housing diameters.

Other considerations

Obtaining focus can be frustrating. Some experimentation and patience will serve you well here. You'll probably need to focus both the smartphone and telescope. I recommend that you leave one fixed at first and observe what happens when you vary the other. Take some time and play with the zoom on your camera and observe the results.

When your planetary shots are getting overexposed, it's probably because your light metering is attempting to compensate for the dark background. One solution is to change the camera to spot metering directly on the object you're imaging. If your camera app does not have that option, you can try experimenting with filters. Often a neutral density filter (like those used for lunar observation) will do the trick. Alternatively, another camera app might help unlock the full potential of the camera. Aspiring iPhone astrophotographers should investigate NightCap Pro, a camera app designed to reduce or eliminate many of the limitations of traditional smartphone cameras.

Most smartphones require a tap on the screen or a press of the volume rocker to take a photo. Touching your setup while imaging is a recipe for disaster. If your phone allows you to take the photo by pressing the volume button, try using a set of headphones with volume control as a shutter release. If not, look for a timer function in your camera app. Some apps even have a voice-activated shutter.

Once you've mastered taking basic snapshots of bright deep-sky objects, you may wish to push your smartphone to the limit. Try experimenting with video and using something like RegiStax to digitally combine the best images in a process called stacking.

Smartphone astrophotography can be both outreach and a way to record those beautiful nights. It's inexpensive and does not involve a lot of effort, so why not give it a shot?

SEND IN YOUR PICS!

We'd love to see your "astro-camera" pictures of the universe! Send them to **smartphone@astronomy.com** and they may be featured on our website!

WE TEST

Sky-Watcher USA's new COMPOUND SCOPE

This 7½-inch Maksutov-Newtonian provides tack-sharp stars all across the field of view. **by Phil Harrington**

Sky-Watcher USA's Maksutov-Newtonian 190mm is a 7½-inch telescope that uses both a lens and a mirror to form its image. ALL PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

UNTIL FAIRLY RECENTLY, Maksutov telescopes were not commonly seen at star parties. Amateur astronomers considered them exotic. But that changed in recent years with the introduction of several lower-priced models.

Maksutovs come in two basic varieties: Maksutov-Cassegrains and Maksutov-Newtonians. Each uses a front corrector plate, or meniscus, and a rear-mounted primary mirror to collect light and bring it to a focus. Maksutov-Cassegrains, in which light passes through a central hole in the primary out to an eyepiece, have become popular among today's amateurs thanks to improved mass-production methods (and thus lower costs).

But Maksutov-Newtonians, on which the eyepiece is at the tube's front like a traditional Newtonian reflector, have always been custom-made telescopes carrying hefty price tags. The compound optical design eliminates two fundamental drawbacks of the mirror-only Newtonian reflector: astigmatism (where light rays focus at different points) and coma (where stars at the edge of the field of view have comet-like tails).

Astronomy columnist and contributing editor **Phil Harrington** *just loves observing, especially when he's using a top-notch telescope.*

The Mak-Newt's unattainability has started to erode over the past few years, with prices coming down and availability going up. To that end, Sky-Watcher USA offers its Maksutov-Newtonian 190mm, a 7½-inch f/5.3 Mak-Newt that proved to be an outstanding yet affordable example of the breed.

The beast within

At the heart of the 190mm is a spherical primary mirror teamed with a deeply curved front meniscus lens. Both are made of low-expansion borosilicate glass. Manufacturers prefer this type because it holds its precise curvature better as the temperature changes through the night.

Sky-Watcher USA uses an enhanced aluminizing for both the primary and secondary mirrors, resulting in 94 percent reflectivity. The meniscus lens is also fully multicoated with the company's proprietary Metallic High Transmission Coatings to maximize image contrast. As I discovered, the results speak for themselves.

The primary mirrors in all Maksutov telescopes need to be larger than the stated aperture to work correctly. In this case, the primary is 8 inches (203 millimeters) across. The meniscus measures 7.48 inches (190mm), the determining aperture.

To accommodate photography, the secondary mirror has a stated minor axis of 2.5 inches (64mm) to illuminate the entire field of the sensors used in many popular digital single-lens reflex (DSLR) cameras and CCD imagers. That results in roughly a 30 percent central obstruction, about the same as a Schmidt-Cassegrain telescope.

Because the secondary attaches directly to the front meniscus, there are no spider veins like in traditional Newtonians.

PRODUCT INFORMATION

Sky-Watcher USA Maksutov-Newtonian 190mm
Aperture: 7.5 inches (190 millimeters)
Focal length: 1000mm
Focal ratio: f/5.3
Optics: Fully multicoated
Focuser: 2" dual-speed Crayford
Finder: 9x50 right angle, correct image
Dovetail plate: Vixen style
Length: 37.5 inches (952mm)
Weight: 27.4 pounds (12.4kg)
Price: $1,500
Contact: Sky-Watcher USA
475 Alaska Avenue
Torrance, CA 90503
[t] 855.327.1587
[w] www.skywatcherusa.com

Therefore, photographs taken through this scope will be free of diffraction spikes around bright stars.

Inside, the tube has five baffles to help maximize image contrast. Baffles prevent extraneous light from infiltrating the optical path. The tube's interior is flat black, but to help improve image contrast even further, the manufacturer glued a small square of ultra-flat black material to the inside wall directly opposite the focuser.

Finish and extras

The optics sit in an attractive steel tube that sports metal-flake glossy black paint. The tube comes with white end rings as well as a backing plate that covers and seals the primary mirror's cell.

The backing plate protects against dust infiltration, reducing the need to have the optics periodically recoated. A sealed optical system like this extends cool-down time, however, so take that into account when you're setting up. You can attach a small fan to the rear plate to circulate air and accelerate acclimation. Sky-Watcher does not offer a fan at present, but other dealers (like Orion Telescopes) do.

Standard accessories that come with the 190mm include a dual-speed 2" focuser, a 9x50 correct-image right-angle finder scope and mount, white rotating tube rings, and a Vixen-style dovetail plate for attaching the scope to many mounts.

Unlike some early dual-speed focusers packaged with imported scopes, the 190mm's unit is well made. Focusing was sharp and precise. The included 1¼" adapter is an unusual "sliced" design that claims to keep eyepieces centered more precisely. It worked fine for me.

The focuser is low profile for photographic use, but also includes a built-in extension tube that extends 2.13 inches (54mm) for eyepieces that require more back-focus. That's a nice touch that I grew to appreciate during viewing.

The test scope arrived well packed in a foam-lined double box. Despite the inevitable bumps and bangs during shipment, the scope arrived in near-perfect alignment. When you need to adjust the collimation, the primary mirror pivots via three Phillips-head screws on the backing plate. And you can change the tilt of the secondary mirror with three screws hidden behind a cover you can pry off with a small screwdriver — carefully, so as not to scratch the scope's front lens. Not being a fan of using screwdrivers in the dark for this sort of thing, I am glad that Bob's Knobs offers a set of stainless steel thumbscrews that can replace those provided.

The 190mm's optical tube assembly (OTA) measures 37.5 inches (952mm) long and weighs 27.4 pounds (12.4kg). That put it at the upper limit of the German equatorial mount I used for this evaluation. And that points to one of the few drawbacks of Mak-Newts: They are heavy. Because most amateurs usually purchase only the OTA, make sure your mount is sturdy enough for the task, especially if you are planning to use it for astrophotography. Sky-Watcher USA's own EQ-6 mount is a good match.

The tube's weight makes rotating it in the rings a challenge. I had to loosen them fully to move it. The tube is also front heavy because of the lens, so you'll have to move it back from the center position between the rings to achieve balance.

Although you can't see it in this photo, the front of the telescope sports a meniscus lens that works with the primary mirror at the bottom of the tube to produce superb images.

Under the stars

After setting up the scope in my suburban yard and allowing time for it to acclimate to the ambient temperature, I swung it toward Saturn, which was in Scorpius. Despite the planet's low altitude, the image was sharp and clear. The rule of thumb states not to exceed a magnification of 50x per inch of aperture. I easily surpassed that on this steady summer night. Saturn remained sharp even as I approached 500x with a top-end 5mm eyepiece and 2.5x Barlow lens.

Precise focusing with the two-speed Crayford focuser was easy, even at a high power like the one I used on Saturn. And you can lock the focuser in place to prevent slippage. I found the lock sufficiently strong to hold my DSLR in place. While some owners may be tempted to upgrade to an aftermarket focuser, I'd recommend you give the stock unit a good test first. You just may be pleasantly surprised.

The telescope comes with a 2" two-speed Crayford focuser. The black fine-focus knob moves the unit one-tenth as fast as the two silver coarse-focus knobs.

Nearby, globular cluster M4 awaited. Stellar resolution was easy at 150x, and I spotted the cluster's unique "bar" of stars across its core. Other summer globulars in Ophiuchus, Sagittarius, and, of course, the Hercules Cluster (M13) also clearly resolved into myriad stars.

Tight binary stars were a snap to split, thanks to the superior optical quality of the 190mm, and they remained sharp no matter where they were in the field of view. I purposely moved things around to see how good the optics were. Unlike traditional Newtonians, where coma blurs stars near the field's perimeter, stars in the 190mm remained pinpoints right to the edge.

Summer nights where I live can be damp. And that brings up a second, minor drawback to Mak-Newts (as well as all refractors and catadioptric instruments). The front meniscus can turn into a moisture magnet once the temperature reaches the dew point. Sky-Watcher does not sell a simple dew shield for the scope. Fortunately, many vendors do. A flexible dew shield is the minimum you'll need. A powered dew heater system is even better.

Bottom line

Issues like dewing and weight can be dealt with. Those minor hindrances aside, I came away impressed with the Sky-Watcher USA's 190mm scope. It is an exceptionally versatile instrument. The images were among the best I have ever seen through any comparably sized scope, regardless of design or price. The 190mm is just as adept at visual deep-sky observing as it is for guided astrophotography. But make no mistake, it provides stunning planetary views, too. After spending many enjoyable hours with the 190mm, I can now appreciate why a growing number of amateurs feel that Maksutov-Newtonians are the finest telescopes of all.

OBSERVINGBASICS

BY GLENN CHAPLE

Double star marathon redux

A small scope is all you need to track them down.

Castor (Alpha [α] Geminorum) is the second-brightest star in the double star marathon. Just 2.2" separate its two bright suns while a third member of the system appears directly south (below) of this pair. JEREMY PEREZ

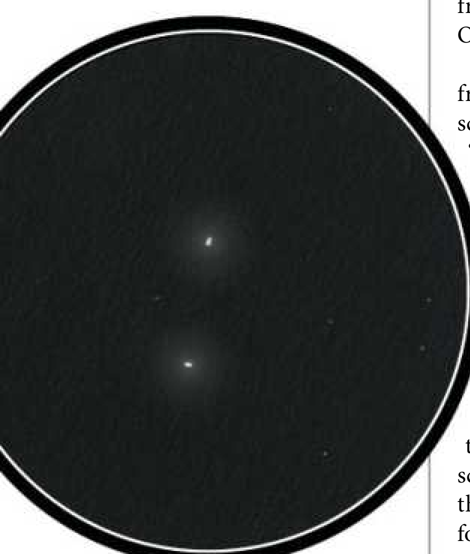
Porrima (Gamma [γ] Virginis) is fairly easy to split today, when 2.3" separate its components. In 2008 (seen here), they were only 0.4" apart. JEREMY PEREZ

One year ago, I introduced the double star marathon — a double star enthusiast's answer to the annual Messier marathon. Nearly 70 of you requested the list, and two — Ben Rubel of Framingham, Massachusetts, and Jerry Oltion of Eugene, Oregon — captured all or most of them.

I wasn't as successful. A week prior to the March 12–13 Messier marathon weekend, I did a trial run on the doubles hugging the western horizon after sunset. Starting at 7 P.M. with my trusty 10-inch reflector, I whipped through the soon-to-set doubles in Cassiopeia, Aries, Triangulum, Andromeda, Perseus, Pisces, and Eridanus. Once I completed the trial run, I couldn't help but continue. (Once you've "tasted" one double star, you can't stop.) I notched Polaris and then hit the doubles in Taurus and Orion. I then worked my way eastward, finally stopping at 9:50 P.M. with the pretty pair 54 Leonis. My final tally was 43 of the first 46. I missed three close pairs because of iffy seeing conditions.

I was primed for the main event when the bug hit — and it wasn't the double star variety. A few days after my trial run, I came down with a nasty, lingering cold that sidelined me well into April. It denied me an opportunity to test the visibility of the double stars coming up in the east before dawn. My best take on the viability of my double star marathon list comes from the reports Rubel and Oltion sent me.

Rubel tackled the list on two fronts, using 4.5- and 8-inch scopes and a zoom eyepiece. "I did find it a bit easy for an 8-inch, and most of the stars were easy in the 4.5-inch," he says. "I did the first half in close to the order on my sheet, and I jumped around more with the second half. In all I'd say I had about four hours of break time during the night, and that's with using two telescopes for each star. The marathon helped my appreciation for double stars."



Although binoculars will split Epsilon [ε] Lyrae — the famous "Double Double" — into a pair of suns, you'll need a telescope to see that each member itself is a double star. JEREMY PEREZ

This was the first astronomical all-nighter for the 16-year-old. His success with a 4.5-inch validated what I had hoped: The double star marathon can be completed with a small-aperture scope.

After being clouded out during a stay in Arizona, Oltion returned to his Oregon home, where he conducted the double star marathon over a two-night span using a 12.5-inch scope. "I got about 85 objects in one night, missing only the ones that were too far to the south for the site I was observing from and the ones that were too far east when the Moon rose, but I picked up the southerly ones the next night from a different site and wound up with 96 total over the two nights," he writes. "The only reason I didn't pick up all 110 was because I didn't stay up all night either night.

"I didn't find any doubles that I thought shouldn't be on the list. There were a few tight ones and a few that were pretty low to the horizon, but the entire list is certainly doable from 44° north," he adds. "The only suggestion I would make is to arrange them in the order that a person would most likely want to observe them, rather than strictly by R.A."

Several of you asked if it would be appropriate to use go-to technology to track down the doubles. Why not? Because some go-tos identify double stars by their SAO number, California double star enthusiast Phil Kane took my list and added SAO designations. For a copy of his Excel file, contact Phil at icycomet1944@gmail.com.

This year's Messier marathon occurs the weekend of March 25–26, so that's when we'll run the second double star marathon. Based on last year's results, it seems the list doesn't need much tweaking. I'm looking for reader help in checking the visibility of doubles setting in the west after sunset and those rising in the east before dawn. Kane recommends adding Psi[1] (ψ^1) Piscium (SAO 74482), which isn't far from M74 and might be easier to spy in the twilight glow. As an upgrade to my list, which you can request through my email address, I've taken Oltion's suggestion and added a section arranging the pairs in a practical observing sequence.

A final note: At the time of the Messier marathon, the Sun is in an area devoid of Messier objects. This is not the situation with double stars. Next September, I'll look at some of the best pairs that can't be seen during the double star marathon.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: When does one-quarter equal one-half?

Glenn Chaple has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

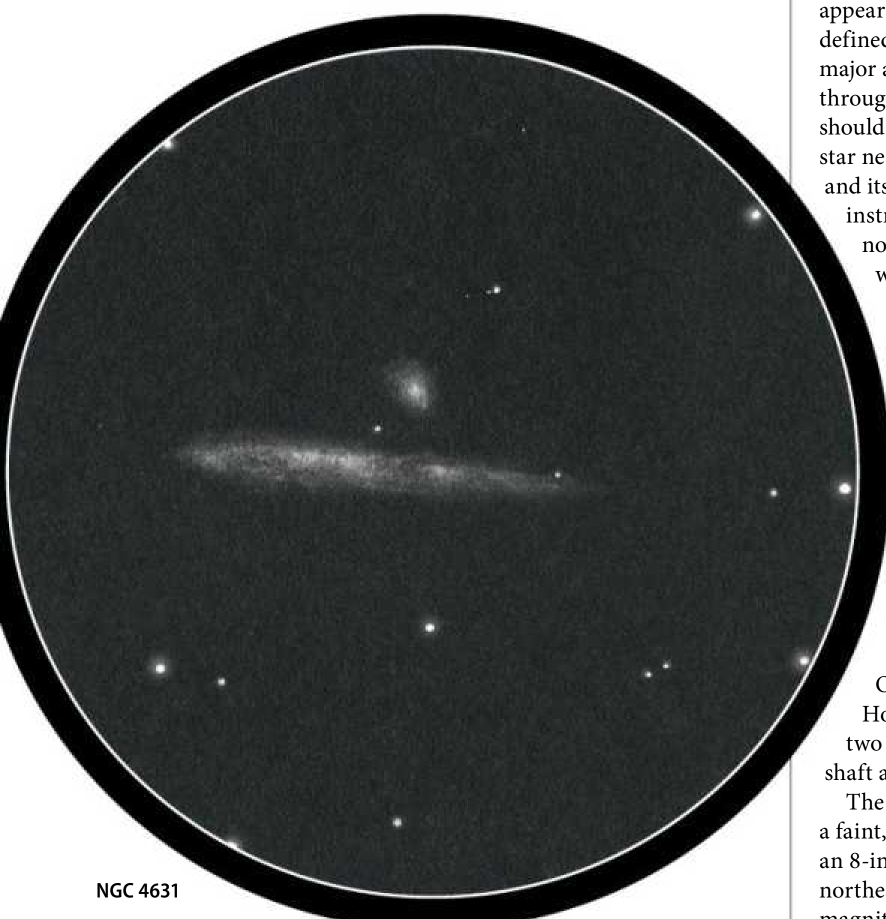
ASTRO**SKETCHING**

BY ERIKA RIX

Distorted galaxies

Two relatively large edge-on galaxies, the Whale (NGC 4631) and the Hockey Stick (NGC 4656–7), lie 25 million light-years away toward the constellation Canes Venatici the Hunting Dogs. Because of the mass and energy of these objects, a weak gravitational interaction occurs between the two, and it affects their neighboring dwarf galaxies as well. This force pulls material from one galaxy to the other, distorting their shapes and triggering star formation.

You'll find the pair nearly halfway down and a tad southeast of an imaginary line between Cor Caroli (Alpha [α] Canum Venaticorum) and Gamma (γ) Comae Berenices. You'll likely spot NGC 4631 first. Shining at 10th magnitude, it's one of the brightest edge-on galaxies in the sky. It spans 17' by 3.5' and has a small elliptical galaxy, NGC 4627, hovering 2.5' to its northwest. Together, they form Arp 281 from Halton Arp's *Atlas of Peculiar Galaxies.*



NGC 4631

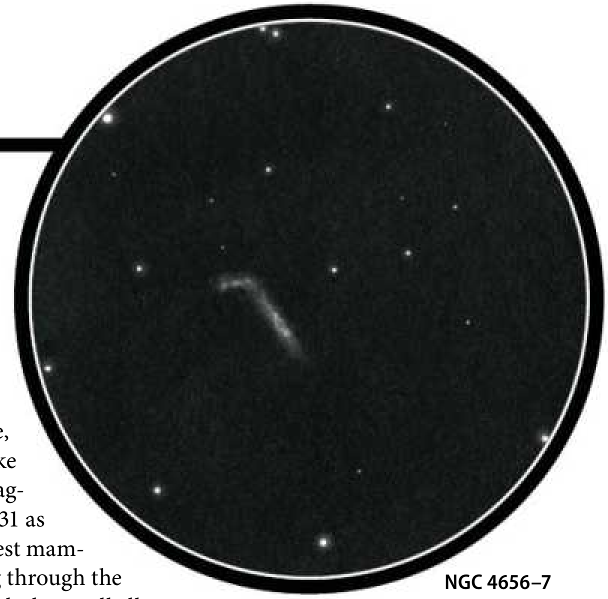
The author drew both galaxies while observing through a 16-inch f/4.5 Newtonian reflector on a Dobsonian mount. She paired the scope with a 12mm eyepiece for a magnification of 152x. She used 8B, 2B, and 2H graphite pencils on white paper to depict the stars and their magnitudes, and used a blending stump to render the galaxies. She then scanned the sketches and inverted them using Photoshop. Both sketches show north up and west to the right. ALL SKETCHES BY ERIKA RIX

Pegged as the Whale for its unusual wedge shape, it doesn't take much to imagine NGC 4631 as Earth's largest mammal drifting through the eyepiece, with the small elliptical galaxy as its spray.

Through an 8-inch telescope, NGC 4631 is bright and elongated east to west with tapered ends. Its mottled appearance will become more defined and knotted along its major axis if you view it through a 12-inch scope. You should spot a 12th-magnitude star nestled between the Whale and its companion. A 16-inch instrument sharpens the northern edge, and the whale's head to the east brightens and bulges before narrowing along the tail. There, a 13th-magnitude star balances above its tip.

Once you've had your fill of the Whale, look 0.5° southeast to find NGC 4656–7, which glows at magnitude 10.4 and covers an area 14' by 3' in size. Observers call it the Hockey Stick because its two visible parts resemble a shaft and blade.

The Hockey Stick appears as a faint, hooked sliver through an 8-inch telescope, running northeast to southwest. A 10th-magnitude star glows 11' northeast of the galaxy. Use a 12-inch scope, and you'll see a bright knot within the blade at the northeast tip of the galaxy. It's this knot that carries the



NGC 4656–7

separate designation NGC 4657. The shaft broadens and diffuses to the southwest. A 16-inch scope reveals a three-knotted blade with two more nestled within the mottled nebulosity of the shaft.

Because I used a mount that didn't track, I began each sketching session by framing the field of view so that a few of the brighter stars were near its edge. Those key stars, along with marking the directions as they drifted through the field, became reference points that let me easily re-center the eyepiece view after I made additions to the sketch.

Next, I completed the majority of the star field using a set of graphite pencils to render their varying magnitudes. As I worked, I made small adjustments to their sizes so that each was recognizable when I compared my drawing to the eyepiece view. I then added the galaxies with the tip of a blending stump that I coated with graphite. And finally, I dotted in the faintest stars to complete the sketch.

If you have questions or comments, please contact me at erikarix1@gmail.com.

Erika Rix is co-author of Sketching the Moon: An Astronomical Artist's Guide *(Springer-Verlag, 2011).*

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

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The Image Catalyst
Sofia, Bulgaria

Image Catalyst's *Astro Photography Tool* can help you plan, control, monitor, and analyze your imaging session. It also controls alignment, focusing, and the imaging itself. The software currently works on Windows XP through Windows 10 platforms, and it supports a large number of cameras and accessories.

Price: 18.70 euros
[e] support@astroplace.net
[w] www.astroplace.net

Stick-and-shoot camera

Podo Labs, San Francisco

Podo is a portable camera that uses Bluetooth technology to let you control the shooting with your smartphone. It measures 2 by 2 by 1 inches, weighs 1.8 ounces, sports an 8-megapixel chip, shoots 720p video at 30 frames per second, and has a reusable micro-suction foot for mounting. The battery lets you shoot two hours of video.

Price: $99
[t] 805.750.7582
[w] www.podolabs.com

Focuser

Starlight Instruments
Columbia City, Indiana

Starlight Instruments' FTF1575BCR is a single-speed, 1¼" focuser with 0.75 inch of drawtube travel. It also features a brake and a compression ring, which secures the eyepiece. The company added a T-thread to the drawtube to make attaching cameras and accessories easy.

Price: $249
[t] 260.244.0020
[w] www.starlightinstruments.com

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Santa Fe, New Mexico

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BINOCULARUNIVERSE

BY PHIL HARRINGTON

The star clusters of Puppis

The winter Milky Way flows to the east of brilliant Sirius and Canis Major through a region of our southern sky filled with faint stars. Once, those faint stars formed the constellation Argo Navis, the mighty mythical ship that carried Jason and the Argonauts as they searched for the Golden Fleece on the eastern shores of the Black Sea in present-day Georgia. Or so the story went.

To commemorate those adventures, Ptolemy immortalized the ship as one of the original 48 constellations in his work, the *Almagest*. Like the ship, the constellation was huge, covering almost 1,700 square degrees, or 4 percent of the entire sky.

Because of this unwieldiness, the 18th-century astronomer Nicolas Louis de Lacaille divided Argo into three parts, which we still recognize and use today: Puppis the Poop Deck or stern; Carina the Keel or body; and Vela the Sails.

This month, we will set sail for Puppis, a small region of the late winter Milky Way that is rich in buried binocular treasure.

First, to zero in on Puppis, focus your attention on Canis Major. If Sirius is a jewel or tag on the Big Dog's collar, the profile of its head curves northeastward using the 4th-magnitude stars Iota (ι), Gamma (γ), and Theta (θ) Canis Majoris. Depending on local conditions, you might need to use your binoculars to see them.

Pause at Gamma, and place it at the western edge of your field of view through your binoculars. Then glance just a bit farther east. You'll first see a knot of 6th- to 8th-magnitude stars bunched together. That's open cluster **M47**.

Of the 50 stars that make up M47, I can count up to 11 through my 10x50s. Four form a fuzzy-looking "Y" asterism in the middle of the cluster. That cloudiness is just due to the low magnification, however. It clears up when I examine the cluster with my 16x70s.

You're bound to notice an orange 5th-magnitude star set about 40' west of M47. That's the variable star KQ Puppis. Although they probably have no affiliation with each other (some studies suggest they may), the color contrast between it and M47 is eye-catching. Defocusing your binoculars slightly will enhance the color.

Located near M47, open cluster M46 is composed of a large number of fainter stars. Lying in front of this cluster is the ring-shaped planetary nebula NGC 2438. BERNHARD HUBL

A close-up of planetary nebula NGC 2438 shows its bright ring structure surrounded by a fainter, older ring of gas. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The bright open cluster M47 in Puppis makes an easy binocular target. BERNHARD HUBL

KQ Puppis is actually a binary system, made up of a red supergiant star and a blue-white main sequence star. Like many similar red supergiants, KQ fluctuates slightly in brightness, causing the overall magnitude to change between 4.82 and 5.17.

Open cluster **M46** lies just over a degree east of M47, so it easily fits into the same field of view. In reality, they are nowhere near each other in space. M47 is estimated to lie 1,600 light-years away, while M46 is much more distant at 5,400 light-years.

Like snowflakes and fingerprints, no two open star clusters are exactly the same. I can't think of anywhere in the sky where this is better illustrated than with M46 and M47. While M47 is a young pup of a cluster, only 78 million years old, the 500 stars that make up M46 are about 300 million years old.

Even though M46 is much richer in stars than M47, the greater distance veils their individuality through binoculars. Most of us will see M46 as a soft, amorphous glow suspended in a starry field. If you own 70mm or larger binoculars and have good sky conditions and a pretty good eye, you just may be able to spy a few faint points peeking out through the glow. The brightest star in M46 shines at 9th magnitude, but most hover below 11th magnitude.

Images of M46 show that it is being photo-bombed by a celestial interloper, planetary nebula **NGC 2438**. The planetary shines faintly at about 10th magnitude, so again it is just within reach of some giant binoculars. The problem in convincingly seeing the planetary is twofold. Not only is it dim, but it's also tiny. That's this month's challenge: Can you spot NGC 2438 through binoculars? Please email me your results.

Incidentally, NGC 2438 is not inside M46. It is actually much closer, "only" about 2,900 light-years from Earth. Thinking spatially, it's actually closer to M47 than to M46.

We all have favorite binocular objects. I'd enjoy hearing about yours, and possibly feature them in future columns. Contact me through my website, philharrington.net.

Until next month, remember that two eyes are better than one.

Phil Harrington is a longtime contributor to Astronomy *and the author of many books.*

READER GALLERY

1. STARRY MEADOW
The photographer created this dramatic image of the Milky Way from 30 separate 15-second exposures taken from Arches National Park in Utah. It combines atmospheric clouds with those from our galaxy, with a bit of light pollution from the city of Moab thrown in. • ***Matt Dieterich***

2. I'M SAILING AWAY ...
Open cluster NGC 225 in the constellation Cassiopeia also goes by the common name of the Sailboat Cluster. This image captures not only stars but also reflection and dark nebulosity. As an added bonus, the tiny open cluster Berkeley 3 lies near the right edge. • ***Frederick Steiling***


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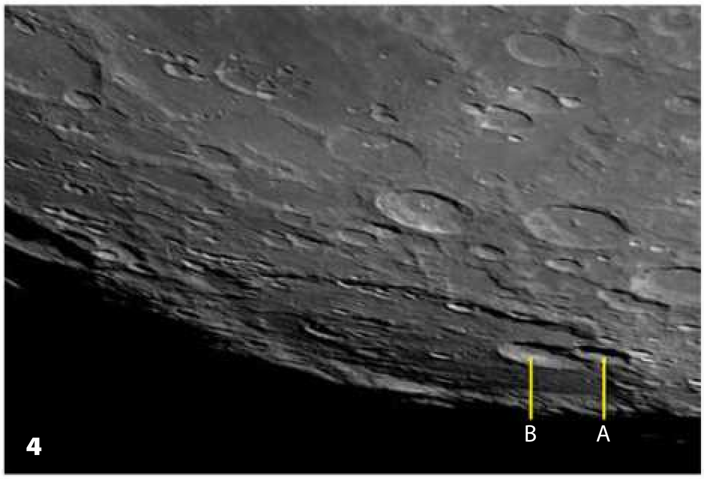

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3. THE LION NEBULA
More than 20 hours of exposures went into creating this image of Sharpless 2–132. It has a wider field of view than most shots, so it captures the dimmer clouds of hydrogen surrounding the object. It also contains two tiny planetary nebulae at left and bottom right. • ***Brian Peterson***

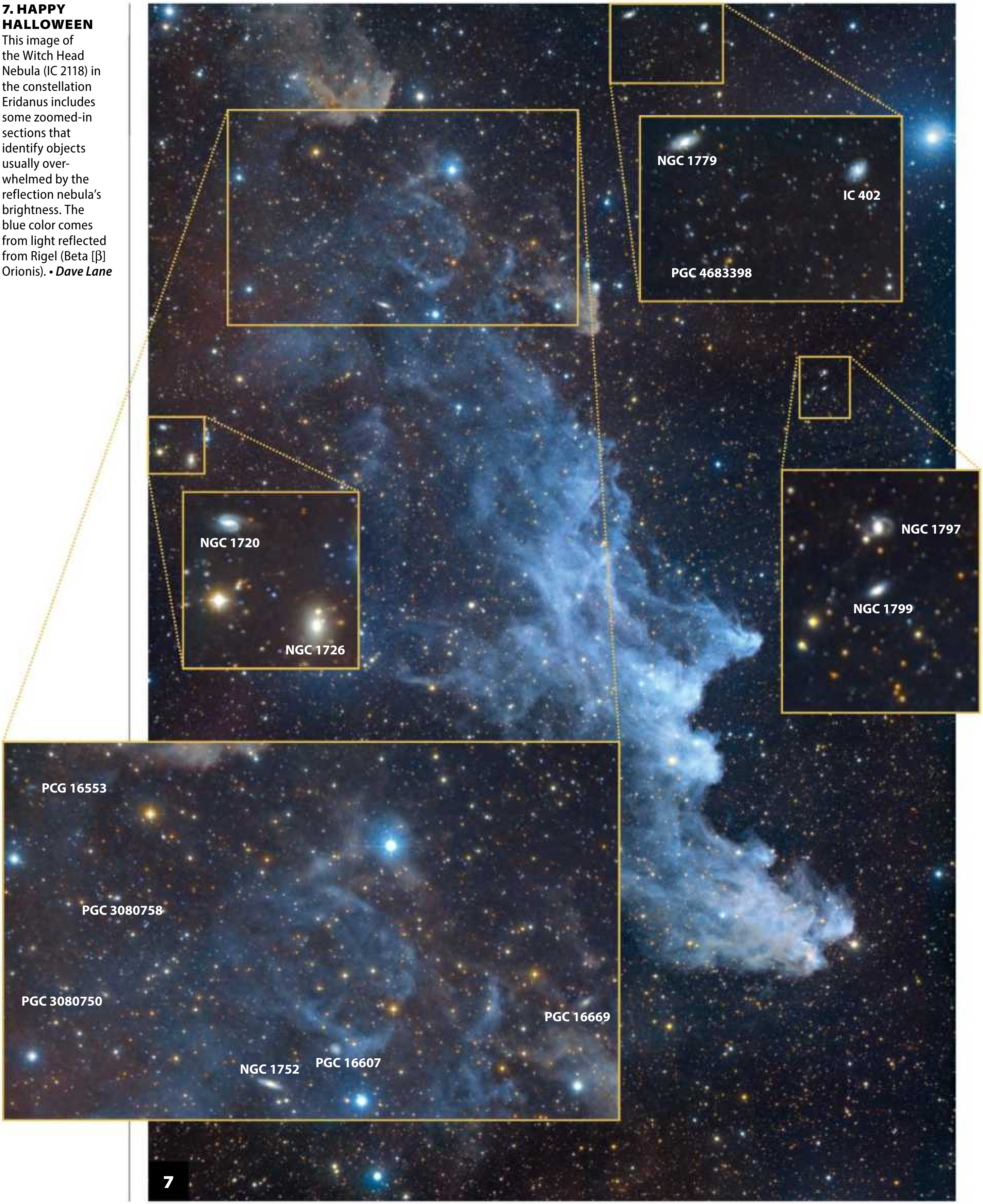
4. SILENT BUT DEADLY
Bailly Crater is the 180-mile-wide (300 kilometers) lunar basin at the bottom of this image. Since it formed, it has experienced some sizable impacts, which have left it scarred. Most notable is the pair of craters at bottom right: Bailly B and Bailly A. • ***Brian Ford***

5. EDGE OF TOMORROW
NGC 891 is a classic edge-on spiral galaxy in Andromeda. In addition to this standout object, however, take a close look at this image. Can you spot the dozens of additional — albeit much smaller and fainter — galaxies around the big bright one? • ***Dan Crowson***

6. DELICATE DARKNESS
The dark nebula Barnard 343 in Cygnus doesn't get a lot of attention from astroimagers. This image shows a bit of detail in the dust cloud within the nebula — it's not just a featureless blob. Furthermore, close inspection of the image shows it lies in front of fairly faint Hydrogen-alpha nebulosity.
• ***Rodney Pommier***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

7. HAPPY HALLOWEEN
This image of the Witch Head Nebula (IC 2118) in the constellation Eridanus includes some zoomed-in sections that identify objects usually overwhelmed by the reflection nebula's brightness. The blue color comes from light reflected from Rigel (Beta [β] Orionis). • ***Dave Lane***



INDEX *of* ADVERTISERS

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BREAK THROUGH

Caught in a spider's web

Deep in the heart of the Tarantula Nebula — a vast stellar nursery in the Milky Way's largest satellite galaxy, the Large Magellanic Cloud — lurks the massive star cluster R136. Astronomers recently used the Hubble Space Telescope to identify nine cluster stars that tip the scales at more than 100 times the Sun's mass, the highest concentration of such luminaries in the known universe. Together, these nine behemoths shine 35 million times brighter than our star. And individually, each of these suns loses up to an Earth's mass of material every month due to fierce stellar winds. NASA/ESA/P. CROWTHER (UNIVERSITY OF SHEFFIELD)

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

May 2017: March of the gas giants

For those with a clear view toward the northwestern horizon, **Mars** clings to visibility in evening twilight. As May begins, the Red Planet shines at magnitude 1.6 and appears some 8° high a half-hour after sunset. Don't confuse it with ruddy Aldebaran, which stands directly above Mars and about twice as high. First-magnitude Aldebaran is the luminary of Taurus the Bull, and it appears noticeably brighter than the planet. Mars becomes hard to see as it drops closer to the horizon late this month.

Fortunately, two brighter planets come to the fore as Mars exits the evening stage. **Jupiter** dominates the eastern sky during twilight and grows even more prominent after darkness falls. The giant planet shines at magnitude –2.3 against the much fainter backdrop of Virgo. It lies about 10° northwest (left) of the Maiden's brightest star, 1st-magnitude Spica, which glows with a distinct blue-white hue.

Although Jupiter reached opposition and peak visibility in April, it remains a great subject to view through a telescope. And it now appears higher in the evening sky, which should translate into sharper views. The giant world shows a wealth of detail across its 42"-diameter disk. Even a small instrument shows the planet's two dark equatorial belts and its four bright moons.

Jupiter isn't the only gas giant planet on view in the evening sky. Magnitude 0.2 **Saturn** rises around 8 P.M. local time in early May and some two hours earlier by month's end. It appears below the distinctive shape of Scorpius as the Scorpion climbs higher in the east. Officially, however, Saturn resides near the border between Sagittarius and Ophiuchus. The planet's westward motion relative to the background stars carries it from the former into the latter constellation during May's third week.

With Saturn at a declination of –22°, it is beautifully placed in the Southern Hemisphere sky. It becomes a telescopic showpiece once it climbs halfway to the zenith by late evening. The Sun's second largest planet never fails to impress, particularly when its rings open as wide as they do now. Even the smallest scope reveals the world's 18"-diameter disk wrapped in an exquisite ring system that spans 41" and tilts 26° to our line of sight. Also look for the 8th-magnitude moon Titan. Several other moons glow between 10th and 12th magnitude and show up through moderate apertures.

While the two gas giant worlds rule the skies for most of the night, the two inner planets make splendid predawn sights. **Venus** rises first, clearing the eastern horizon by 3:30 A.M. local time all month. Shining at magnitude –4.7 in early May (and fading just 0.2 magnitude during the month), the planet outshines every other planet and star from then until daybreak.

A telescope delivers fine views of Venus' rapidly changing appearance as it pulls away from Earth. On May 1, the world appears 38" across and 27 percent lit. By month's end, Venus' disk spans 25" and the Sun illuminates 48 percent of it.

Although **Mercury** pales in comparison with Venus, it puts on a fine show in its own right. The innermost planet has its best morning appearance of the year in the latter half of May. At greatest elongation on the 17th, Mercury lies 26° west of the Sun and climbs some 13° high in the east-northeast an hour before sunrise. It then shines at magnitude 0.5 and is the brightest object to Venus' lower right. The planet brightens as the month goes on, reaching magnitude –0.3 by the 31st.

Mercury puts on an equally good telescopic show. In mid-May, the small world spans 9" and is about one-third illuminated. By the 31st, Mercury appears 6" across and nearly two-thirds lit.

A waxing gibbous Moon occults 1st-magnitude Regulus on May 4. Observers in New Zealand and much of Australia can see this event in a dark sky. From Sydney, Regulus disappears behind the Moon's dark limb at 10h13m UT and reappears from behind the bright limb at 11h35m UT.

Viewers in Madagascar and parts of eastern Africa can see a second Regulus occultation May 31. From Madagascar's capital, Antananarivo, the waxing crescent Moon covers Regulus at 17h14m UT; Regulus returns to view at 18h26m UT.

The starry sky

While brilliant Jupiter dominates Virgo this month, it conveniently points to the 3rd-magnitude star Porrima (Gamma [γ] Virginis). The star lies no more than 5° northwest of the planet all month.

In mythology, Porrima was a Roman goddess of prophecy. Also known as Antevorta, she had knowledge of the future while her sister, Postvorta, knew of the past. Unlike the majority of proper star names, which derive from Arabic, Porrima comes from Latin.

The star's main claim to fame is as one of the sky's most famous double stars. English astronomers James Bradley, who would became Astronomer Royal in 1742, and his uncle, James Pound, discovered Porrima's duplicity in 1718.

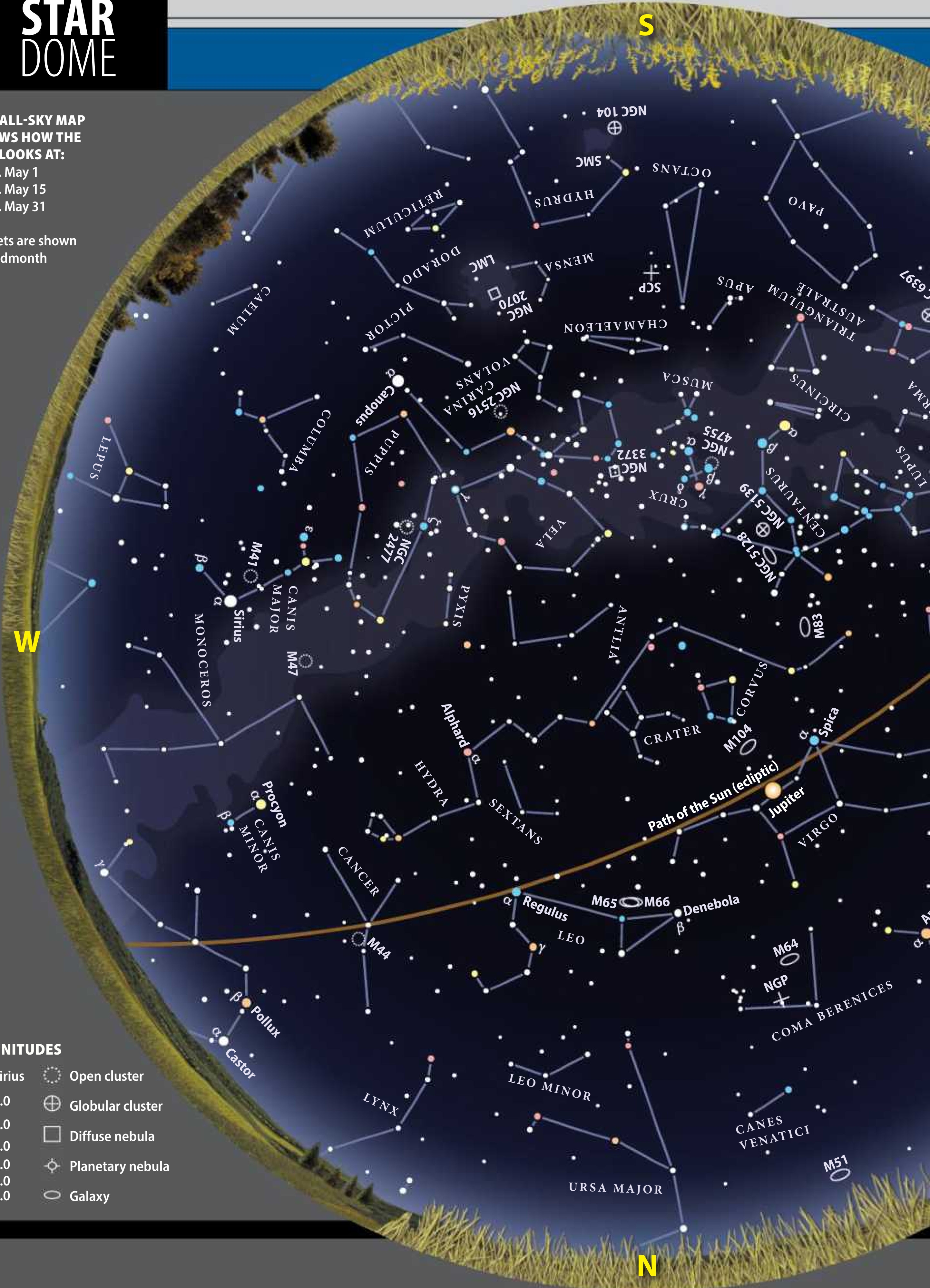
Observations over nearly three centuries have helped astronomers pin down the orbits of the nearly identical magnitude 3.5 stars. The two made their closest approach to each other in 2005, when only 0.34" separated them. So it's not a stretch to say that I would not have written about this star as an interesting telescopic object a dozen years ago!

A recent set of orbital elements — the quantities that define the size and shape of the orbit together with the stars' relative positions at any given moment — shows that the two complete one revolution about each other every 169.1 years. The gap between them has been widening since 2005, and they now lie about 2.5" apart. An observer with a modest scope should be able to split them fairly easily with high power on a steady night.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. May 1
8 P.M. May 15
7 P.M. May 31

Planets are shown at midmonth



MAGNITUDES

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

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

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

MAY 2017

Calendar of events

2 Mercury is stationary, 14h UT

3 First Quarter Moon occurs at 2h47m UT

4 The Moon passes 0.5° south of Regulus, 10h UT

6 Eta Aquariid meteor show peaks

7 Mars passes 6° north of Aldebaran, 7h UT

The Moon passes 2° north of Jupiter, 21h UT

Mercury passes 2° south of Uranus, 23h UT

8 Asteroid Juno is stationary, 8h UT

10 Full Moon occurs at 21h42m UT

12 The Moon is at apogee (406,210 kilometers from Earth), 19h51m UT

13 The Moon passes 3° north of Saturn, 23h UT

17 Mercury is at greatest western elongation (26°), 23h UT

19 Last Quarter Moon occurs at 0h33m UT

20 The Moon passes 0.5° south of Neptune, 6h UT

22 The Moon passes 2° south of Venus, 13h UT

23 The Moon passes 4° south of Uranus, 5h UT

24 The Moon passes 1.6° south of Mercury, 1h UT

25 New Moon occurs at 19h44m UT

26 The Moon is at perigee (357,207 kilometers from Earth), 1h21m UT

27 The Moon passes 5° south of Mars, 2h UT

31 The Moon passes 0.3° south of Regulus, 17h UT

Astronomy magazine

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