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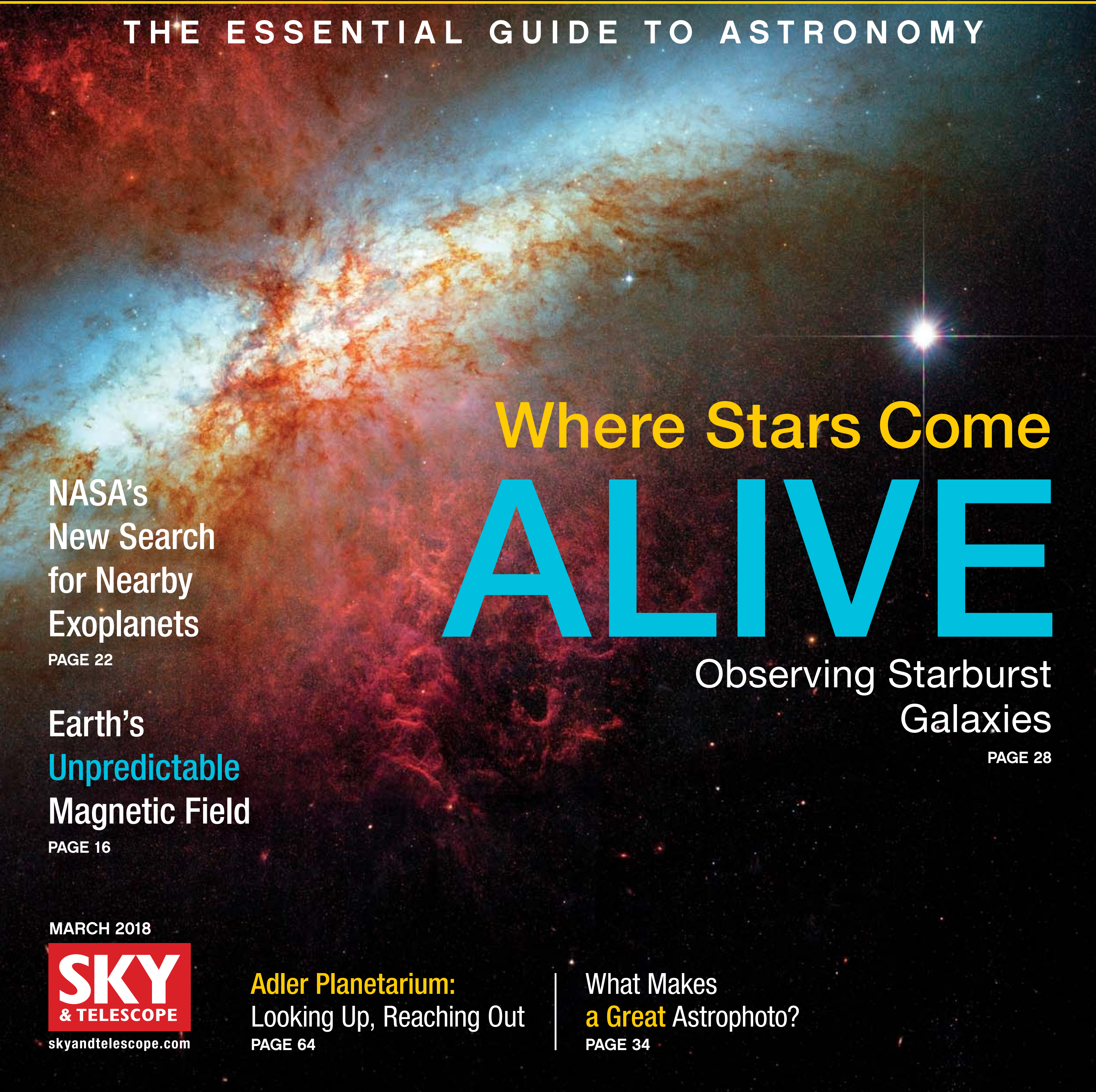
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



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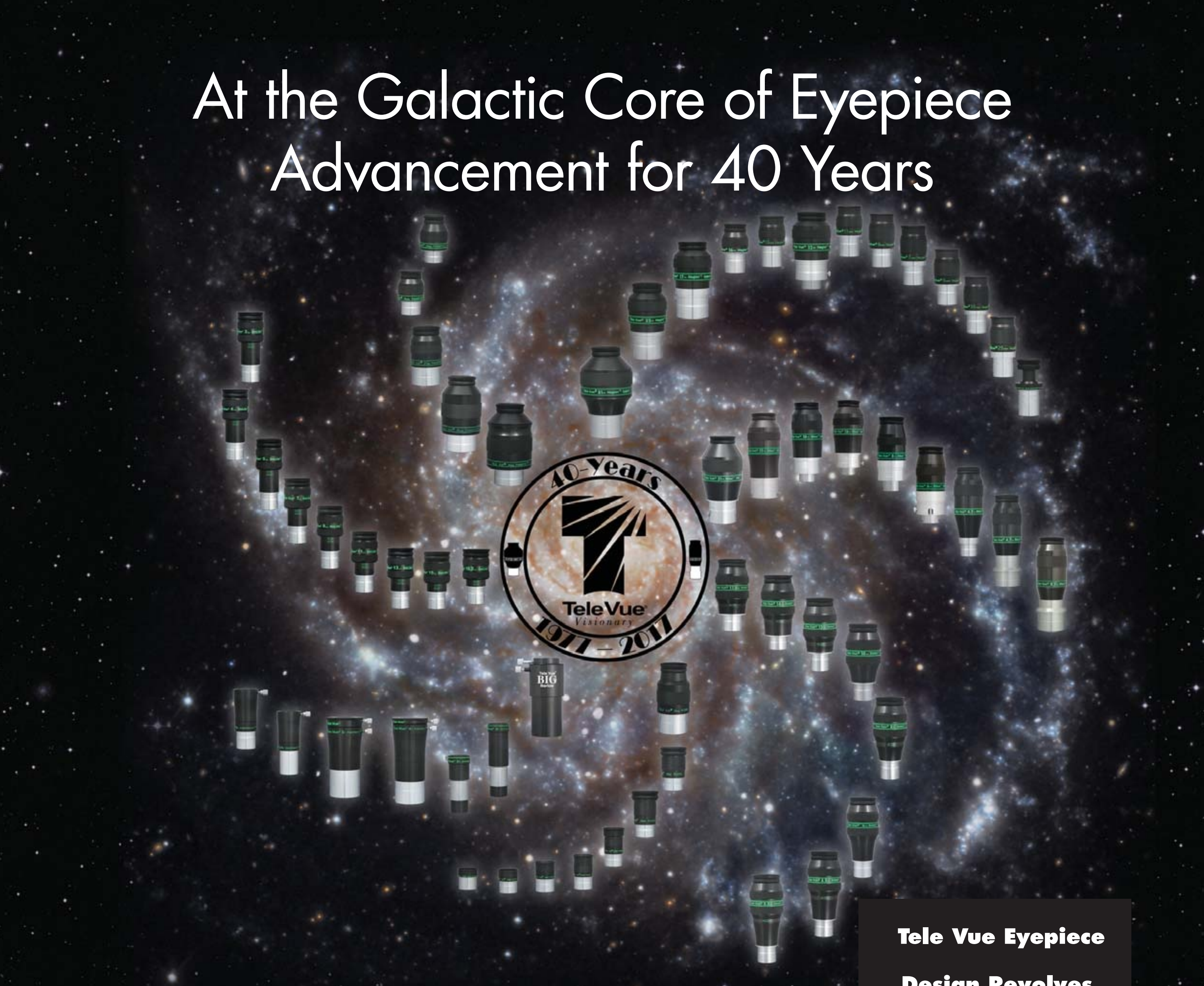
At the Galactic Core of Eyepiece Advancement for 40 Years
40-Years
TeleVue
Visionary
1977 – 2017

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

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ON THE COVER

This mosaic of M82 shows the galaxy's star-blown outflows.

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The Stellar Soul of Wit

WHERE WOULD WE BE in astronomy without acronyms? Say you run into someone working on a certain study of galaxy formation. You don't want to have to ask, "Hey, what's the latest with Galaxy Halos, Outer disks, Substructure, Thick disks, and Star clusters?" You'd much rather just ask, "Hey, what's the latest with GHOSTS?"

Acronym comes from the Greek *akron* (end, tip) and *onuma* (name). The idea, at least initially, was to take the first letter of each word in a series and make a new "word," as in NASA or SETI. But astronomers found using just the initial letter far too limiting. (And it would really wreck GHOSTS.) Consider OSIRIS-REx. That's short for Origins, Spectral Interpretation, Resource Identification, Security, and Regolith Explorer. Such flexibility! Free rein, of course, can lead to bolting horses. For examples, amuse yourself on the Dumb Or Overly Forced Astronomical Acronyms Site, or DOOFAAS (see **https://is.gd/astroacronyms**).

All astronomical acronyms are helpful, though. Imagine how worn out we'd have been in recent months if we'd had to verbalize "Laser Interferometer Gravitational-wave Observatory" every time we mentioned that top newsmaker. Happily, we could just say "LIGO." It was even easier because we pronounce it "LIE-go" instead of spelling it out every time, as in "L-I-G-O." We do use initialism for certain terms, for good reason. Try enunciating RGB (red giant branch) or AGN (active galactic nucleus) as if they were words.

Acronyms offer endless opportunities for cleverness. How diverting, for instance, if you wind up with one bearing a catchy cultural innuendo, as in SHERLOC or PEPSSI. (I'll let you google these.) Even better, craft one to be finessable later if the project expands or proceeds in a different form, as in CREAM and ISS-CREAM. (Gosh, I wonder how you pronounce that?)

While reading a draft of our feature on TESS (Transiting Exoplanet Survey Satellite, page 22), it occurred to me that far and away the most popular variety of astro acronym is feminine names. Think LORRI, ALMA, SOFIA, AMBER, LISA, AMANDA — the list goes on. (The guys get FRED.)

Some acronyms can make you chortle, such as WIMP or KREEP. Others might leave you scratching your head. ASAS-SN? GERLUMPH? ARMPIT? One project focusing on star systems elbowed us all gently in the side when it settled on ACRONYM (All-sky Co-moving Recovery Of Nearby Young Members).

Whether all-business, playful, or groan-inducing, astro acronyms allow us to cut to the chase with what are often unimaginably complicated experiments, instruments, or missions. They're also a sign of how wonderfully active and varied astronomy is today. Most notably, though, they're a relief. Why stumble over "ZonEd Proportional scintillation in LIquid Noble gases"? Just say "ZEPLIN"!

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Subscription Rates: U.S. and possessions: $42.95 per year (12 issues); Canada: $49.95 (including GST); all other countries: $61.95, by expedited delivery. All prices are in U.S. dollars.

Newsstand and Retail Distribution: Curtis Circulation Co., 201-634-7400.

Perfecting Your Nightscapes

As soon as I retrieved my January issue from the mailbox, I recognized the cover picture by Rogelio Bernal Andreo. My wife, Donna, and I took this daytime version of the same waterfall on August 30, 2014, while in Big Sur, California.

Tom Mason
Azusa, California

I think it is a bad mistake to publish over-processed photographs (*S&T:* Jan. 2018, p. 36). The night sky is such a subtle thing to see, and to lose that subtlety by over-processing is a terrible mistake. When our club shows celestial objects to beginners, a number of them are so disappointed because of their experience seeing Hubble photographs. We do a disservice by not representing the night sky faithfully.

I have been a professional photographer all my life, both as a newspaper staffer and as a freelancer for magazines. With the advent of digital photography back in 2000, my newspaper realized that there needed to be rules to limit what photographers could do in manipulating their photographs. That pretty much allowed us only the options of burning, dodging, and minor corrections to exposure and color. If photographs were over-processed, or faked outright by combining two or more photographs into a single image, the newspaper would suffer reduced credibility with its readers.

With this in mind, I hope that you'll consider changing your guidelines for what is acceptable in terms of image processing for the magazine.

Ken Spencer
Sea Cliff, New York

When Will the Sun Die?

Peter Tyson's article on the fate of our solar system (*S&T:* Oct. 2017, p. 22) was very interesting and informative. One other factor possibly affecting the future of Earth is intelligent intervention. If human civilization can avoid extinction catastrophes, including self-inflicted annihilation, a billion years is a long time to implement effective strategies to compensate for a 10% increase in solar luminosity.

Some possibilities include increasing the overall reflectivity of Earth, putting reflectors in orbit to block a fraction of the Sun's light, and increasing the radius of Earth's orbit.

Obviously, implementing any of these strategies on the required scale would be no small task, but the incentive for coordinated action eventually would become compelling.

Tom Wik
Livermore, California

"Written in the Star" seems to add about a billion years to the Sun's expected lifespan. I've seen one reference that has the Sun leaving the main sequence in about 5.4 billion years, whereas your figure is 6.5 billion years. Do we really have enough computing accuracy to know which figure is better — or whether we need a different one entirely?

Larry Gerstman
Long Beach, New York

Greg Laughlin (Yale) replies: Our understanding of the future evolution of the Sun (or at least its evolution up to the tip of the red-giant branch when mass loss makes things slightly uncertain) hasn't changed much during the past 30 years. The classic 1993 *Astrophysical Journal* paper by J. Sackmann, A. Boothroyd, and K. Kraemer ("SBK"; see **https://is.gd/gOzgfN**) remains authoritative and, additionally, continues to make for good reading.

The discrepancies stem from exactly what one adopts for the main sequence's endpoint. One reasonable definition is the moment at which the hydrogen at the very center of the Sun's core is exhausted. SBK's calculations have this occurring 9.37 billion years after the Sun's earliest formation phases, or "only" 4.83 billion years from now.

But there will still be hydrogen in the layers just above the center, which will allow the Sun to continue more or less normal operations for well over a billion additional years. In that sense, SBK's definition of the main sequence's end is about 6.5 billion years from now, after the Sun is left with a significantly hydrogen-depleted core and has begun to move fairly rapidly to lower temperatures, becoming a "subgiant" star.

A Fond Memory of NGC 253

Like Matt Wedel, I also vividly remember my first sight of NGC 253, the Silver Coin Galaxy in Sculptor (*S&T:* Nov. 2017, p. 43). It was August 9, 1977, at Nairne in the dark hills east of Ade-

TOM & DONNA MASON

laide, South Australia. My instrument was an 11-cm f/8 Newtonian reflector on an alt-azimuth mount. I was star-hopping through faint fuzzies in and near Sculptor using Antonín Bečvář's *Atlas Coeli 1950.0*.

As I star-hopped using the finder-scope, suddenly a large, bright splodge of light moved into the field. I was startled. I remember thinking that this thing would get in the way as I tried to see the galaxy. And then it dawned — this *was* the galaxy. In the eyepiece, it took my breath away. I described it as "Enormous, bright, narrowly elliptical; brightening gradually to the centre and extending to about 25′ in its long axis." I couldn't see any internal structure.

Nowadays, a 11-cm reflector would be considered a humble instrument. An alt-azimuth mount with no drive, star-hopping, Bečvář's charts — these are terms familiar mainly to those with long memories. But my excitement and joy as I discovered the heavens back then was as intense as it is for astronomers today.

Marilyn Hewish
Darley, Victoria, Australia

Enduring Love, Thanks to *S&T*

My wife, Brenda F. Branchett, passed away on October 26, 2017, after a long illness. Brenda founded the Ancient City Astronomy Club of St. Augustine in 1973, and she remained an active observer in the 43 years that followed, with particular interests in meteors, deep-sky objects, and the Sun. Brenda was also a founder of the Astronomical League's Herschel 400 project.

I met Brenda thanks to an article by Dennis di Cicco about the Herschel Club in *Sky & Telescope*'s July 1977 issue. At the time I was observing some of these objects from my home in England, and in response to the article I began corresponding regularly with Brenda. We became pen pals and married in November of 1981, soon after I had immigrated to the United States to be with my future bride. In 1991 she and I finally got to meet Dennis and were able to thank him in person for that article. It led to 35 years of adventure both in the celestial realm as well as under the stars.

David Branchett
Deltona, Florida

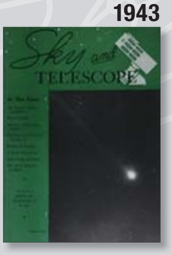
FOR THE RECORD

- The Geminid meteor shower's radiant, at declination +27°, is observable from all of South America, Africa, and Australia (*S&T:* Dec. 2017, p. 49).
- In the bottom panel of the illustration showing the evolution of stellar interiors (*S&T:* Jan. 2018, p. 26), the label "He→H" should instead be "He→C".

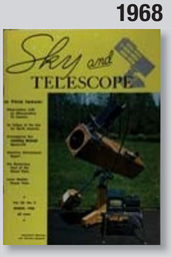
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

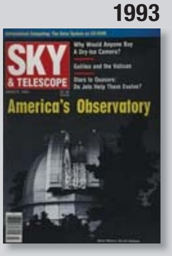
1943



1968



1993



◖ March 1943

Active Galaxies "Dr. Carl K. Seyfert, of Warner and Swasey Observatory, has been studying six of a rare class of spirals whose nuclei exhibit high-excitation nebular emission lines superposed on the usual *G*-type absorption spectrum. . . .

"The lines in all the objects studied are widened, presumably by rapid motion of the material emitting the light — the total widths of the lines corresponding to speeds of [up to] 8,500 kilometers per second. [The] composition of the nuclei [is unknown], and further progress of Dr. Seyfert's investigations will be awaited with considerable interest."

Seyfert's classic paper, read at a meeting of the American Astronomical Society, launched the close attention being paid today to active galactic nuclei or AGNs. Seyfert galaxies are one type, quasars another.

◖ March 1968

Star Sizes "Narrabri Observatory in Australia has a strange-looking instrument that is proving to be very successful for measuring the angular diameters of bright stars. It consists of a circular railway 600 feet across along which can be moved two 22-foot mosaic mirrors, each with a photocell at its focus. [R. Hanbury Brown's] intensity interferometer is a considerable advance over the Michelson phase interferometer [used] at Mount Wilson in the 1920's. . . .

"Detailed results for 15 stars have just been published. . . . The largest object on the list is Canopus [at 0.0069 arcsecond]. The smallest, Epsilon Orionis [0.0007 arcsecond], appears no bigger than a large truck tire lying on the moon!"

The best-resolution device today (in visible light) is the Navy Precision Optical Interferometer near Flagstaff, Arizona. It can "see" star shapes, surface spots, and components of spectroscopic binaries.

◖ March 1993

Ozone Hole "Since its discovery in 1985, the hole in the ozone layer over Antarctica has grown, and last fall it reached its greatest extent yet. NASA's Total Ozone Mapping Spectrometer (TOMS) determined that the hole covered 23 million square kilometers on September 23, 1992 . . .

"As measured by TOMS, the hole typically begins to enlarge every August and reaches its peak extent in October. The ozone is then slowly restored by natural means until the cycle repeats the following year. . . .

"The ozone molecule, O_3, is an important ingredient in our atmosphere, since it screens out harmful ultraviolet rays. . . . Scientists have speculated that overexposure to ultraviolet rays may increase skin cancer rates and weaken human immune systems."

NASA reports that the ozone hole totaled just 20 million square kilometers in October 2017, its smallest extent in three decades.

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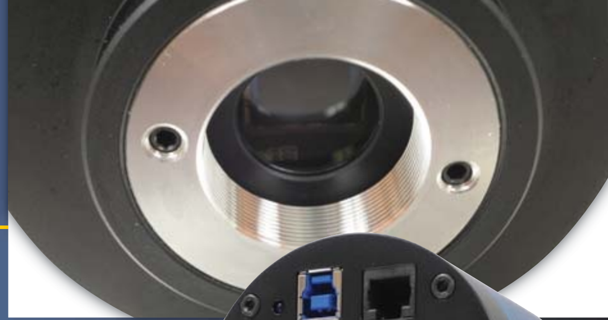


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- Transfer method: all-pixel scan
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- Hand-selected scientific grade sensor
- Sealed multicoated optical window
- FPS/resolution: up to 30 @1936 x 1216 (computer performance dependent)
- Progressive scan, global shutter
- Pixel (µm): 5.86 square
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- Sensor gain: variable to 50x
- Sensor G sensitivity: 1000mv @1/30s with IR filter
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- Ideal for motorized alt-az mounted telescopes
- Support includes full trigger mode
- Built-in memory
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- 16.3-megapixel CMOS ceramic colour sensor
- 22mm diagonal
- Number of effective pixels: 4656 x 3518 (16,379,808)
- Transfer method: all-pixel scan
- Progressive scan
- Full HD support
- Hand-selected sensor class 1 scientific grade
- Sealed multicoated no IR optical window
- Pixel (µm): 3.80 x 3.80 square
- Connectivity USB 3.0 (USB 2 compatible)
- Sensor gain: variable to 20x
- Sensor G sensitivity: 2413mv @1/30s
- Binning resolution: 4640 x 3506, 2304 x 1750, 1536 x 1168
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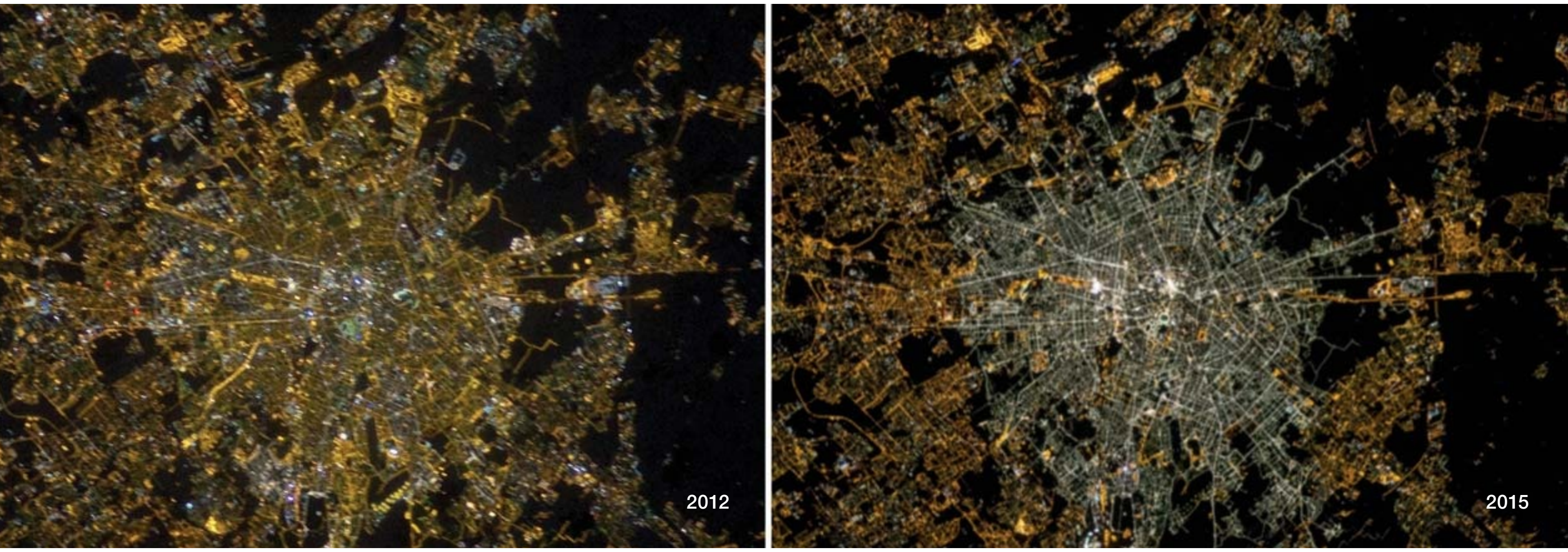


▲ As Milan, Italy, transitioned from high-pressure sodium-vapor lights to white LEDs, its nighttime appearance changed, as is visible in these photographs taken from the International Space Station.

INTERNATIONAL DARK-SKY ASSOCIATION / NASA

LIGHT POLLUTION

The Lost LED Revolution

THE TRANSITION from sodium-vapor lights to LEDs, the so-called "lighting revolution," was supposed to both reduce energy consumption and bring back starry skies. But in the November 22nd *Science Advances*, Christopher Kyba (German Research Center for Geosciences) and colleagues showed that even as regions around the globe move to LED lighting, night skies are becoming brighter than ever.

The team used the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on the Suomi National Polar-orbiting Partnership weather satellite to measure the change in global light emissions between October 2012 and October 2016. The VIIRS instrument is the first-ever calibrated satellite radiometer designed to measure nighttime lights — earlier investigations were often based on an uncalibrated sensor on a military satellite.

Among the spectral ranges VIIRS observes is the so-called day-night band, which picks up visible through near-infrared wavelengths. Each pixel covers ½ km^2, a higher spatial resolution than previous instruments. This enables scientists for the first time to investigate neighborhood-scale changes rather than city or national.

Between 2012 and 2016, these satellite data show that our planet brightened by 9.1%, an annual increase of roughly 2.2%. Artificially lit outdoor area also grew by 2.2% per year. Only a few places showed a decrease in lit area (mostly war-torn countries like Syria and Yemen). Some of the already brightest-lit countries remained stable, among them Spain, Italy, and the United States. But with few exceptions, all countries in Asia, Africa, and South America emit significantly more light now than they used to five years ago.

The trend itself isn't unexpected — artificial lighting has long been an indicator for growing wealth and population. What's surprising is that the ongoing transition to LEDs isn't counteracting the effect.

"While we know that LEDs save energy in specific projects, for example when a city transitions all of its street lighting from sodium lamps to LED," Kyba explains, "when we look at our data at the national and the global level, it indicates that these savings are being offset by either new or brighter lights in other places."

In other words, cheaper lights lead not to savings in energy consumption, but to more light.

That's not just bad news for astronomers. Because these changes are quickly bringing light to places, times, and intensities at which it doesn't naturally occur, many organisms have no chance to adapt. Light pollution affects about 30% of vertebrates and more than 60% of invertebrates on our planet that are nocturnal. Artificial lights also affect plants and microorganisms, and scientists are only beginning to learn about its possible negative effects on human health (*S&T:* Sept. 2011, p. 86).

To make matters worse, the results that Kyba and colleagues present are likely underestimates. The day-night band measurements are insensitive to wavelengths below 500 nanometers, so they don't pick up blue light, which the atmosphere scatters more than other visible wavelengths. Many LED lights peak at blue wavelengths, but they don't have to. "PC Amber" or "True Amber" lights, so far used almost exclusively in designated dark-sky places, could be implemented in cities as well.

■ JAN HATTENBACH

● **Help counteract light pollution, and complement satellite observations, by measuring the skyglow in your area. Participate in Globe at Night, which runs February 5–14 and March 8–17. Find out more at globeatnight.org.**

EXOPLANETS

Ross 128b Orbits Quiet Nearby Star

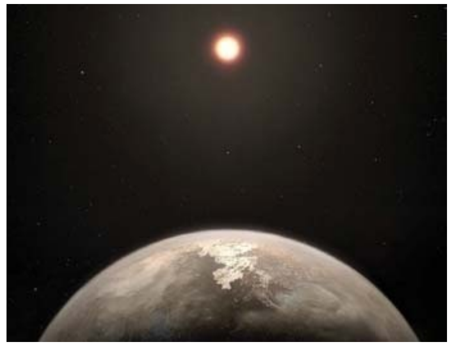
A LIKELY ROCKY PLANET orbits a red dwarf star 11 light-years away, astronomers announced in *Astronomy & Astrophysics*.

Xavier Bonfils (University Grenoble Alpes, France) and colleagues turned the HARPS spectrograph at the La Silla Observatory in Chile on Ross 128, the 15th-closest star to the Sun. The star's motions reveal a planet, Ross 128b, that circles it every 9.9 days. The tight orbit puts Ross 128b 20 times closer to its host star than Earth is to the Sun, but the planet receives just 40% more light than our own. The star is small and cool, so that light would also be much redder than our Sun's. With a mass at least 1.35 times that of Earth, Ross 128b is the second-closest, potentially Earth-size planet within the habitable zone of its star, after Proxima Centauri b.

The star itself, unlike many low-mass stars, is relatively well-behaved. Most low-mass stars are cauldrons of magnetic activity, unleashing flares typically an order of magnitude more powerful than the Sun's. Such flares could severely limit the development of life in these star systems.

However, even though Ross 128 is technically classified as a flare star, it's old and doesn't flare as often as its younger counterparts, such as Proxima Centauri and Trappist-1. Expect Ross 128b to be a target of future atmospheric studies.

■ JOHN BOCHANSKI



▲ Artist's impression of a temperate Ross 128b

GALAXIES

Deeper View of Hubble's Deep Field

ASTRONOMERS HAVE upgraded the Hubble Ultra Deep Field (HUDF).

Hubble imaged a tiny, now-famous square of sky in Fornax for almost 12 days in 2003, revealing thousands of faraway galaxies. Now, the Multi Unit Spectroscopic Explorer (MUSE) on the European Southern Observatory's Very Large Telescope in Chile has taken a visible spectrum of virtually every pixel in the 10-square-arcminute field of view using a technique known as *integral field spectroscopy*. Ten papers in a special issue of *Astronomy & Astrophysics* discuss the data and their implications.

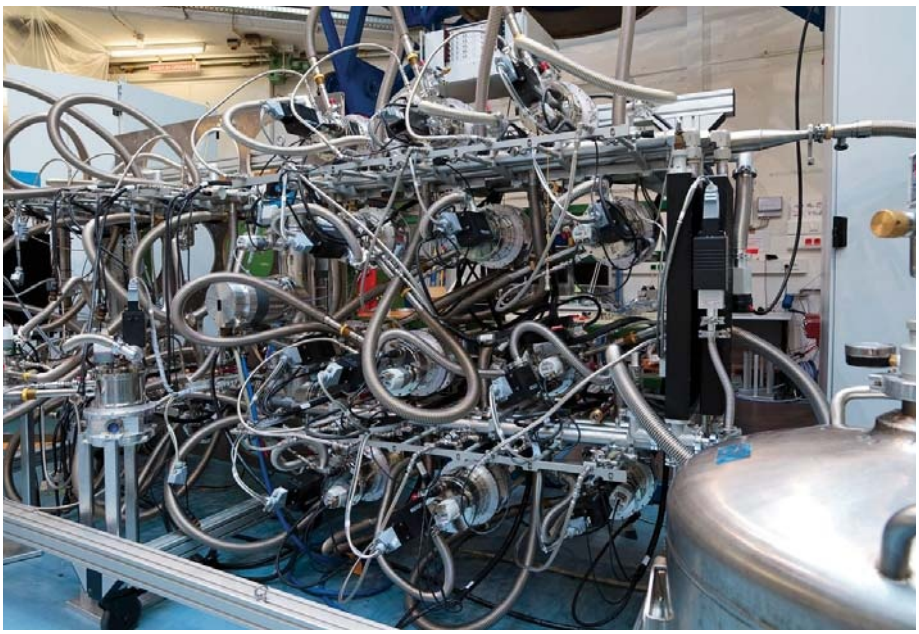
Previously, astronomers had only measured precise distances, via spectroscopic redshift, for 161 galaxies in the HUDF. Distances to the rest of the roughly 10,000 galaxies in the field were less well known. MUSE's pixel-by-pixel spectra increased the number of precise redshift measurements by an order of magnitude, to 1,338 galaxies.

These new measurements have far-reaching effects. Emmy Ventou (University of Toulouse, France) and colleagues, for example, used the data to identify close pairs of galaxies across cosmic time, showing that the rate of galaxy mergers peaked roughly 2 billion years after the Big Bang — in tandem with the early universe's star-formation activity.

MUSE also revealed 160 previously uncataloged distant galaxies, known as *Lyman-alpha emitters*, including 72 undetected in Hubble images. The faint, low-mass galaxies are teeming with newborn stars that excite abundant neutral hydrogen gas. As a result, the galaxies emit most of their radiation at a single wavelength, making them difficult to detect. The MUSE team sliced apart the data by wavelength to search specifically for these objects, catching 692 of them in all.

Alyssa Drake (then at University of Lyon, France) and colleagues show that these diminutive galaxies, as prevalent as dust bunnies during early times, could have single-handedly lit up the young universe during what is known as the *epoch of reionization*.

■ MONICA YOUNG

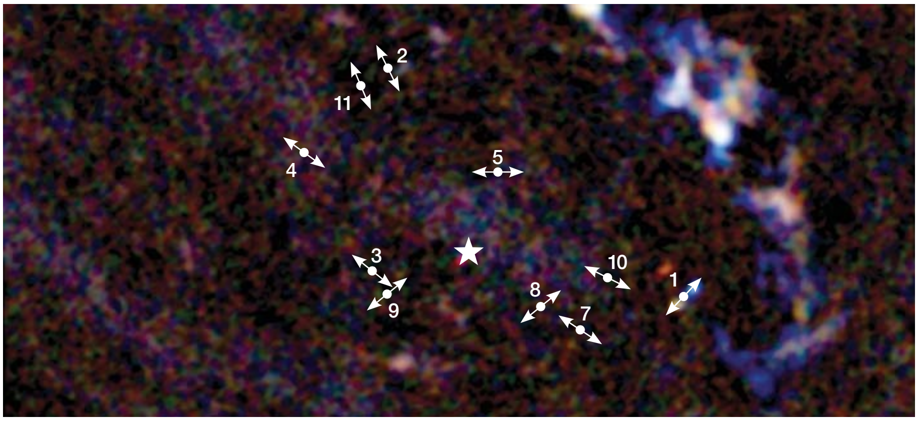


▲ The medusa-like MUSE instrument

ROSS 128B: ESO / M. KORNMESSER; HUDF: ESO

● **Read the full story and find original papers at https://is.gd/muse_hudf.**

STELLAR



◀ Ten of the 11 protostar outflows are marked on the ALMA image of the area around the Milky Way's central black hole (star).

Infant Stars Huddle Near Black Hole

A TEAM OF ASTRONOMERS has found signs of low-mass stars forming within a few light-years of the Milky Way's central black hole.

Theoretically, the black hole's violent gravitational effects, coupled with the high-powered radiation pumped out by nearby massive stars, should make star formation here about as easy as cooking a perfect omelet on a storm-tossed dinghy. Clouds in the galactic center need to be at least 10 times denser than normal in order to coalesce into stars. Yet clearly that's not stopping them. Astronomers have seen hints of current starbirth here before, such as lopsided gas concentrations that resemble the disks around forming suns (*S&T:* June 2015, p. 16). However, these observations haven't been definitive.

Farhad Yusef-Zadeh (Northwestern University) and colleagues report in the December 1st *Astrophysical Journal Letters* that they've now uncovered strong evidence of small stars that began forming near the black hole very recently. Using ALMA to peer through the dust toward the galactic center, the team found 11 gaseous outflows tucked within a bigger ring of molecular gas that surrounds the black hole (spanning 6 to 15-20 light-years out from it). The dumbbell-shaped objects look a lot like the two-lobed outflows created by protostars. Making some assumptions about the masses involved, the team estimates that the outflows come from stars between 3,000 and 15,000 years old. That's roughly comparable to previous protostar suspects.

The ALMA observations only include the innermost few light-years, so it remains unclear if there are more of these outflows peppering the gas ring, Yusef-Zadeh says. The team will need to create a larger map in order to know how common current star formation in the galactic center really is.

■ CAMILLE M. CARLISLE

EXOPLANETS

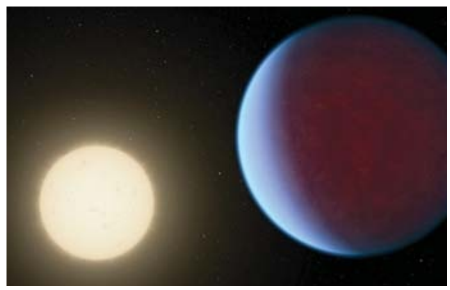
55 Cancri e Has an Atmosphere

A NEW ANALYSIS has settled one of the many questions about the puzzling planet 55 Cancri e: It's not an airless hellscape after all. Instead, it appears to have a substantial atmosphere.

This super-Earth — eight times Earth's mass and almost twice its radius — is in a scorchingly close orbit around a star 40 light-years away. In 2015 Brice-Olivier Demory (then at Cavendish Laboratory, UK) and colleagues published Spitzer Space Telescope observations of the planet as it circled its star. The infrared telescope acted like night-vision goggles, enabling astronomers to see how much heat the planet was emitting throughout its orbit.

The team's interpretation of the data led to two contradictory results. The temperature difference between dayside and nightside was so extreme that it precluded an atmosphere, which ought to circulate heat from the dayside to the nightside. Yet a shift of the hottest spot on the planet of at least 30 degrees from the center of the dayside hemisphere suggested that *something* was recirculating the heat there — if not an atmosphere, then what? To solve the discrepancy, Demory's team suggested lava flows carry heat away from the center of the dayside hemisphere, but as Demory notes, "we always felt uncomfortable with this explanation."

Now, theorists Isabel Angelo and Renyu Hu (both at JPL-Caltech) have compared those same Spitzer observations to their computer model of the planet's atmosphere, publishing the results in the December 2017 *Astronomical Journal*. The model describes how well the atmosphere transports



▲ Artist's impression of 55 Cancri e

the star's heat. The result is a smaller temperature difference between day and night — one that's compatible with an atmosphere surrounding the planet.

In addition to eliminating the lava-flow scenario, Angelo and Hu also constrain the atmospheric makeup, which could be based on nitrogen or carbon monoxide but not water or carbon dioxide. Whatever constitutes the atmosphere, though, it must be thick to survive so close to the star.

■ MONICA YOUNG

PROTOSTARS: ALMA (ESO / NAOJ / NRAO), F. YUSEF-ZADEH ET AL., B. SAXTON (NRAO / AUI / NSF); 55 CANCRI E: NASA / JPL-CALTECH

SOLAR SYSTEM

Why Isn't Venus Magnetized?

BASED ON DENSITY alone, Venus must have an iron-rich core that's at least partly molten. So why does our like-sized neighbor lack the kind of global magnetic field that Earth has? Theorists long suspected that the planet's slow, 243-day spin was inhibiting the necessary internal churning needed to generate a field. But recent research says that's not the cause.

A new idea has emerged that attacks the problem from a wholly new angle. As Seth Jacobson (now at Northwestern University) and four colleagues detail in the September 15th *Earth and Planetary Science Letters,* Earth and Venus might *both* have ended up without magnetic fields save for one critical difference: The nearly assembled Earth endured a catastrophic collision late in its formation — the one that led to the Moon's creation — and Venus did not.

Jacobson and his team simulated the assembly of rocky planets early in the solar system's history. Over time the hot, molten cores developed several layers of differing compositions. Such an onion-like core would lack the wholesale circulation necessary for a dynamo, so there'd be no magnetic field. This might explain the fate of Venus.

On Earth, meanwhile, the Moon-forming impact affected our planet literally to its core, creating turbulent mixing that disrupted any compositional layering. With the same mix of elements throughout, the core started circulating heat into the mantle. The churning core became the dynamo that created our planet's global, life-sustaining magnetic field.

■ J. KELLY BEATTY

SPACE

Reentry of China's Tiangong 1 Proto-Station

CHINA'S FIRST PROTOTYPE space station will make an uncontrolled reentry into Earth's atmosphere in mid-March, give or take a month, according to a prediction by the Aerospace Corporation on December 8, 2017. It will be the largest object to reenter Earth's atmosphere since January 2012, when Russia's 13-metric-ton Phobos-Grunt mission fell to Earth.

The China National Space Administration (CNSA) launched Tiangong 1 ("heavenly palace" in Chinese) on September 29, 2011. The school bus–size, 8½-metric-ton space station was used to test automated rendezvous and docking techniques, and Chinese astronauts briefly visited the station in 2012 and 2013. Tiangong 1 and the slightly larger Tiangong 2, launched on September 15, 2016, are precursors to the more permanent Tiangong 3, expected to be operational in 2022.

Ground controllers lost contact with Tiangong 1 in late 2016, and in May 2017 China stated in a letter to the United Nations that the station's altitude was decaying at a rate of about 160 meters (0.1 mile) per day. Its orbit is inclined 42.8° to Earth's equator, which means its reentry could occur anywhere between latitudes 43°N and 43°S.

"Even shortly before reentry, only a very large time and geographical window can be estimated," says Holger Krag (ESA). Variable atmospheric drag makes predictions uncertain.

The Inter-Agency Space Debris Coordination Committee, a forum of 13 space agencies (including CNSA) that coordinates activities related to space debris mitigation and management, will be monitoring the reentry to improve prediction accuracy.

■ DAVID DICKINSON

▲ Artist's concept of Tiangong 1 in orbit

TIANGONG 1: CHINA MANNED SPACE ENGINEERING

IN BRIEF

Most Distant Black Hole

Astronomers have discovered a supermassive black hole scarfing down gas just 690 million years after the Big Bang, at a redshift of 7.54. Eduardo Bañados (Carnegie Institution for Science) and colleagues announce the source, called J1342+0928, in *Nature*. While astronomers have netted galaxies back to when the universe was a mere 400 million years old, J1342+0928 contains the earliest supermassive black hole detected, squeaking into first place some 50 million years ahead of the previous record holder. With a mass of about 800 million Suns, it's a little less massive than the supplanted contender (J1120+0641, at 2 billion Suns) and within the ballpark for other supermassive black holes found a few hundred million years later. The discovery of such objects will help determine how they formed so early in the universe's history. Read more at **https://is.gd/J1342quasar**.

■ CAMILLE M. CARLISLE

First Light for Sky-Sweeping Telescope

The Zwicky Transient Facility has taken its first image, capturing a chunk of Orion, including the Orion, Flame, and Horsehead nebulae, in a single shot that covers a 47-square-degree field of view with 24,000 by 24,000 pixels. This image precedes the facility's science phase, set to begin in February and be completed by 2020. The ZTF is installed on the 48-inch Samuel Oschin Telescope and is the sequel to the Palomar Transient Factory (PTF). ZTF scans the sky 12 times faster than PTF, recording 3,750 square degrees per hour at its full speed. It could cover the entire sky in a single, good night, but astronomers plan to repeatedly observe some regions of sky to catch transient celestial objects that vary on a shorter cadence, such as supernovae. As a result, the facility will scan the full sky every three nights. See the first-light image and read more about future plans for ZTF at **https://is.gd/firstlightZTF**.

■ MONICA YOUNG

Alien Visitor

The first interstellar object seen entering the solar system is really quite bizarre.

Artist's impression of 'Oumuamua

IN A SENSE, those of us who study planetary systems expected 'Oumuamua (*S&T:* Feb. 2018, p. 10). Planet formation is messy and involves chucking a lot of material beyond the clutches of the central star. We've long thought a steady-state population of wanderers must exist between the stars, and it was just a matter of time until we became instrumented, skilled, or lucky enough to find them entering our own system.

This one came without warning and dashed through, making it hard to get a good look. That's no coincidence — the great velocity reveals its interstellar origin and destiny. Fortunately, we did get some spectra and a light curve. The spectrum was "normal," the bland, reddish color of an ancient, radiation-darkened surface, familiar from the outer solar system and Kuiper Belt.

The light curve, however, shows extreme variations in brightness. The initial interpretation: a rapidly spinning object with a most irregular shape, one with a ratio of between 10 and 5 to 1 between the longest and shortest axes, greater than or comparable to the most elongated solar system objects. This is bothersome. Why should the first interstellar drifter have such a weird shape?

The light curve doesn't require such a ridiculous configuration if, instead, the object has highly contrasting surface markings. What if one side is extremely bright and reflective, and the other as dark as charcoal? We do know of such objects, such as Saturn's moon Iapetus. Yet these stem from "leading and trailing" hemisphere differences on moons orbiting in a fixed orientation, picking up debris like windshields sweep up bugs, or from migration of icy material away from warmer areas.

Neither scenario works for a rapidly spinning interstellar object. So does 'Oumuamua have a very strange shape or a very strange surface pattern? Occam's razor doesn't help here. Why should it have either?

There's something else idiosyncratic about 'Oumuamua. We expected it to be cometary, because the planetesimals ejected from forming planetary systems should (we think) consist mostly of icy material. It's much rarer and more difficult to eject rocky or metallic shards that form closer to a star and therefore deeper in its gravitational well. But 'Oumuamua is not a comet. When it swung close to the Sun, it exhibited no sign of any gas or dust emission. Also, its atypical shape and brisk rotation imply a strong and rigid object, most likely rocky.

Actually, it's not quite true that there aren't any local objects with such an unusual light curve. However, they're all made by human hands. Could 'Oumuamua be some sort of extraterrestrial artifact?

We want to bat this question away, lest we open the floodgates, but there's no ironclad reason to reject it. Sure, extraordinary claims require extraordinary evidence, and there's no basis on which to believe this is an alien construction. But the claim that this odd body *could conceivably* be an ET artifact is not all that extraordinary.

Comparisons to our own creations don't tell us much. This isn't a terrestrial rocket coated with chipped aluminum paint. But we already knew that. Chances are it's just a chunk of rock or metal that's been wandering the galaxy for way too long. But still, I can't help but wonder. Why is it so peculiar, and what does its unexpected quirkiness imply about the nature of other planetary systems?

Why is it so peculiar, and what does its unexpected quirkiness imply about the nature of other planetary systems?

Fortunately, we won't have to wait too long to learn more. We'll likely never get another good look at 'Oumuamua, but we can expect more such discoveries soon, providing needed context for the curious nature of our first interstellar guest.

■ **DAVID GRINSPOON**, an astrobiologist, is co-author with Alan Stern of *Chasing New Horizons*, to be published in May. Follow him on Twitter **@DrFunkySpoon**.

ESO / M. KORNMESSER

FIELD FLIP AHEAD? by Robert Naeye

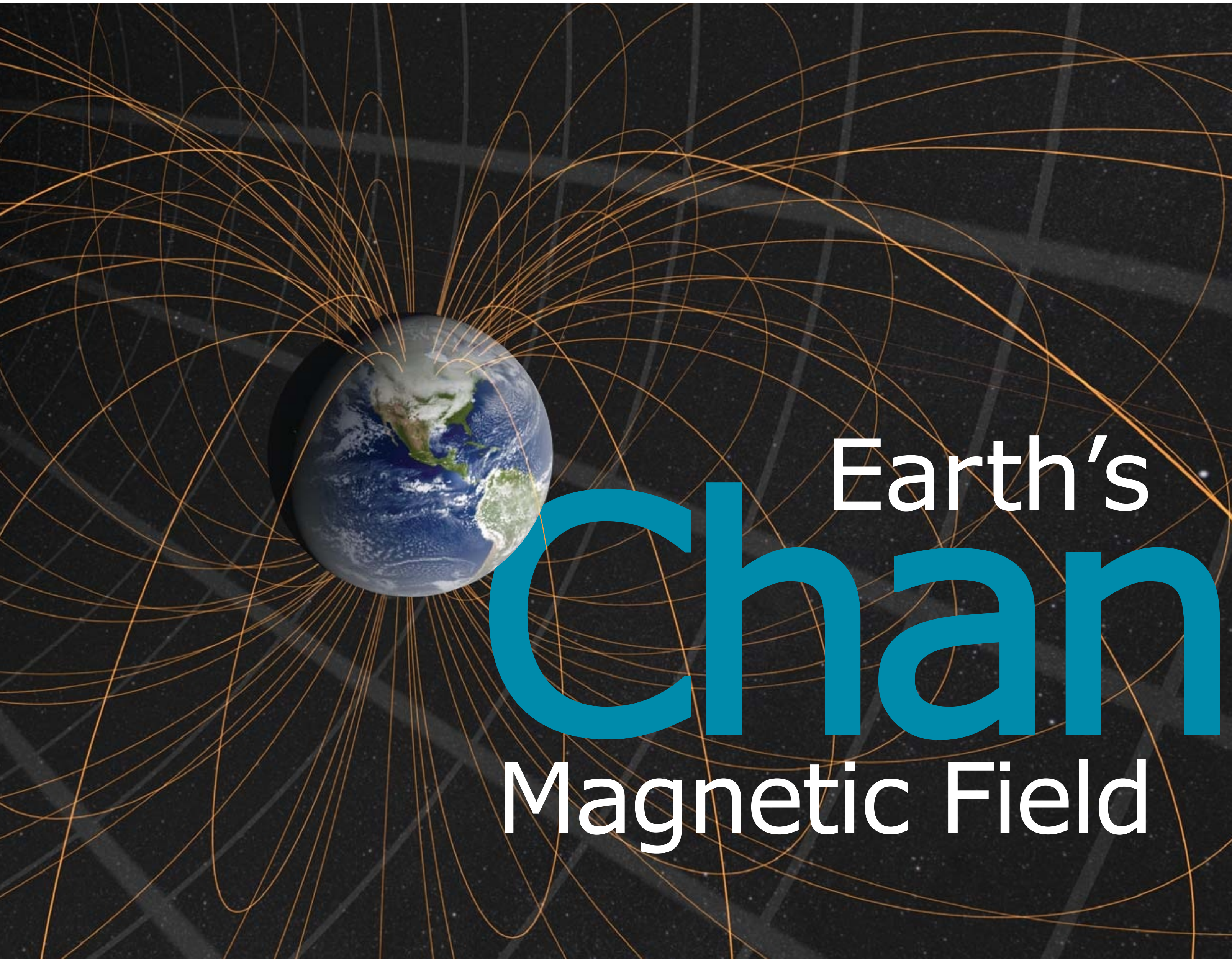
As geologists and mariners have long known, Earth's magnetic field is dynamic and ever-changing. The location of our planet's north and south magnetic poles are both wandering, recently by as much as 40 kilometers (25 miles) per year. The strength of Earth's field varies significantly from one location to another — in the South Atlantic Ocean, for example, the field is only half as strong as the global norm.

Even the familiar north-south polarity is not fixed for all eternity. The paleomagnetic record clearly shows that our planet's field is capable of flip-flopping in such radical fashion that north becomes south and south becomes north.

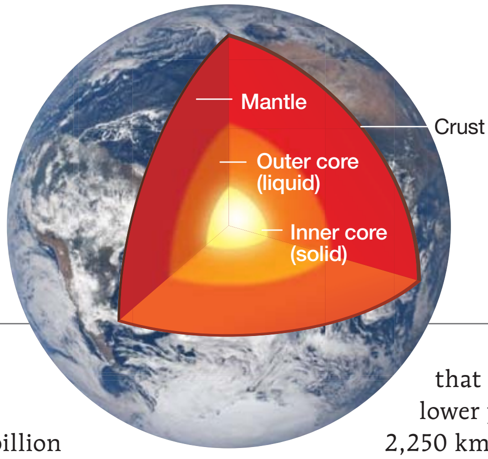
In fact, Earth's magnetic field has weakened overall by about 9% over the past 175 years. This has led to concern that our home planet could be heading for one of these polarity reversals, an event that would have serious repercussions for our technology-dependent global economy.

But this concern might be unfounded. Despite its short-term fluctuations, Earth's magnetic dynamo has maintained its powerful dipolar field for billions of years. This is in stark contrast to our solar system's other terrestrial planets, which raises fascinating questions about whether our planet's strong, long-lived magnetic field was necessary for preserving our atmosphere and sustaining life.

▼ **THREADED EARTH** Thanks to churning convection in its liquid outer core, Earth has a substantial magnetic field that extends more than 50,000 km into space.



Today the inner core has an estimated diameter of 2,440 km (1,520 miles), making it about 70% the size of the Moon.



◀ **IRON HEART** Earth's iron-nickel core takes up about half of its radius and roughly 15% of its volume. Our planet's magnetic field is generated by convective motions in the liquid outer core.

Earth's Dynamo

The origin of Earth's magnetic field can be traced back to our planet's formation 4.54 billion years ago. As countless chunks of interplanetary matter collected into an ever-larger sphere, they delivered abundant iron, whose high density caused it to sink through the infant Earth's molten interior toward the center in a process known as *differentiation*. Iron became the dominant material in the core, intermixed with small amounts of several *siderophile* ("iron-loving") elements such as nickel and sulfur.

Although the core was entirely molten for most of Earth's history, over billions of years it cooled gradually yet steadily by conducting its heat outward through the mantle's base. According to recent research, the inner core started to solidify into an iron-nickel alloy sometime between 1 billion and 600 million years ago. That's when temperatures dropped below the point at which these metals can remain molten under such tremendous pressure — some 3½ million times the atmospheric pressure at sea level.

Today the inner core has an estimated diameter of 2,440 km (1,520 miles), making it about 70% the size of the Moon. Its surface temperature is 5,000 to 5,700 K, close to that of the Sun's photosphere. But at the lower pressures in the outer core, a layer 2,250 km thick, the iron and nickel remain in a molten state.

Our planet's magnetic field arises in this still-liquid outer core via what's called a *dynamo*. Thanks to decades of seismic studies, laboratory experiments, computer simulations, and other techniques, geophysicists have developed a model of how this process operates. A planetary dynamo can arise wherever an electrically conducting fluid undergoes the cyclic motion known as convection. We see convective currents in a pot of boiling water, with hot bubbles rising to the top and cooler water sinking to the bottom.

Likewise, the outer core's liquid iron rises, transfers heat to the lower mantle, becomes denser as it cools, and then sinks in an ongoing convective cycle. Thanks to iron's conductive properties, this churning fluid motion generates strong electrical currents that create our planet's robust magnetic field.

The entire core continues to cool very slowly — just 100°C per billion years — and its solid center continues to enlarge. Eventually, the last of the outer core's liquid iron will solidify, turning off the dynamo. But don't hit the panic button. "It will be billions of years before the inner core freezes the entire core," says Brad Foley (Penn State University). "There's nothing for us to worry about."

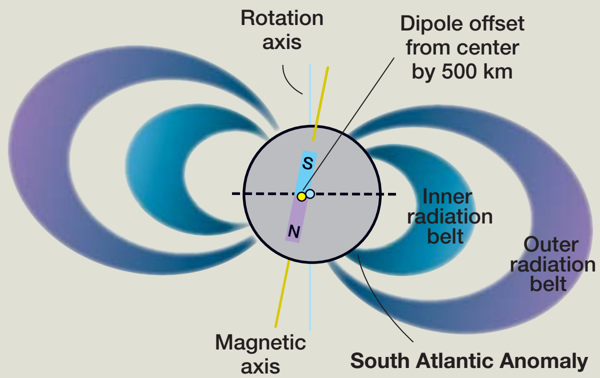
Even though the dynamo arises in the outer core, the mantle plays a passive but vital role in sustaining the magnetic field. As Sabine Stanley (Johns Hopkins University) explains, "The vigor of the convection is related to how much heat can escape from the core through the core-mantle boundary." If the mantle were ever to block the heat flowing from the outer core, the convective motions would grind to a halt and the dynamo would shut down.

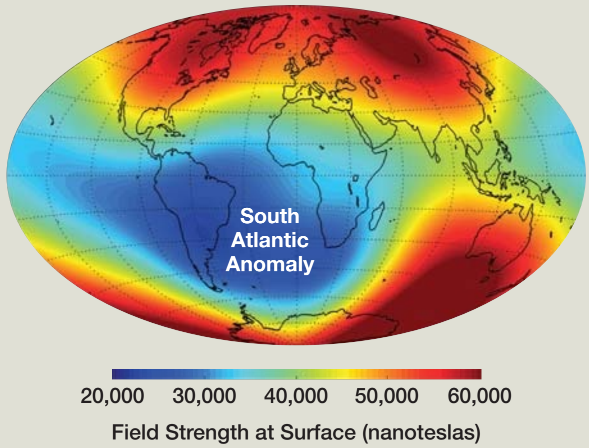
Earth's rotation also plays an important role, though it does not power the dynamo by itself. Instead, our planet's spin organizes the convective motions in the outer core to produce a strong dipolar field closely aligned with the rotation axis. This gives Earth the outward appearance of having a bar magnet at its center, with invisible lines of force emanating outward at the north magnetic pole (which is in the Southern Hemisphere) and coming in at its south pole. Those lines currently extend about nine Earth radii (57,000 km) into space, where they're balanced by the solar wind.

ging

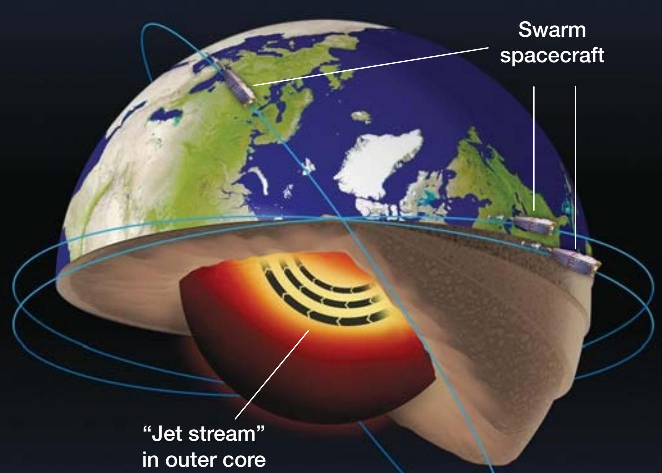
We depend on a global electromagnetic bubble to protect us from hazardous space radiation. Is that stalwart defense wavering?

FACING PAGE: NASA-GODDARD SCIENCE VISUALIZATION STUDIO / JPL / NAIF; IRON HEART: *SKY & TELESCOPE* / LEAH TISCIONE; IMAGE: NASA





▲ **CRUCIAL OFFSET** *Top:* Earth's magnetic field is strongly dipolar, as if an enormous bar magnet lay near its center. But the field is tilted slightly and offset from Earth's center. *Above:* This snapshot of the strength of the magnetic field at Earth's surface in June 2014 reveals an especially weak area between South America and Africa, known as the South Atlantic Anomaly, created by the dipole field's offset from Earth's center.



▲ **FAST CURRENT** ESA's Swarm satellites have discovered a "jet stream" moving westward in Earth's liquid outer core. The molten current appears to be gradually speeding up.

Short-Term Chaos

Magnetic signatures preserved in ancient rocks show that Earth's dynamo has been operating at more or less its current healthy level for almost all of our planet's history. But when geophysicists zoom in with their equivalent of a microscope, they see crazy things happening.

For example, they can now track changes in field strength more precisely than ever before. Measurements taken by the European Space Agency's three orbiting Swarm satellites, combined with earlier data from the CHAMP (Challenging Minisatellite Payload) and Ørsted spacecraft, show that the field strength rose 2% over Asia and fell 3.5% over North America from 1999 to 2016. And that broad intensity dip south of the equator, known as the South Atlantic Anomaly (pictured at left), is moving 20 km westward each year and continues to weaken.

These local variations demonstrate that Earth's magnetic field is far more complicated than a simple dipole. Chaotic, turbulent fluid motions in the outer core drag regions of strong and weak fields around. These movements concentrate magnetic field lines in some areas — at high latitudes, for example — and thin them in other areas, such as the South Atlantic. Swarm researcher Chris Finlay (Technical University of Denmark) points out that these chaotic motions explain why an extended region of weaker field is currently being pulled westward toward the Americas, while regions of stronger field are converging near Asia.

Swarm data enabled scientists to identify a "jet stream" of molten iron in the outer core that is flowing westward at about 40 km per year. This unexpected feature lies mostly under Alaska and Siberia. The stream appears to be moving patches of strong magnetism at high northern latitudes, leading to the local changes seen at the surface. It's uncertain how much the jet stream is connected to the wandering of the north magnetic pole, and whether processes at lower latitudes are also contributing.

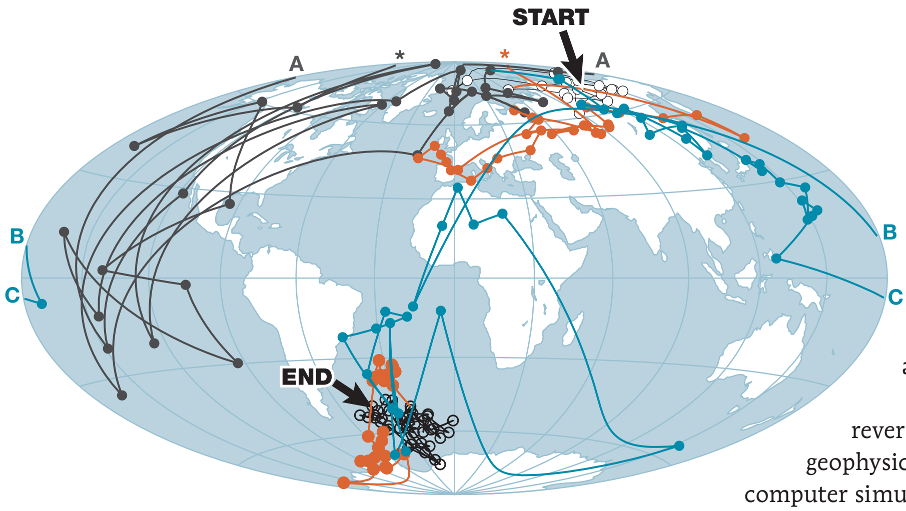
And superposed on top of these small-scale changes is the general weakening trend in the global field over the past 175 years, leading to speculation that we could be heading toward a reversal.

The Ultimate Flip-Flop

Reversals are clearly documented in the paleomagnetic record, particularly in sequences of seafloor rocks created along tectonic spreading centers. These planet-wide records confirm that Earth's magnetic field has been flip-flopping for hundreds of millions of years. But the reversal rate has changed drastically over very long time scales.

For example, there are no recorded reversals from 120 million to 83 million years ago, one of three such "supercrons" dating back 550 million years. Over the past few tens of millions of years, the reversals have occurred about once every 250,000 years on average. But they're inherently unpredictable — the last major reversal was 780,000 years ago — making it natural to wonder if our planet is long overdue for a flip-flop.

CRUCIAL OFFSET (TOP): *SKY & TELESCOPE* / LEAH TISCIONE; (BOTTOM): ESA / DTU SPACE; FAST CURRENT: ESA / AOES MEDIALAB



WANDERING POLE Lakebed sediments reveal that Earth's virtual geomagnetic pole wandered all over the planet during the Gauss-Matuyama field reversal, 2.58 million years ago. The initial and final stages appear in orange, rapid oscillations in dark gray, and the main reversing event — including two wide swings in latitude — in blue.

Scientists have never directly observed a reversal in action, so it's not entirely clear what happens. Still, they generally agree that the field strength doesn't just drop to zero and then ramp back up. Instead, the dipolar field will probably break down into many small-scale localized patches. Bundles of magnetic field lines should intersect the surface in numerous locations, including at mid-latitudes and the equator. As Peter Driscoll (Carnegie Institution for Science) says, "You'd see lots of South Atlantic Anomalies all over the place." After a few thousand years, the dipole field would eventually recover its strength and turn back on with the opposite polarity.

Despite sensationalized media reports that our home planet could be heading for a magnetic reversal "soon," researchers have no such short-term concerns. "The soonest one might begin is probably a couple thousand years from now," says Gary Glatzmaier (University of California, Santa Cruz), "and if it does, then the reversal itself would likely last about 5,000 years. But it's just as likely that one won't occur that soon."

It's possible, however, that we could instead be heading toward a period of significantly reduced field intensity. The last of these "excursions" was the Laschamp event of 41,000 years ago, when the magnetic poles moved substantially but didn't actually switch polarity. "The field strength has fluctuated by 10% many times in the past without resulting in a reversal," Finlay says, "and the presently observed decrease in the dipole strength does not seem to be unusually large."

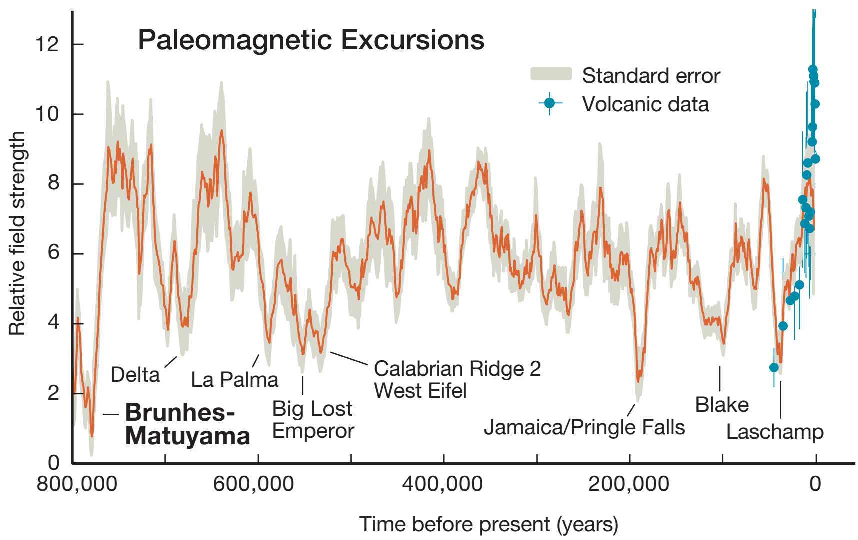
In fact, Earth's magnetic field is so chaotic that whether it's strengthening or weakening depends on your time frame. "If you back out to a 10,000-year time scale, we're near an uptick," says Driscoll.

Although the details of what triggers field reversals remain unknown, Driscoll and other geophysicists have successfully produced them in computer simulations of fluid motions in the outer core. As he explains, "Your model can be a stable dipole fluctuating happily in its initial orientation for a long time, and then it reverses randomly, and then it will be happy in its new orientation for a while."

A geomagnetic reversal would be very bad news, but it would not spell the end of humankind. There is little or no correlation in the fossil record between reversals and major extinctions of life, so apparently the biosphere can withstand these flip-flops without too much disruption.

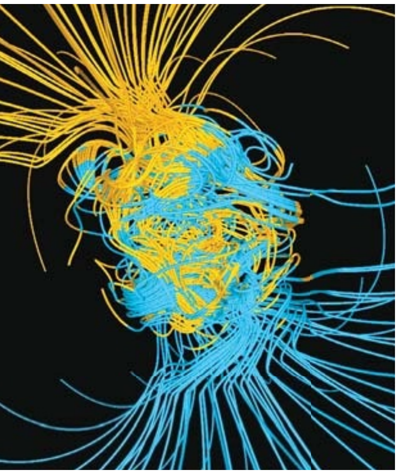
But the negative impact on our society would probably be huge. "People don't realize how much of our technological advances rely on the Earth's magnetic field," says Stanley. "Our magnetic field lines protect all of our electronics from high-energy particles from the Sun."

With that natural shield greatly reduced, satellites would be exposed to intense particle bombardment. Worse, we'd lose the magnetic field's ability to fend off solar outbursts. Even a relatively modest solar flare or coronal mass ejection could pump enough electrical energy into the lower atmosphere to blow transmission lines over wide regions of the planet, leading to long-lasting power outages affecting hundreds of millions of people.

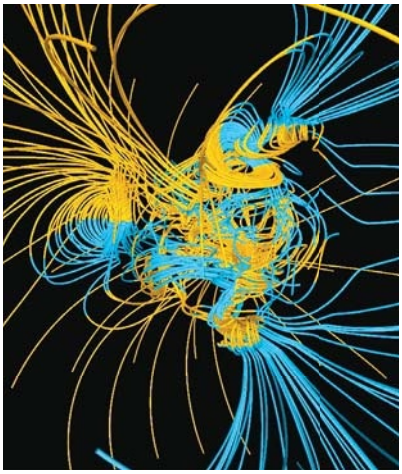


PREHISTORIC REVERSAL Earth's last field flip, the Brunhes-Matuyama reversal, occurred 780,000 years ago. Since then, the field strength has varied wildly. Gray denotes measurement uncertainty; dots at far right show recent data from volcanic flows.

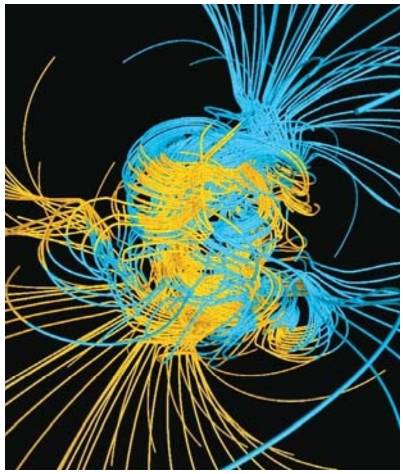
WANDERING POLE: SOURCE: J. GLEN / R. COE / J. LIDDICOAT / *JOURNAL OF GEOPHYSICAL RESEARCH*; PREHISTORIC REVERSAL: YOHAN GUYODO & JEAN-PIERRE VALET / *NATURE*



500 years before midpoint



Midpoint



500 years after midpoint

CHAOTIC REVERSAL These three snapshots show the contorted state of the dipolar magnetic field in Earth's liquid outer core during three stages in a computer-simulated field reversal. Yellow denotes outward-directed (with north polarity) field lines; blue denotes inward-directed (south) lines.

Our Planetary Neighbors

Although our field is considerably weaker than those of the gas giants, Earth stands alone as the solar system's only terrestrial planet that can currently muster a strong global magnetic field.

Mercury has a very weak dipolar field with an average surface strength only about 1% that of Earth's. Venus has no measurable global field at all. The Moon and Mars lack a global field, but their rocks have locked in patches of ancient crustal magnetism. The most pronounced fields on Mars appear in a series of magnetic stripes of alternating polarity in the southern hemisphere. The rocks in these linear features preserve a record of a dipolar field that experienced reversals before it shut down eons ago.

Geophysicists wonder why Mercury's magnetic field is not stronger, and why Venus can't whip up a magnetic field at all. Mercury has a huge iron-rich core that's at least partially molten, and Venus has almost the same size, mass, and bulk density as Earth. In one or both cases, the lower mantle might be acting as an impenetrable lid — inhibiting heat from escaping from the core, stifling vigorous convection and thus preventing a dynamo from revving up.

Plate tectonics might be the critical factor that explains why Earth has a magnetic field and these other worlds do not. In a process known as *subduction,* which occurs where crustal plates collide, slabs of cold oceanic crust sink all the way down to the core-mantle boundary, making it easy for heat to escape the core through the lower mantle. This cooling mechanism drives the churning convective motions in the outer core that stirs up Earth's dynamo.

Another recent idea suggests that Venus lacks a global field because its core has distinct compositional layers, like an onion, that prevent the kind of wholesale convection that's taking place inside Earth (see page 13).

The lack of present-day magnetism within the Moon and Mars is less mysterious. Both worlds once had fields, perhaps substantial ones, but they're both so small that their interiors would have cooled off rather quickly. Once the liquid in their cores froze, any dynamo action would have ceased.

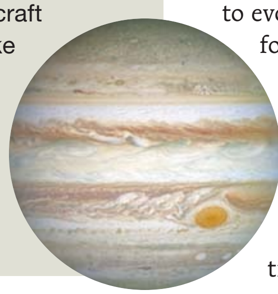
Magnetic Fields and Life

So, geophysically speaking, Earth and its inhabitants really lucked out. Our planet's magnetic influence extends deep into space, providing an invisible force field that at least partially shields our atmosphere from the ravages of the solar wind and cosmic radiation.

By shielding a planet's atmosphere, a strong global magnetic field can also play a critical role in keeping liquid water stable on the surface for the billions of years needed for primitive life to evolve into more complex forms. It's easy to draw the conclusion that having a respectable magnetic field for billions of years was essential to preserving Earth's atmosphere and nurturing the evolution of complex life.

The Giant Planets

Earth's magnetic field pales in comparison to those of Jupiter and Saturn. In particular, Jupiter's mighty dynamo generates a magnetic field that's roughly 20,000 times more powerful than ours. Its magnetosphere extends deep into space, with the oomph to deflect the solar wind 3 million km before it reaches the planet. Jupiter's magnetic tail extends all the way to the orbit of Saturn. NASA's Juno spacecraft recently found that Jupiter's field, like Earth's, changes significantly from one location to another (*S&T:* Dec. 2017, p. 14). This local variability suggests that the dynamo region is closer to the planet's cloudtops than previously thought.



CHAOTIC REVERSAL: GARY GLATZMAIER & PAUL ROBERTS; JUPITER: NASA / ESA / A. SIMON; FACING PAGE: NASA-GODDARD SPACE SCIENTIFIC VISUALIZATION STUDIO

Anyone making this argument can point to Mars. The Red Planet has lacked a global magnetic field for most of its history, with dire consequences for the Martian atmosphere (*S&T:* Sept. 2014, p. 20). NASA's MAVEN orbiter has documented how the solar wind slowly erodes gas at high altitudes, especially lighter atomic species such as hydrogen. Over the eons, the solar wind has likely stripped away almost all of the atmosphere that Mars once had.

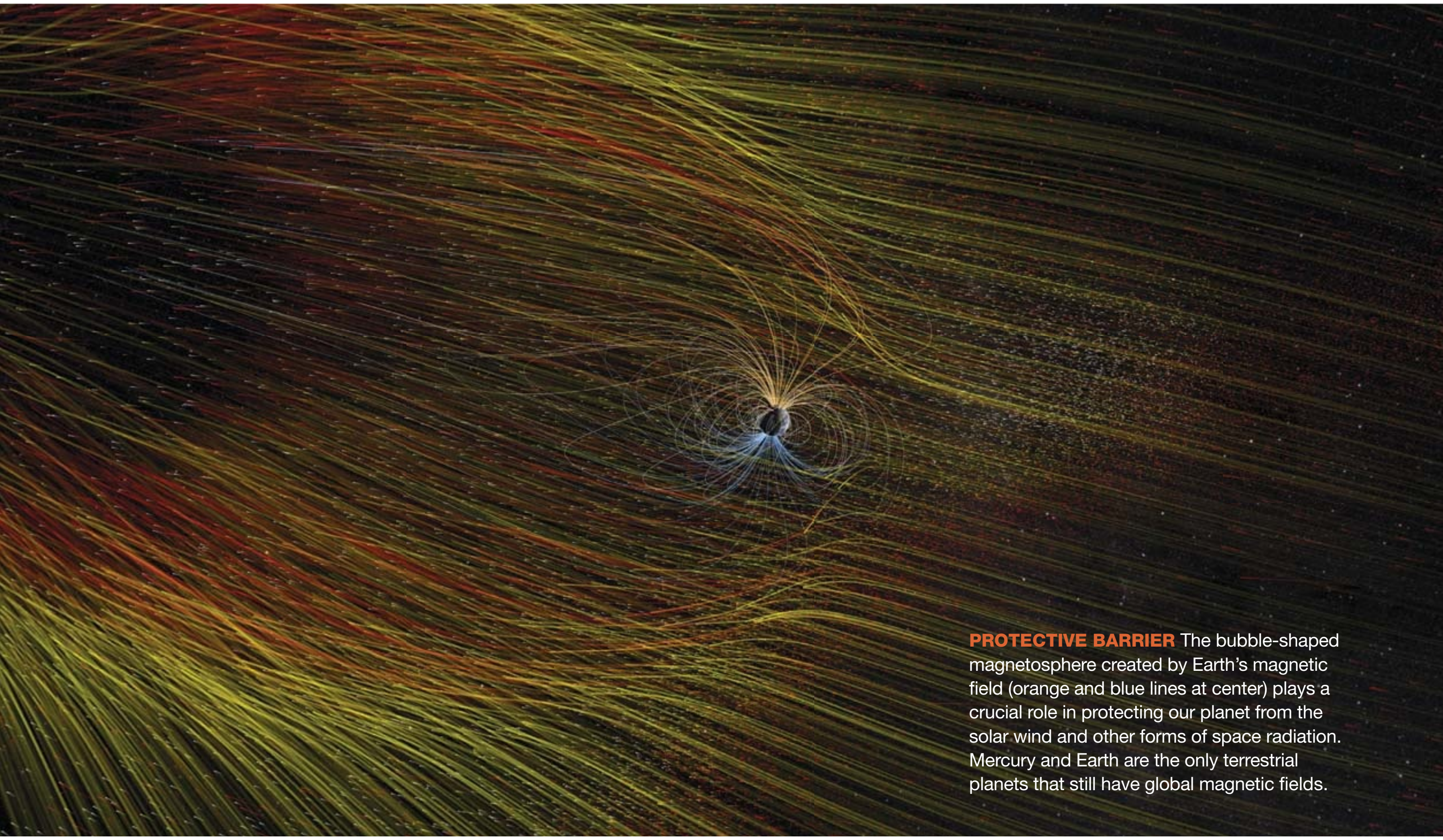
The spacecraft has also measured changing atmospheric escape rates over the southern hemisphere's magnetic stripes. As MAVEN project scientist Gina DiBraccio (NASA Goddard Space Flight Center) notes, "We're finding that these crustal magnetic fields can both prevent and facilitate atmospheric escape at Mars," she says. The crustal field "bubbles" prevent the local atmosphere from being stripped away. But often the solar wind's magnetic field connects with these localized Martian fields, providing a conduit for atmospheric particles to escape (see **https://is.gd/Mars_magnetism**).

Like Mars and Earth, Venus probably once had abundant water and, therefore, lots of atmospheric hydrogen, created when solar ultraviolet light *dissociated* (broke apart) water molecules. But because Venus lacked a global field, the solar wind could penetrate the planet's upper atmosphere and eventually stripped away the loose hydrogen atoms. With the hydrogen gone, any chance of reconstituting the planet's original cache of water was lost.

Some scientists have explored whether a strong magnetic field might do more harm than good. Earth's magnetosphere keeps the solar wind from slamming directly into our atmosphere, which sounds beneficial. But as Driscoll points out, there are competing effects: "The stronger the magnetic field, the larger the magnetosphere. This makes the magnetosphere a larger target to the solar wind, and that could actually be funneling more solar wind energy into the magnetosphere, which causes additional atmospheric escape."

Because strong dipolar fields can play both helpful and potentially harmful roles, the importance of a magnetic field for retaining an atmosphere — and for the rise of complex life — remains an open question. Ultimately, we know of one terrestrial-size planet with a rich abundance of life forms, and that planet has maintained a strong dipolar field for billions of years. As Stanley says, "Perhaps it's just a coincidence that life is on a planet with a magnetic field, but it's likely that the field is an important part."

■ **ROBERT NAEYE,** a former Editor in Chief of *Sky & Telescope,* lives next door to Hershey, Pennsylvania — also known as "Chocolatetown USA."



PROTECTIVE BARRIER The bubble-shaped magnetosphere created by Earth's magnetic field (orange and blue lines at center) plays a crucial role in protecting our planet from the solar wind and other forms of space radiation. Mercury and Earth are the only terrestrial planets that still have global magnetic fields.

THE EXOPLANETS NEXT DOOR by Sara Seager

NASA's next planet mission will survey roughly 200,000 nearby stars for signs of alien worlds.

Looking up at a dark night sky we can see thousands of stars. Every star is a sun, and if our Sun has planets, then it makes sense that the other stars would have planets, too. And they do. Astronomers now know of thousands of exoplanets, and they suspect that nearly every star has a planetary system, meaning our Milky Way Galaxy is teeming with alien worlds.

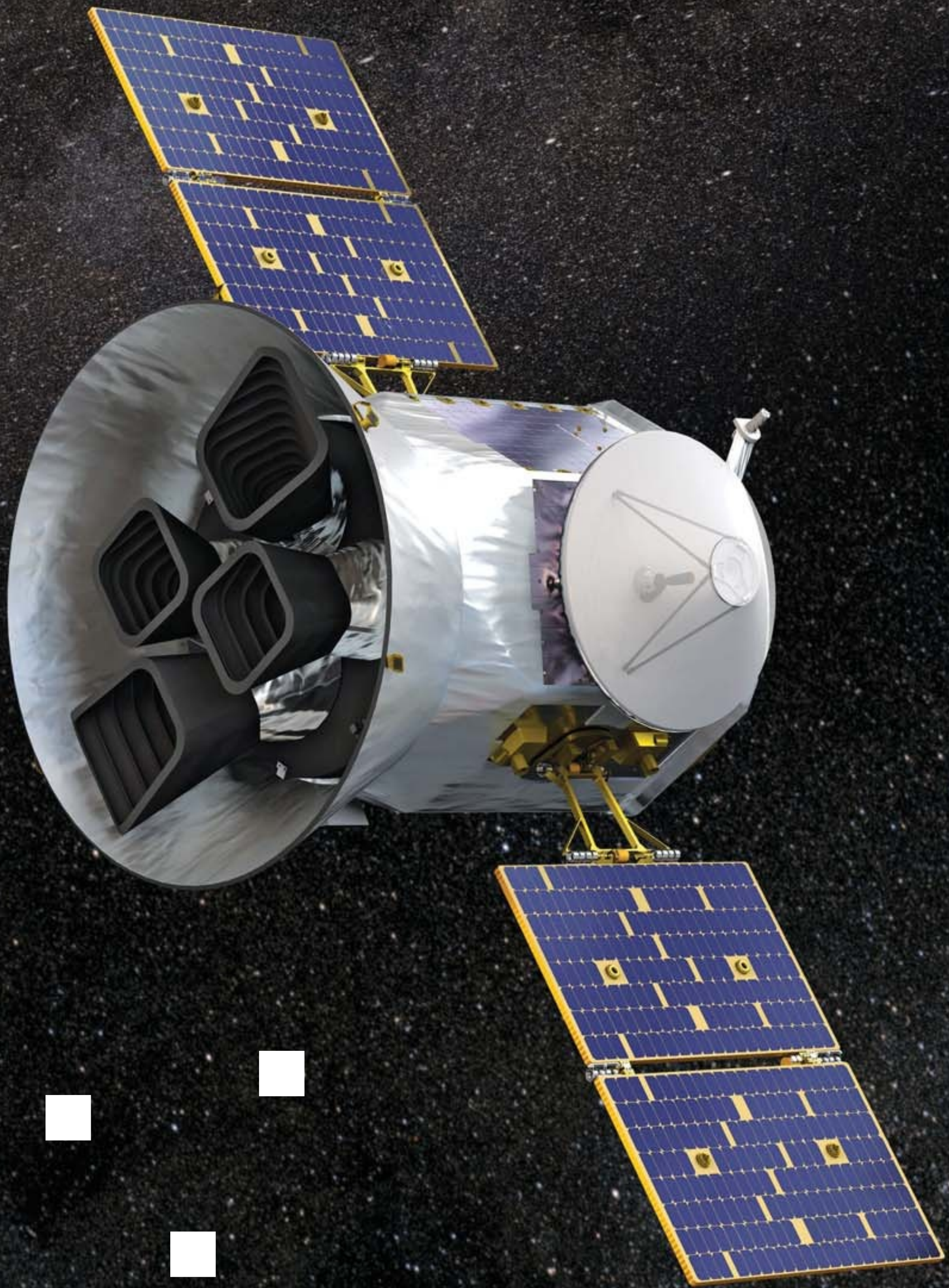
Thanks largely to the pioneering Kepler space telescope, we also now know that small, rocky exoplanets are common and that planetary systems are astonishing in their diversity.

But many of our exoplanet searches have targeted specific areas of sky. The natural next step is to do a space-based all-sky survey. A specific plan for just such a survey mission was envisioned a decade ago by my MIT colleagues George Ricker and Roland Vanderspek, in collaboration with David Latham at the Smithsonian Astrophysical Observatory. The realization of this mission is the soon-to-be-launched NASA Transiting Exoplanet Survey Satellite (TESS), which George leads as principal investigator (PI) and Roland as deputy PI.

The motivation behind TESS is to find planets transiting stars relatively near Earth. Nearby stars generally look brighter to us than distant ones, and with all that additional light reaching us, it will be easier for us to detect the tiny

TESS

The Transiting Exoplanet Hunter



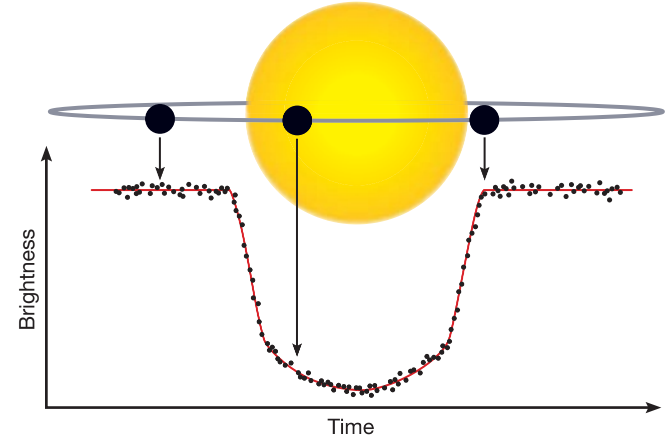
TESS AND EARTH

TESS's closest approach to Earth, or its perigee, will be 17 Earth radii (about 108,000 km). That's three times higher than the geosynchronous orbit many communications satellites occupy. It's farthest approach, or apogee, is about 59 Earth radii or 376,000 km — just shy of the Moon's average distance of 60 Earth radii.

NASA GODDARD SPACE FLIGHT CENTER

blip as a small planet passes in front of the star and blocks some of its light. Bright stars will also make detailed follow-up observations possible. Specifically, astronomers want to be able to measure exoplanets' masses and to observe the atmospheres of small, rocky planets — planetary properties impossible to determine for the vast majority of the distant (and therefore faint) stars observed during Kepler's original mission. The TESS stars of prime interest, on the other hand, will be only hundreds of light-years away and therefore typically a few hundred times brighter than Kepler's stars.

TESS's main *raison d'être*, or Level 1 Science Requirements in formal NASA-speak, is to deliver to the community 50 planets with sizes less than 4 Earth radii and with measured masses. Fifty might not sound like an impressive number, but these 50 exoplanets will be *the list* of most promising transiting planets for further study, a list of planets that with follow-up observations will ultimately tell us a lot about the small-exoplanet population.



▲ **TRANSIT METHOD** When a planet passes in front of its star from our perspective, it blocks a small fraction of the star's light, which instruments such as TESS see as a dip in starlight. The graph of brightness changes with time is called a *light curve*.

Scanning the Sky

Transits are hands down the current best way to find small exoplanets. The reason is that all of the starlight can be used together. For other techniques, that is not always the case. The *radial velocity method*, for example, measures the wiggle in the star's position along our line of sight, but to do that we must divide the light up into tiny bins of constituent colors (spectra). Inevitably, we lose some light when we do that. We also use only a fraction of the starlight in the *direct imaging technique*, because the coronagraph device that blocks the starlight to reveal the planet only works for small wavelength chunks.

But when a planet passes in front of a star, its bulk blocks all of the wavelengths. Thus with transits, there's more bang for our buck.

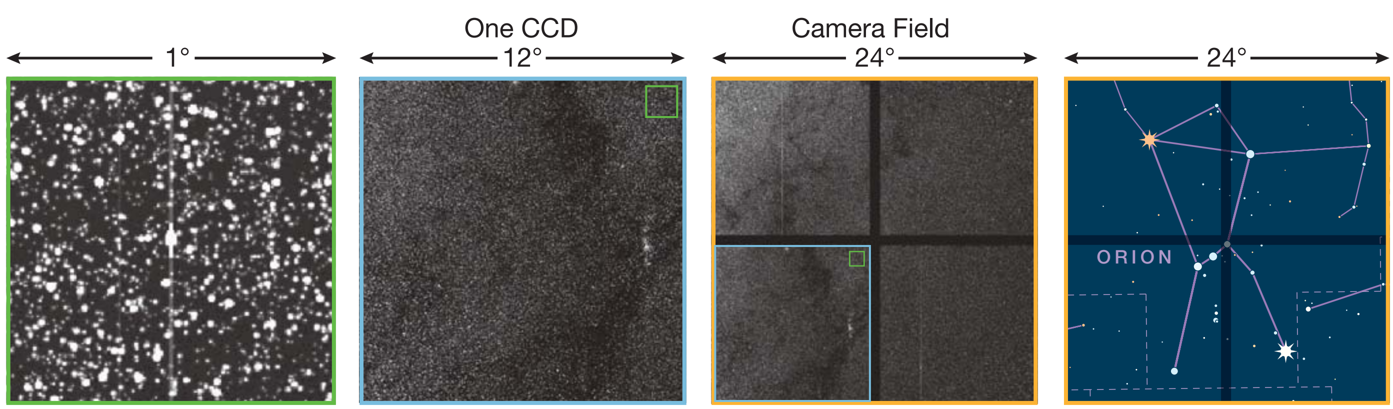
Because nearby stars are bright, TESS's aperture can be small. The search for transiting planets orbiting bright stars, therefore, does not rely on huge telescopes such as the 10-meter mirrors of the renowned Keck telescopes or even a 2.4-m mirror like Hubble's. The TESS cameras have an effective aperture of only 10 cm (4 inches).

But transits are rare, and so, like other transit surveys before it, TESS must monitor a large number of stars. The TESS cameras therefore each have custom f/1.4 lenses to provide a wide field of view that's 24°×24° — equivalent to the area covered by about 50 full Moons, or roughly the area of the constellation Orion. To get even more observing real estate, TESS carries four of these cameras, all identical, arranged in such a way as to cover a giant strip on the sky (24°×96°). This setup of four small "telescopes" instead of one large one makes TESS unique among space telescopes.

Each camera has a seven-element lens, plus a package of detectors and electronics to enable transit detections. Lens hoods shield the cameras from stray light from the Moon and Earth, and a large sunshade encloses the plate that all four cameras are attached to, all to improve TESS's chances of finding other planetary systems.

Premier equipment isn't enough, though. To carry out a two-year, all-sky survey of exoplanets, TESS also needs the

▼ **TESS'S VIEW** This sequence of simulated images illustrates the space telescope's field of view. Each camera contains four CCDs. A single CCD covers a square of sky 12° wide, which is approximately the same size field as the Kepler space telescope observes. In all, each TESS camera images a square 24° wide. This field of view would encompass the main stars of the constellation Orion (right).



TRANSIT METHOD: LEAH TISCIONE / *S&T*, SOURCE: NASA;
TESS'S VIEW: GREGG DINDERMAN / *S&T*, SIMULATED DATA: ZACHORY BERTA-THOMPSON

TESS's main raison d'être, or Level 1 Science Requirements in formal NASA-speak, is to deliver to the community **50 planets** with sizes less than 4 Earth radii and with measured masses.

ideal orbit. This is not a trivial problem. The Hubble Space Telescope's orbit, just 550 km (340 miles) above Earth, is relatively easy to get to but is bad for survey astronomy. Earth is bright and hot, and its radiation can easily reflect into a telescope or onto a spacecraft, contaminating images. Furthermore, Hubble's orbit has a day-night cycle like we do on the ground, and not only does the changing sunlight level require careful shielding to avoid thermal variations in instruments (which can mess with things like focus), it's also bad for the continuous observations needed to discover transits.

Another common choice, the Earth-Sun gravitational balance site called the second Lagrangian point, is less than ideal, too. At 1.5 million km from Earth's nightside, the location would challenge our ability to download in a cost-effective way the reams of survey data that TESS will amass. Presenting a similar problem is an Earth-trailing solar orbit like that of Kepler or the Spitzer Space Telescope, which are both slowly drifting away from our planet with time.

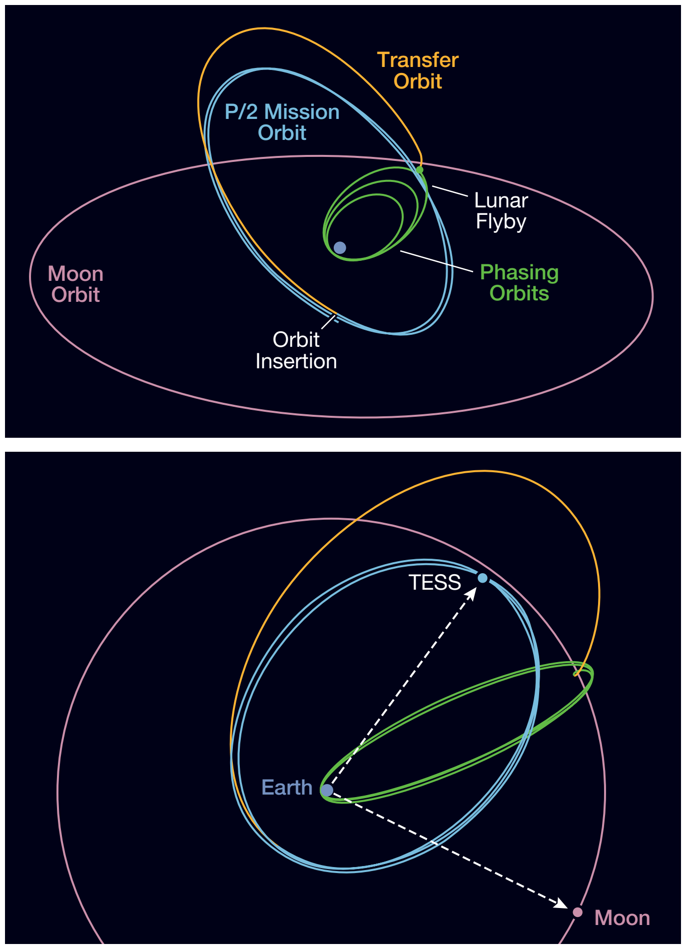
After extensive investigations, the MIT, Aerospace Corporation, and Orbital ATK collaborators on the TESS team devised a never-before-used orbit that fits the bill. The orbit avoids the frequent dips into Earth's shadow that Hubble experiences, and it's not as communications-constrained as L2 or a drift-away solar circuit. Known as P/2, TESS's path will be a highly elongated, 13.7-day Earth orbit in resonance with the Moon that will carry it nearly as far away from our planet as our natural satellite is. The lunar resonance means that, when at its farthest point, the spacecraft will always be roughly 90° ahead of or behind the Moon in its orbit — although there's quite a bit of wiggle room in this separation. TESS will spend most of its time far from Earth, then speed up as it approaches Earth and downlink data while zipping by.

Planet Pipeline

TESS's launch window opens in late March 2018. It will shoot skyward from Cape Canaveral aboard a SpaceX Falcon 9 rocket. Once it's safely in space, the team will work nonstop during a two-month commissioning phase to make sure TESS is working as planned. Then the real excitement will begin.

To complete its survey, TESS will slice the celestial sphere from pole to equator in long, thin strips of sky that match the 24°x96° dimensions of its four-camera view. Each hemisphere is split into 13 of these segments, with overlap at the poles. The spacecraft will stare at a single strip for 27 days, then move on to the next one. In its first year, TESS will tile the southern hemisphere; in the second year, the northern hemisphere. Over a two-year nominal mission, it will observe nearly all of the sky: Only small gaps around the ecliptic will remain untouched.

Once the data come down extensive computer codes, built upon those used to analyze the Kepler and its later K2 mission observations, will tackle the data using systems located both at NASA Ames and at MIT. Next is the fun part of the job. Assisted by software, human vetters will pore over the data to identify which signals most likely come from planets transiting their host stars, versus those that come from binaries, stellar "junk" from variability, or instrumental noise. Looking through the thousands of light curves that trigger software, out of the tens of thousands of light curves per observing sector, is like a page-turning mystery novel: One never knows what might be uncovered on the next page. Vetters search for clues in the light curve that indicate the signal

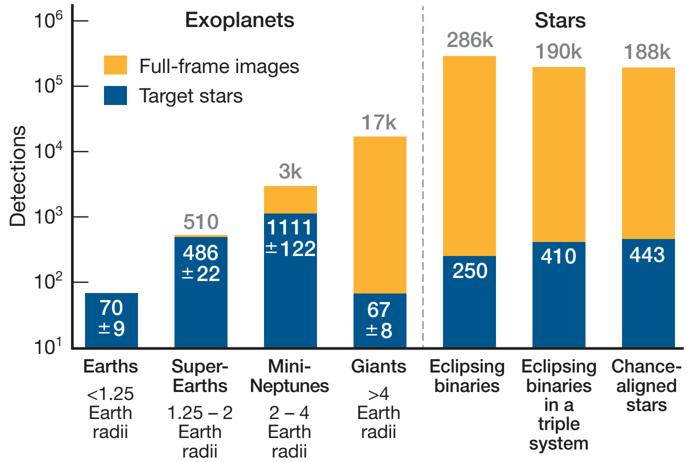


▲ **RING AROUND THE EARTH** The TESS spacecraft will follow a unique orbit, looping out of the Moon's orbital plane *(top)* so as to keep both Earth and its natural satellite out of TESS's field of view as much as possible. The orbit also occupies a 2:1 resonance with the Moon, keeping the spacecraft roughly 90° from the Moon *(above)*.

LEAH TISCIONE / S&T, IN-PLANE SOURCE: NASA, OUT-OF-PLANE SOURCE: G. RICKER ET AL. / *JOURNAL OF ASTRONOMICAL TELESCOPES, INSTRUMENTS, AND SYSTEMS* 2014 could be from a transiting planet, then put those candidates at the top of the TESS Object of Interest list, which is sent out simultaneously to the TESS team and to the wider astronomical community. Making all of the data public (with no proprietary period) is one of the unique features of TESS's mission: We aim to encourage the entire community to participate in planet finding and follow-up science.

Each TESS exoplanet candidate won't necessarily be a true planet. The international TESS follow-up team will scrutinize candidates using many ground-based observations to rule out imposters. Then they'll funnel the bona fide worlds to astronomers working with the most precise radial-velocity and photometric instruments on ground-based telescopes so that they can measure the planets' masses. Beyond the 50 small exoplanets TESS has promised to deliver, the team anticipates finding thousands of planet candidates of all sizes and around a variety of star types.

Once the transit signals are confirmed as planets and have measured masses, members of the TESS Science Team and other exoplanet astronomers around the globe will pick the choicest transiting planets for follow-up observations, in order to try to detect their atmospheric makeup. Although we aim to investigate any planets of interest, we're especially keen to find small, rocky planets in the habitable zones of red dwarf stars. These stars are abundant in the galaxy, and knowing the composition of their exoplanets' atmospheres might give us a good picture of conditions around the most common stars across the Milky Way. I would imagine that over the next decade, dozens of small exoplanets and hundreds of larger planets will have their atmospheres studied.

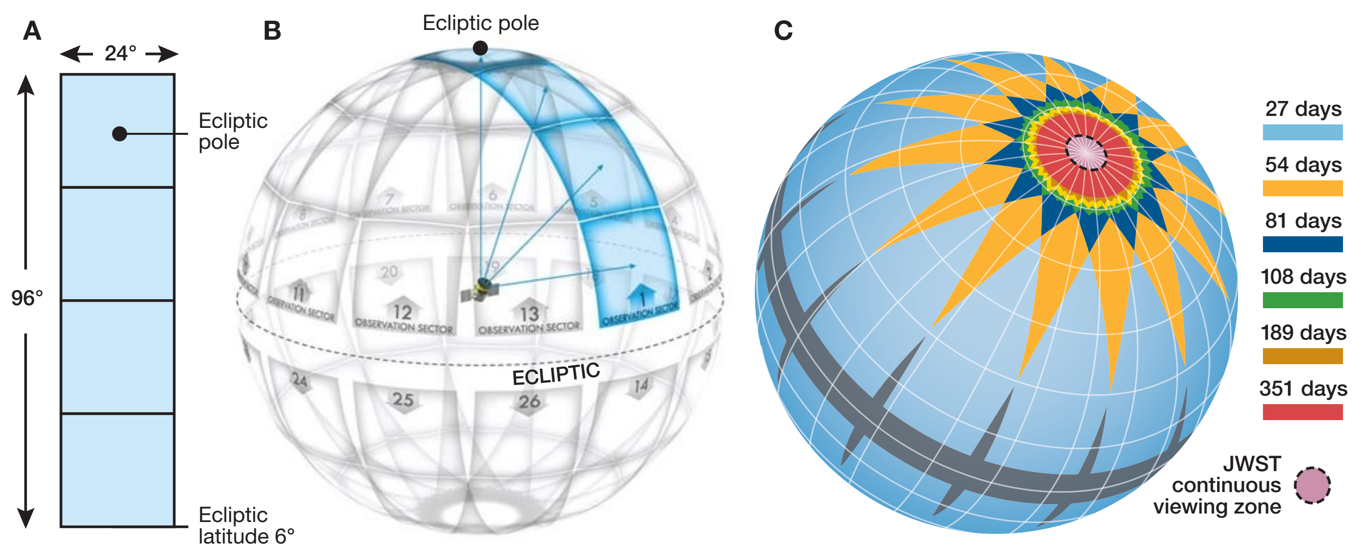


▶ **WHAT TESS MAY FIND** Team members expect TESS to detect roughly 70 Earth-size planets around nearby stars and about seven times as many super-Earths. Full-frame images will only enable the discovery of deeper transits (and, thus, larger objects) because the stars they include are fainter than those in the high-time-resolution "postage stamp" segments.

A Database for Discovery

TESS's 27-day observing strategy will make it sensitive to planets with orbital periods up to about 13 days long, corresponding to the habitable zone of some small red dwarf stars. However, the overlap at the ecliptic poles adds up to more than 300 days, enabling us to discover worlds with much longer orbits or habitable-zone planets around more massive, Sun-like stars, especially if we stack the data.

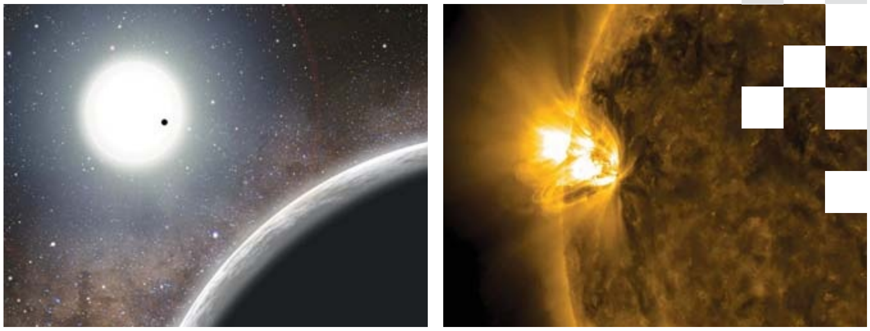
The most exciting possibility, of course, is the discovery of a transiting rocky exoplanet orbiting in an *M* dwarf star's habitable zone, one whose atmosphere follow-up observations



▲ **OBSERVING SECTORS** The combined field of view of TESS's four cameras spans a long, 24°×96° strip of sky (A). Every 27 days, the spacecraft will observe a different strip of sky (B), slicing it into 26 sectors (13 per hemisphere). These sectors overlap near the ecliptic pole (C). The dashed black circle around the pole shows the region that the upcoming James Webb Space Telescope can observe uninterrupted.

WHAT TESS MAY FIND: LEAH TISCIONE / S&T, SOURCE: TESS TEAM; OBSERVING SECTORS: LEAH TISCIONE / S&T, SECTORS SOURCE: C. BEALS / MIT, COVERAGE MAP SOURCE: D. DEMING / TESS TEAM reveal has water vapor and oxygen. But there are several other questions TESS data could help us answer.

One of the most perplexing questions concerning exoplanets today, for example, is the composition of the so-called mini-Neptunes, exoplanets two to three times the size of Earth. When combined with the slightly smaller super-Earths, mini-Neptunes appear to be the most common planet in our galaxy, yet we have no counterpart in the solar system (*S&T:* Mar. 2017, p. 22). We think these planets are too large and too fluffy to be predominantly made of rock, but they can't be Jupiter-like giants, either. Since we don't know what they're made of, there is no consensus on how they might form.



▲ **DATA-DRIVEN ANSWERS** TESS's observations may help astronomers determine the compositions of mini-Neptunes (artist's concept of Kepler-19b at left) and how planets fare around stars that release frequent, powerful flares.

The hope is that TESS will uncover dozens of mini-Neptunes around a variety of nearby host stars. We will then be able to combine the exoplanet radii measured from transit observations with masses from follow-up radial-velocity studies to discover these worlds' average densities. Together with atmospheric measurements, the densities might reveal patterns that help us understand mini-Neptunes as an ensemble. This data-fusion approach may yield satisfying results on a variety of other topics, too.

Flares are another forefront topic in exoplanets (*S&T:* Nov. 2015, p. 22), because many *M* dwarf stars are active and flare frequently. Trappist-1, for example, flared some 40 times in an 80-day observational period; Proxima Centauri has even more frequent outbursts. We'll be able to search the entire TESS data set for stars that show evidence of both planets and flares at optical wavelengths. This, together with the atmospheric compositions of these planets and other stellar-activity indicators, may help shed light on whether active stars completely erode rocky exoplanets' atmospheres or not.

▲ **DETAIL WORK** Visible in this lab shot are TESS's four cameras (top), which appear to sit like eggs inside the nest of the sunshield.

MINI-NEPTUNE: DAVID A. AGUILAR / CFA; FLARE: SOLAR DYNAMICS OBSERVATORY / NASA; DETAIL WORK: ORBITAL ATK

Transits Are the Future

TESS is by nature a "catalog machine": Its main goal is to create a big list of transiting exoplanets orbiting bright, nearby stars. That might sound boring, but it's not. By creating this catalog, TESS will help open the door to a breathtaking new era in exoplanet science. Exoplanet science's first era, that of 1995–2009, saw the discovery and initial characterization of individual objects; in the next decade (2010–2018), Kepler ushered in the era of big data and exoplanet statistics. TESS will enable us to merge the two, fostering the study of individual exoplanets' characteristics on a big-data scale.

Space-based exoplanet transit surveys are so popular an endeavor, in fact, that astronomers have several more in the pipeline on a range of scales. On the small end there's the MIT and Jet Propulsion Laboratory's CubeSat ASTERIA, which is a prototype for a fleet of CubeSats that would search for exoplanet transits around the very nearest, very brightest Sun-like stars. It launched in August 2017 and began working in November 2017. On the large end, there's the joint Swiss and European Space Agency CHEOPS mission (launch 2018), which will focus on one star with a transiting exoplanet at a time, and ESA's PLATO (launch 2026), a compound telescope with 26 cameras affixed to one platform that aims to find longer-period planets transiting nearby, Sun-like stars.

Despite the huge amount of activity, transits are the first part of a longer journey. Only planets fortuitously aligned will show up as transits, but this alignment not only limits us to systems tilted just right with respect to our perspective, it also favors planets close to their stars (because geometrically they're more likely to cover the stellar disk). Thus the technique leaves out worlds in larger or non-transiting orbits. These systems will hopefully be caught up by projects such as NASA's WFIRST microlensing survey (launch mid-2020s) and both ground- and space-based direct imaging campaigns. But transit surveys like TESS are a supreme stepping stone on our way to understanding our galaxy's planets.

■ **SARA SEAGER** is the TESS mission's deputy science director and a professor at MIT, which is one of eight partners on the project. Learn more about the mission at tess.mit.edu.

STARBURST GALAXIES by Richard Jakiel

When galaxies interact, stars form in SPECTACULAR fashion.

Currently, one of the hottest areas of research in galactic astronomy is the study of *starburst galaxies*. These objects have star-formation rates that are hundreds, or even thousands, of times greater than in normal galaxies. The star "burst" may occur across the entire galaxy, or it may be concentrated in a smaller region several hundred light-years across, often near the core of the galaxy. The starburst phase is typically a short-lived galactic event lasting only a few hundred million years and is often the result of tidal interaction or a collision with, or even cannibalism of, another galaxy.

Embedded deep within these regions of intense star formation are *super star clusters* (SSCs) comprised of brilliant, young blue stars and thought to be the precursors of globular clusters. Many of the galaxies presented in this survey contain these spectacular star clusters, which may be accessible to observers with large telescopes under very dark skies.

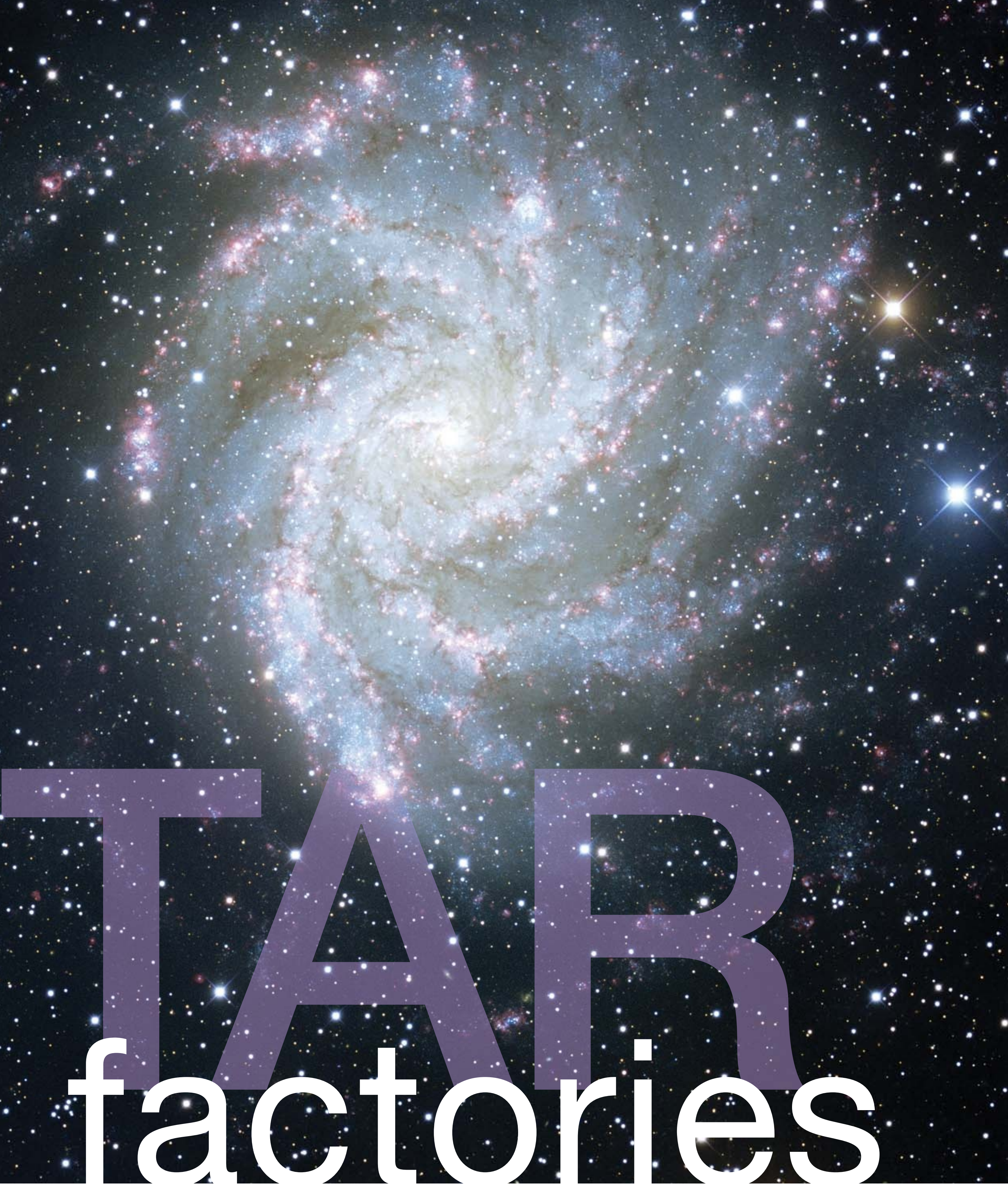
In many starburst galaxies, shock waves from large numbers of supernovae have produced *supergalactic winds*, vast plumes and bubble-like structures of dust and gas. Perhaps the most famous example of supergalactic winds can be seen in hydrogen-alpha (Hα) images of M82.

Typical Starburst Galaxies: M82 and Friends

Numerous excellent examples of starburst galaxies are observable with the typical amateur setup. Perhaps the best place to start is **M82**, the "Cigar Galaxy," the archetype of all starburst galaxies. M82 and its immense neighbor, M81, were discovered by German astronomer J. E. Bode in 1774. The pair is located some 12 million light-years away. Originally classified as an irregular galaxy, M82 images taken in 2005 in the near infrared revealed two symmetric spiral arms aligned edge-on to our line of sight. Though considerably smaller than our own Milky Way, M82 produces new stars at a furious rate. Most of this activity is concentrated in the core region, where the Hubble Space Telescope (HST) identified nearly 200 SSCs. While the entire galaxy puts out five times the light of our Milky Way, the amazingly dynamic core region is 100 times as luminous.

▶ **FIREWORKS IN THE SKY** Lying some 22 million light-years away on the border between Cygnus and Cepheus, NGC 6946 is well known for having produced at least 10 supernovae that we know of. See if you can disentangle the H II regions and star-forming knots with your telescope.

T. A. RECTOR / UNIVERSITY OF ALASKA ANCHORAGE / H. SCHWEIKER / WIYN / NOAO / AURA / NSF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factories

There appear to have been two main episodes of star formation in M82. The first episode, yielding most of the older stars in the disk, started around 450 million years ago and lasted for some 350 million years. This would have been triggered by tidal forces due to a close interaction with its massive neighbor, M81. More recent starburst activity dating back to less than 10 million years is concentrated in the nuclear region of the galaxy and is associated with the SSCs observed by the HST.

Located about 10° northwest of Alpha (α) Ursae Majoris (Dubhe) and about 2° east of 24 Ursae Majoris, the Cigar Galaxy is a stunning sight in even the smallest aperture. In a modest refractor, M82 is a mottled, silvery streak with unusually high surface brightness for a galaxy. As a result, it can be observed under moderately light-polluted urban skies and under much higher magnifications than the typical galaxy. Larger telescopes reveal numerous dark, dusty rifts and bright knots scattered along the disk that become much more intricate around the galaxy's core region. Using a 24-inch f/5 at 339×, I could clearly see several of the SSC complex regions, including a few possible SSCs as very faint "stars" embedded in the bright nebulosity. However, the southern and northern superwind plumes, normally so prominent as a bipolar outflow in Hα images, weren't visible other than as slight diffuse glows above and below the equatorial plane of the galaxy.

Photographically, this is an exciting target yielding beautiful images, especially in cameras equipped with Hα filters, or those with good red sensitivity for capturing the superwind plumes that were produced during periods of elevated supernova activity. You can also try narrowband filters to capture details missed by more conventional imaging.

▼ **WHERE STARS COME ALIVE** This close-up of the core region of NGC 1569 in Camelopardalis shows the roiling star-forming regions. Challenge yourself and see if you can detect the two SSCs separated by 6″ masquerading as a 15th-magnitude "double star." Use a large telescope with high power and point it toward the core of this galaxy.

▲ **TIDAL FORCES** Around 450 million years ago, M82 and its massive companion, M81, swept by each other. The tidal forces from the close passage triggered star formation and outflows in M82. Even though these galaxies are morphologically different, they are gravitationally locked in a cosmic dance. Look for this odd couple in Ursa Major.

Not nearly as striking but still a very interesting galaxy in a larger telescope is **NGC 1569** in Camelopardalis. A member of the IC 342/Maffei Group of galaxies, NGC 1569 is classified as a Magellanic irregular galaxy due to its distorted shape. At 11 million light-years, this galaxy lies somewhat closer to us than M82 and, like most members of this group, is heavily obscured (or reddened) by the Milky Way. An outburst began around 100 million years ago, and following a final surge some 5 to 10 million years ago, the starburst phase has now finished, but star formation is still ongoing. Visually, this is a small, fairly high surface brightness galaxy located a little less than 3° southwest of Alpha (α) Camelopardalis. Moderate aperture should reveal the asymmetric disk mottled with dark rifts and bright knots. Use high power and a large scope to spot the two largest SSCs visible as a tiny 15th-magnitude "double star" separated by 6″ near the galactic core.

Certainly not all starburst galaxies are irregular in appearance, a case in point being **NGC 3310** in Ursa Major. It's a compact grand design spiral that cannibalized a small dwarf galaxy around 100 million years ago. This devouring resulted in a circumnuclear ring of intense star formation. Deep images of the galaxy reveal extensive shells of dust and hydrogen gas. As with many other representatives of this class, NGC 3310 has high surface brightness and takes magnification well. It shares the field with a bright 5.5-magnitude star and appears as a fairly small, round glow with a condensed core region.

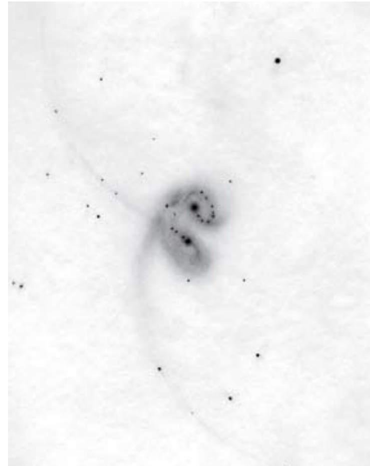
NGC 4038/NGC 4039 in Corvus, also known as the Antennae Galaxies or the Ringtail Galaxy, is a striking example of a pair of merging disk galaxies undergoing a massive outburst of star formation. The galaxies were two separate entities more than a billion years ago but eventually began a

STARS COME ALIVE: NASA / ESA / A. ALOISI / HUBBLE HERITAGE TEAM (STSCI / AURA); TIDAL FORCES: MASIL IMAGING TEAM

▲ **SUPERWINDS IN M82** Contributing Editor Howard Banich sketched M82 based on what he saw through his 28-inch telescope. Clearly seen are the galaxy's complex structure and the superwinds, the outflows emanating from the galaxy's central regions.

tidal dance leading to the formation of extensive plumes as they started to merge. These huge tidal arcs, the "antennae," span at least 360,000 light-years, and the current starburst phase has produced over 1,000 SSCs. In several hundred million years, their merging will result in a single, much larger galaxy. Both systems are spirals: NGC 4038 is a heavily distorted barred spiral, while NGC 4039 is a slightly smaller object. With moderate aperture, the Antennae Galaxies appear as a diffuse double kidney or C-like nebulous glow that is fused at the apex. Bright knots and H II regions can be seen in both galaxies, but resolving the brightest SSCs requires very large instruments under superb skies. At the 2006 Texas Star Party, I saw numerous tiny 17th-magnitude "stars" (SSCs) resolved in Larry Mitchell's 36-inch f/5 scope. Two diffuse arcs were also visible, the delicate "antennae," or plumes of tidally strewn dust and stars of the ongoing merger event.

Most starburst events in galaxies can be traced to tidal interactions with a nearby galaxy, but sometimes the latter can be hard to find. The Magellanic irregular galaxy **NGC 4449** in Canes Venatici is undergoing a galaxy-wide starburst event, but what is causing the enhanced star formation isn't obvious. It wasn't until 2012 that a pair of dwarf spheroidal galaxies were



▲ **THE ANTENNAE GALAXIES** NGC 4038 and NGC 4039 are in the process of merging. Using his 28-inch, Jimi Lowrey's 48-inch, and the Bok 90-inch telescope on Kitt Peak, Howard Banich reproduced the tidal arcs responsible for this source's moniker, as well as the bright knots of furious star formation that occurred as a result of the merger.

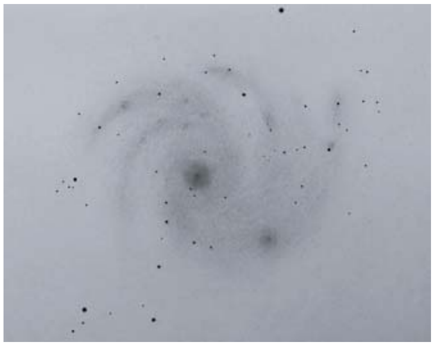
A Cosmic Menagerie

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.
M82	Starburst	12.5	8.4	11.2′ × 4.3′	09^h 55.9^m	69° 41′
NGC 1569	Starburst	12.9	11.0	3.6′ × 1.8′	04^h 30.8^m	64° 51′
NGC 3310	Starburst	12.8	10.8	3.1′ × 2.4′	10^h 38.8^m	53° 30′
NGC 4038	Starburst	12.0	10.3	3.4′ × 1.7′	12^h 01.9^m	–18° 52′
NGC 4039	Starburst	12.2	10.3	3.2′ × 2.1′	12^h 01.9^m	–18° 53′
NGC 4449	Starburst	13.0	9.6	6.2′ × 4.4′	12^h 28.2^m	44° 06′
M94	Starburst	13.7	8.2	14.4′ × 12.1′	12^h 50.9^m	41° 07′
NGC 6946	Starburst	13.8	8.8	11.5′ × 9.8′	20^h 34.9^m	60° 09′
NGC 253	Starburst	12.8	7.2	21.0′ × 5.0′	00^h 47.6^m	–25° 17′
IC 10	Starburst	14.0	10.4	6.3′ × 5.1′	00^h 20.3^m	59° 18′
NGC 2537	BCD	12.6	11.7	1.7′ × 1.5′	08^h 13.2^m	45° 59′
Hen 2-10	W-R	12.3	11.6	1.7′ × 1.3′	08^h 36.2^m	–26° 25′
NGC 5010	LIRG	13.2	13.3	1.4′ × 0.7′	13^h 12.4^m	–15° 48′
NGC 6240	ULIRG	13.7	12.9	2.1′ × 1.1′	16^h 53.0^m	02° 24′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. NGC 4038 and NGC 4039, also known as the Antennae Galaxies, are merging.

HOWARD BANICH (2)

discovered in NGC 4449's halo. SSCs and numerous H II regions are scattered along the length of the disk. At 10th magnitude and measuring 6′ × 4′, NGC 4449 is an easy object to observe and image with relatively small telescopes. A good 8- to 10-inch scope will reveal several bright condensations along the central axis, while larger instruments will make the galaxy "come alive" with numerous knots and dark rifts. Several SSCs are also in the range of 16-inch or larger scopes, including a 15th-magnitude cluster in the core of the galaxy.



▲ **SUPER STAR CLUSTERS** Howard Banich captured some of the stellar clusters in NGC 6946, the Fireworks Galaxy, in his sketch.

From NGC 4449, scan some 5° to the southeast to **M94**, a beautiful face-on galaxy. Few realize it's also a special type of starburst galaxy: Instead of the starburst being either galaxy-wide or concentrated in the core, most of the star-forming activity is located in a ring about 70″ in diameter. Some sources refer to this structure as a *starburst ring*. As the inner region of M94 is quite bright, don't hesitate using high power to examine this structure more closely.

Other bright starburst galaxies of amateur interest are **NGC 6946** in Cygnus and **NGC 253** in Sculptor. The face-on spiral NGC 6946 is also known as the "Fireworks Galaxy," as it's been home to no fewer than 10 supernovae, the latest occurring in May 2017 (SN 2017 eaw) and discovered by amateur astronomer Patrick Wiggins. Just for that reason alone, this galaxy is worth constant monitoring. Overall, NGC 6946 has fairly low surface brightness, but the delicate spiral arms and H II regions are readily visible with larger scopes. In contrast, NGC 253, the "Silver Dollar Galaxy," is a large dusty spiral inclined 60° to our line of sight. It collided with a dwarf system around 200 million years ago, leading to the extensive starburst activity in the core region. The HST identified several large SSCs, the largest having a mass of 1.4 million solar masses and an absolute magnitude of –15, which is much brighter than that of a typical globular cluster. These objects, however, are heavily obscured by the dust in the nuclear region and are best seen at infrared wavelengths. Nevertheless, it's a fascinating area to explore with a larger scope at higher magnifications.

Wrapping up this part of the survey is the tiny dwarf irregular **IC 10** in Cassiopeia. IC 10 has the distinction of being the closest known starburst galaxy at slightly more than 2 million light-years, and the only member of the Local Group currently undergoing starburst activity. Located 1.5° due east

▲ **THE SILVER DOLLAR GALAXY** A collision with a dwarf galaxy some 200 million years ago triggered starburst activity in the core of NGC 253. Several large SSCs lurk in this galaxy, but they're rather heavily obscured and best seen in the infrared. Nevertheless, this 7th-magnitude target is an interesting one to explore, as both Richard Jakiel and Howard Banich did. The image on the left was taken by Richard using a 127-mm f/7 APO refractor, while the sketch on the right shows what Howard saw through his 28-inch telescope.

of Beta (β) Cassiopeiae, it's visible as a soft 10th-magnitude glow. Moderately large-sized imaging setups will not only resolve the H II regions but will also allow for imaging of the brightest stars in the galaxy.

Cosmic Menagerie: BCDs, LIRGs & ULIRGs

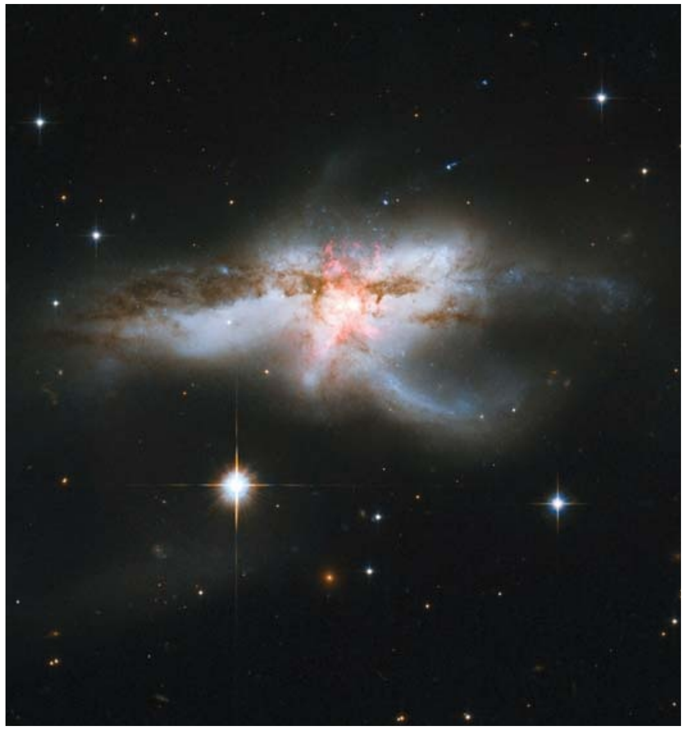
So far, the galaxies in this survey have been rather typical starburst galaxies. But there are far more exotic examples in the cosmos . . . if you know where to look! Let's start with the blue compact dwarf (BCD) class: These are typically small irregular or lenticular galaxies that contain large clusters of young, massive stars, often responsible for shifting the galaxies' appearance toward a bluish color. Somewhat similar are the *Wolf-Rayet galaxies*, which instead have unusually large populations of Wolf-Rayet stars. These rare superluminous blue stars are burning through a short-lived evolutionary phase characterized by a distinct spectral signature that's often useful in determining the rate of star formation.

The BCD best known to amateurs is **NGC 2537**, the "Bear Paw" galaxy in Lynx. This is a small, unusual-looking galaxy with numerous bright knots and H II regions that give rise to the "bear paw" nickname. Though it does share its field of view with a super-thin edge-on galaxy (IC 2233), the two aren't physically interacting, so the origin of the star-forming activity isn't exactly clear. Like many of these galaxies, the "Bear Paw" has an *Arp Atlas of Peculiar Galaxies* designation, Arp 6, due to its unusual shape. Visually, this object lives up to its name, as it actually does look like an animal paw in the eyepiece. My notes using a 17.5-inch telescope describe it as a "round glow, about 1.5′ across with an outer horseshoe-shaped ring of knots and a faint knotty inner bar."

As galaxies go, **Hen 2-10** (ESO 495-21) has a curious history. Located deep in the dense star fields of Pyxis, even at 12th magnitude it was missed by many observers. In the 1960s, Karl Henize finally cataloged it as a planetary nebula due to its strong emission lines. The nature of this source was readdressed in the 1970s, and today it's classified as a Wolf-Rayet galaxy. Though situated in a dense Milky Way star field, it's not too hard to find: You can start by locating Gamma (γ) Pyxidis and star-hopping to Eta (η) Pyxidis. From there it's a short 24′ hop to the southwest. You'll see a small, roundish, 12th-magnitude glow around 1.5′ across that hardly dims with a nebula filter — try it out!

Most of the galaxies in this survey have been small- to medium-sized systems, in direct contrast to the last two classes we will visit here: luminous infrared galaxies (LIRGs) and ultra-luminous infrared galaxies (ULIRGs). Both are extreme examples of starburst galaxies, with the former being some one hundred billion times and the latter one trillion times brighter than our Sun in the infrared. One of the closest LIRGs is the lenticular galaxy **NGC 5010** in Virgo. It's in the process of evolving from a spiral into an elliptical, with most of its luminosity derived from old, red stars. Located around 25′ north of 53 Virginis, it's a small, 13th-magnitude, spindle-shaped glow with a dusty/mottled core.

Much more extreme is **NGC 6240** in Ophiuchus, a massive ULIRG. Here, the process of galactic cannibalism is well underway, as two large galaxies merge into one immense system. Huge tidal tails, dusty gas plumes, and vast star-forming regions are evident in images of this system. Its unusual shape earned it the nickname "Rumpled Starfish," though to me it resembles a lobster. Indeed, when viewed with a 20-inch scope at 175×, some of the diffuse plume structure visible is suggestive of the appendages of some description of cosmic crustacean or starfish. I'll let readers be the judge of this.



▲ **A STARBURST GALAXY FAR, FAR AWAY** If you want to witness galactic cannibalism firsthand, look in the direction of Ophiuchus toward NGC 6240, a ULIRG around 350 million light-years away. Not only are two galaxies merging in this system, triggering starburst activity, but their central supermassive black holes are also spiraling toward each other. The black holes are a mere 3,000 light-years apart and will soon (on cosmic timescales) coalesce into one gargantuan black hole.

SUPERWINDS: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) / A. EVANS (UNIV. OF VIRGINIA, CHARLOTTESVILLE / NRAO / STONY BROOK UNIVERSITY)

■ **RICHARD JAKIEL**, a dedicated deep-sky observer, has contributed to *Sky & Telescope* since 1999.

FURTHER READING: To learn more about interacting galaxies, specifically the Antennae and NGC 6946, see Steve Gottlieb's articles "Galaxies in Collision" (*S&T:* May 2017, p. 28) and "Unraveling NGC 6946" (*S&T:* July 2013, p. 60). See Howard Banich's article "Two Cool Galaxies" (*S&T:* May 2016, p. 18) to read more about his sketches of M82.

What Makes a Great Astrophoto?

Recognizing what goes into an outstanding image can help to improve your own work.

BEST OF THE BEST The most memorable astrophotos are much like the best of other types of photography. They contain wonderful color, contrast, and elegant composition, like this famous Hubble Space Telescope image of M16, popularly known as the "Pillars of Creation."

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

We've all marveled at the amazing celestial images produced by both amateurs and professionals. From dazzling pictures of the Milky Way arching over an equally majestic landscape, to glittering portraits of spiral galaxies exploding with starbirth, we all know a great image when we see one.

So what actually makes for a supurb astrophoto? This question is surprisingly difficult, if not impossible, to answer. One reason is that our personal tastes are often as unique as individual snowflakes — beauty is in the eye of the beholder. What one person finds attractive might not make the grade in someone else's eyes. Another reason is that often it is a combination of things that takes an image to a higher level. Still another consideration is the subject — what makes for an outstanding nightscape image will be completely different than, say, what makes an outstanding planetary picture. So let's look closely at elements found in images most can agree are top-notch and incorporate those into our own photographs.

Focus

One of the first things we notice in any astrophoto is whether it's in focus. To be fair, it can be quite tricky to nail down focus in most astrophotographs. With the exception of images recorded from space-based observatories and planetary exploration missions, every astro-image you see is shot through Earth's usually churning atmosphere, bad "seeing" that often results in fuzzy, blurry photos. And while some detail can be rescued using sharpening filters or complex astronomical deconvolution filters, nothing can completely make up for a poorly focused image.

Fortunately, we can mitigate the effects of seeing in our images in several ways. Monitoring the weather and seeing conditions is easy using websites such as the Clear Sky Chart (**cleardarksky.com**) or smartphone apps including *Scope Nights* that give detailed predictions to let you know when the air is steady or not.

You can still take sharp astro-images in poor seeing if you switch your pixel scale to better match the conditions you're shooting in. For instance, if the seeing produces bloated stars measuring about 3 or 4 arcseconds across, you can switch to a short-focal-length instrument with your camera that produces an image scale of around 4 arcseconds per pixel. Also, if you're using an astronomical CCD or CMOS camera, you can bin the pixels, which groups four adjacent pixels together to function as a single pixel, reducing the resolution of your camera and masking the ill effects of poor seeing. If the seeing is really bad, you can simply switch to low-resolution, wide-field imaging, targeting entire constellations, or even photographing nightscapes. The trick is to match your equipment to the conditions you're shooting under.

▲ **NOT BLACK** Establishing good contrast in a deep-sky photo doesn't simply mean making the sky black and the stars white. Setting the background sky to black would have lost all of the beautiful dust in this exquisite image of NGC 7497.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

Tracking

One aspect unique to astrophotography, compared to other types of photography, is tracking. Because our planet rotates, objects in the sky outside of the atmosphere are perpetually moving with respect to your camera and telescope. This requires a way to cancel out that movement using a motor-driven mount aligned to Earth's rotational axis. Good tracking is most important in telescopic close-ups of galaxies, nebulae, and star-clusters — faint targets that require long exposures to reveal them properly. Perfect tracking also ensures you're able resolve the smallest details possible for your equipment. Otherwise, small-scale features become smeared, mimicking poor focus.

Few mounts track perfectly — most have small, repetitive errors known as *periodic error* that require corrections during an exposure. You can deal with this by attaching an additional camera (called an autoguider) to a guide scope or off-axis guider that monitors a single star during the main exposure, and automatically makes small corrections to ensure a perfectly guided image.

Fortunately, perfect tracking isn't necessary for every astrophoto. Because the Sun, Moon, and planets are relatively nearby and bright, they can be adequately recorded in exposures of a fraction of a second and thus only require enough guiding to keep the target on your camera's detector.

One type of astrophotography that doesn't require tracking at all in most cases is nightscape photography. Shooting the night sky over a picturesque landscape with a simple camera-on-tripod setup and wide-angle lens produces such low resolution that you can get away with exposures of, say, 10 seconds without any noticeable trailing.

There's a simple formula known as the "500 rule" that calculates how long an exposure can be with a particular lens: $500 / fl = T$, where fl is the focal length of your lens, and T is how long you can expose before stars noticeably trail. This works especially well with today's low-noise DSLR and mirrorless cameras operating at high ISO settings, permitting you to capture subjects like the Milky Way over a picturesque landscape, meteor showers, and auroras. In fact, some trailing in a nightscape image doesn't detract from the overall scene, so you can shoot up to 30 seconds with fisheye and other extremely wide-angle lenses.

Color, Contrast, and Saturation

Unless you're shooting the Moon or concentrating on a specific monochromatic wavelength of light such as hydrogen-alpha, pleasing color is an extremely important aspect in the best astrophotos. Note that I say *pleasing* rather than *accurate* — color perception is somewhat subjective, and most people experience color slightly differently. False-color narrowband imaging has become quite popular as well.

That said, a natural-color image of the night sky taken from a dark site should generally have a neutral sky background. The reddish-brown cast recorded in nightscape photos should be corrected (*S&T:* Jan. 2018, p. 36), with the exception of reddish or greenish natural airglow. Likewise, a high-resolution image of a spiral galaxy should still allow your eye to determine where the galaxy ends and the sky background begins. Determining this boundary in a sprawling nebulous field can be tricky but still manageable.

Even tri-color narrowband images of deep-sky objects, which rely on various false-color palettes or combinations, still require a pleasing color balance in order to present the

SOLAR ANGLE Composing interesting images of the Sun, Moon, and planets can be challenging, since all are simply round objects surrounded by a blank sky. But special events can offer unique opportunities. When photographing last August's total solar eclipse, the author planned everything long in advance, though in the excitement of the moment, camera orientation was left to chance. Fortunately, the error produced a better result than originally planned.

▼ **RICH COLOR** When increasing the saturation in your pictures, take care to monitor each color channel and avoid over-saturating the result, which presents problems when printing your results. This detailed image of the Horsehead Nebula, Barnard 33, displays richly saturated color without going overboard. Here north is to the left.

ECLIPSE: SEAN WALKER / *S&T*; HORSEHEAD: KEN CRAWFORD

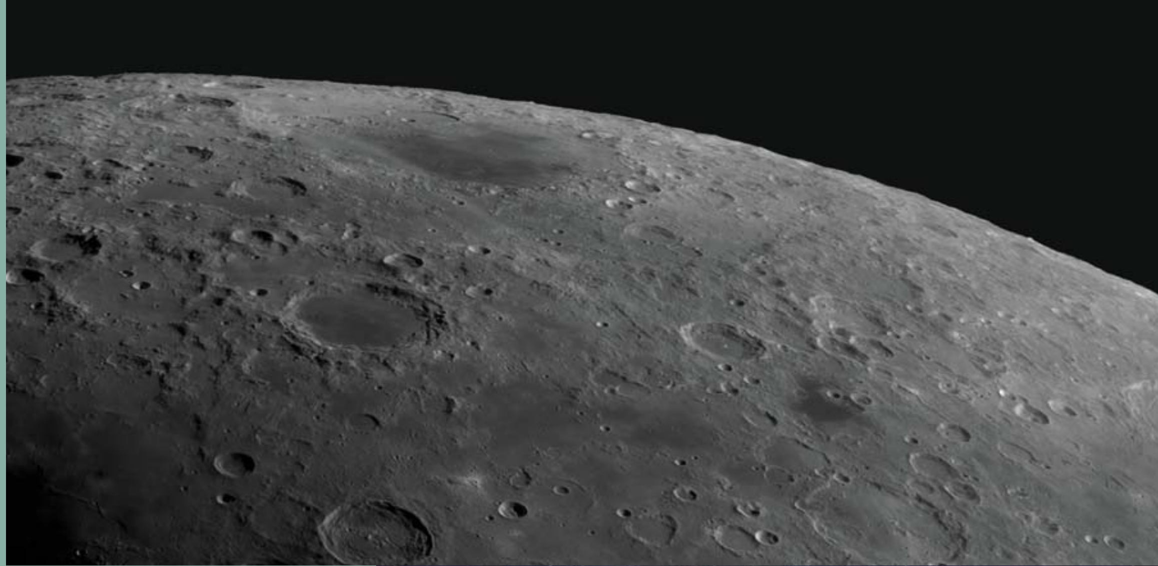
varied hues that occur when ionized elements interact. If we were to be truly accurate, most tri-color narrowband images would be dominated by the color that hydrogen-alpha is assigned to in an image (often green), because it is the most pervasive element in the universe, compared to sulfur II or oxygen III. But to best display the colorful interactions of these elements, imagers equalize the exposures in an image.

Planetary photography also benefits from a pleasing color balance. For instance, while Mars is a tawny-orange color (though not saturated), blue and white are often seen in its thin clouds near the planets limb, and its occasional dust storms have a distinctive yellow hue. A related aspect of color is *contrast*. Astrophotos are tricky to establish proper contrast in, because most targets are seen against a dark sky. You'd think that simply making the background black would be the easiest step, but actually that's not the case. For one thing, there is no truly "black" sky as seen from Earth's surface. There are very few places where some artificial light pollution isn't visible somewhere in the sky. But our planet's atmosphere itself emits a small amount of light called *airglow*. This is commonly seen in nightscape photos taken from dark sites, though airglow can sometimes be very noticeable even from rural locations. I've recorded skyglow in backyard nightscape images taken just a few miles from downtown Manchester, New Hampshire, the state's largest city.

Given these caveats, deep-sky and nightscape imagers should strive to establish a dark, neutral background sky, but it shouldn't be completely black, so that faint nebulosity or the outer extent of spiral galaxies will still be visible in your image. Setting the background to pure black during image processing (known as clipping) often erases these subtle features from an otherwise excellent image.

The only exceptions to this "dark but not black sky" rule in astronomical photography would be lunar and planetary images. Shadows in lunar craters really will be black, particularly since the Moon lacks any appreciable atmosphere to scatter light. Planet images generally appear to be surrounded by inky black skies because of the high focal lengths required to magnify the target enough to resolve details; planetary imagers often shoot at focal ratios of f/20 or more, which translates into highly magnified views, reducing the background sky brightness.

This brings us to saturation. While we all marvel at the colorful images of galaxies, nebulae, and star clusters in the pages of this magazine and elsewhere, the colors of most of these objects are not the blazing magentas or electric blues



▶ **LUNAR ENCOUNTER** Close-ups of the lunar limb can produce compositions with an air of mystery. This mosaic of the northeastern limb includes the dark Mare Humboldtianum and gives viewers the impression they are flying over the edge of the Moon themselves.

that are often depicted. The colors of deep-sky objects are actually more pastel and subdued (watch for an article on this subject in an upcoming issue). The most colorful things we can see through a typical telescope are the stars, planets, and the brightest planetary nebulae.

We are all guilty of pumping up the saturation for dramatic effect. That doesn't make it wrong, but there's a limit to how far we can push the color saturation before it becomes garish and detracts from the final image. One way to avoid over-saturating your images is to monitor the individual color channels in your favorite image-processing program. For instance, when increasing the saturation of an emission nebula, pay close attention to the red channel. Make sure that detail is still apparent in the brightest areas and doesn't appear overexposed after your adjustments.

▲ **SLIGHT TRAILS** While deep-sky pictures require perfectly tracked images that produce round stars, nightscape photos aren't as stringent. This wide-angle, 30-second photo of the Turret Telescope at Breezy Hill in Springfield, Vermont, looks quite nice even with slightly trailed stars.

Composition

Although composing an astronomical subject in an image can be tricky, it's still an important aspect of the best astrophotos. Composition in astrophotography is tough because most things in the night sky are so far away they are essentially motionless, at least on a human timescale. You can't simply move two star clusters closer together for that family portrait!

So take care when composing deep-sky astrophotos. A perfectly tracked, well-processed image of a galaxy still looks odd if the subject is placed too close to one side of the picture frame. And a tiny planetary nebula in the middle of an image surrounded by a nondescript star field might have a better impact if it were shot at an adequate image scale that resolves lots of small-scale detail.

Spend time matching your target to your chosen equipment. There isn't much point spending an entire evening shooting a secluded, distant galaxy just 30 arcseconds across if your telescope and camera can only resolve 5-arcsecond objects or larger. That galaxy will only be about 6 pixels across in the final image!

Another aspect of composition is how your target is placed in the picture plane. A spiral galaxy like M104, the Sombrero Galaxy, might present a more dynamic composition if you rotated your camera slightly so that the long-axis of the target cuts across the frame diagonally rather than straight across.

These considerations also apply when imaging the bright planets. In particular, Jupiter offers more compositional choices than the other planets due to its size, extremely dynamic atmosphere, and retinue of Galilean moons, which can add up to four additional smaller detailed objects to a single composition.

Composing multiple adjacent targets in the same field presents its own challenges. Just because M108 and M97 in Ursa Major can fit in the opposite corners of your camera's field doesn't mean it makes for a good composition. Each object in your image should have a comfortable space between it and the edge of the frame whenever possible.

The same rules apply to nightscape photography. Balancing your terrestrial and celestial targets in your picture frame is how you unify the scene. If you're planning to shoot a young crescent Moon alongside the Eiffel Tower, the photo might

SEAN WALKER / S&T (2)

▲ **NIGHTSCAPE COMPOSITION** Nightscapes benefit greatly from good composition. Babak Tafreshi balanced this extremely bright aurora with its distorted reflection in the waters of a stream in Iceland.

▲ **BLACK CRATERS** One of the few places that will be truly black in a good astrophoto is the shadowed region within lunar craters, like this image of sunrise in the crater Clavius demonstrates.

CRATERS: SEAN WALKER / *S&T*

look better if you don't cut off the tower's base. Aurora photography is the same way: Balance your subject with elements in the foreground to make your photo attractive.

Composition is one aspect of astrophotography that you can modify *after* the image is taken. Today's digital cameras offer dozens of megapixels that make cropping easy and relatively painless. You can crop and rotate images of galaxies, nebulae, and most any subject — as long as you have enough pixels to work with. Cropping an image to better compose your subject is relatively easy, particularly if your picture has lots of extra space around the subjects. This is especially helpful when shooting faint moving targets such as comets with tails that are too faint to see through a camera's viewfinder.

Processing

Perhaps the most talked-about subject in astrophotography is image processing. While everyone's goal is surely to produce the best image possible, it's often tempting to add a little bit more sharpening or to boost the color saturation. Knowing where to draw the line with the impressive tools available in astro-imaging software is definitely a learning curve. It takes time and experience to learn the difference between "just enough" and "going too far."

In the best astrophotos, the viewer shouldn't look at the image and be able to identify which version of deconvolution was used or how much noise-reduction was applied. Good image processing is essentially invisible; it should allow the viewer to enjoy the picture without encountering processing artifacts. Stars aren't surrounded by dark rings, nor do they have dark cores. Likewise, the limbs of planets shouldn't appear like a melon rind, with a bright arc along the edge. These are all telltale signs of too much sharpening.

While I've listed some common attributes found in the best astrophotos, there's often much more to a stunning image than a list to check off when shooting the night sky. Some things you can't put a finger on beforehand, but you'll often recognize what works in the final composition. Keeping these elements in mind when planning and executing your next image can help improve your imaging skills — and even enable you to pull off your own masterpiece.

■ Equipment Editor **SEAN WALKER** has several imaging projects in the works, though the biggest is an all-sky survey partnership that can be seen at mdwskysurvey.org.

OBSERVING
March 2018

1 **DAWN:** An almost-full Moon leads the planets Jupiter, Mars, and Saturn in their march across the sky; this celestial arc is bracketed by the Moon in the west and Saturn in the southeast.

3 **DUSK:** Just 1° separates Venus and Mercury as they sink toward the horizon in the west. Challenge yourself and see if you can tease the two out of twilight.

5 **EVENING:** The zodiacal light may be visible for two weeks at mid-northern latitudes about 90 minutes after sunset. Find a dark site and look toward the west for a tall, hazy pyramid of light.

7 **NIGHT:** The waning gibbous Moon and Jupiter rise together in the east less than 4° apart shortly before midnight for viewers across North America.

11 **DAYLIGHT-SAVING TIME STARTS** at 2 a.m. for most of the United States and Canada.

16–17 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 9:50 p.m. PDT (12:50 a.m. EDT); see page 50.

19 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 9:39 p.m. EDT.

20 Spring begins in the Northern Hemisphere at the equinox, 12:15 p.m. EDT (9:15 a.m. PDT).

22 **EVENING:** A waxing crescent Moon is less than 1° from Aldebaran, occulting the star for northwestern North America and swathes of Europe, including the United Kingdom, Ireland, and the Nordic countries.

28 **DUSK:** Brilliant Venus and challenging Uranus are a mere 4° apart, following the Sun as it sets in the west. Bring binoculars or a telescope.

29 **MORNING:** Find Mars above the Teapot in Sagittarius; from there, scan some 2° left to spot Saturn. Binoculars will help you find the globular cluster M22, sparkling with more than 80,000 suns, about 1½° below the pair, approximately equidistant from both planets.

▲ The globular cluster M22 in Sagittarius sparkles with tens of thousands of stars, contains a planetary nebula, and hosts two black holes.
ESA / HUBBLE / NASA

MARCH 2018 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FULL MOON
March 2
00:51 UT

LAST QUARTER
March 9
11:20 UT

NEW MOON
March 17
13:12 UT

FIRST QUARTER
March 24
15:35 UT

FULL MOON
March 31
12:37 UT

DISTANCES

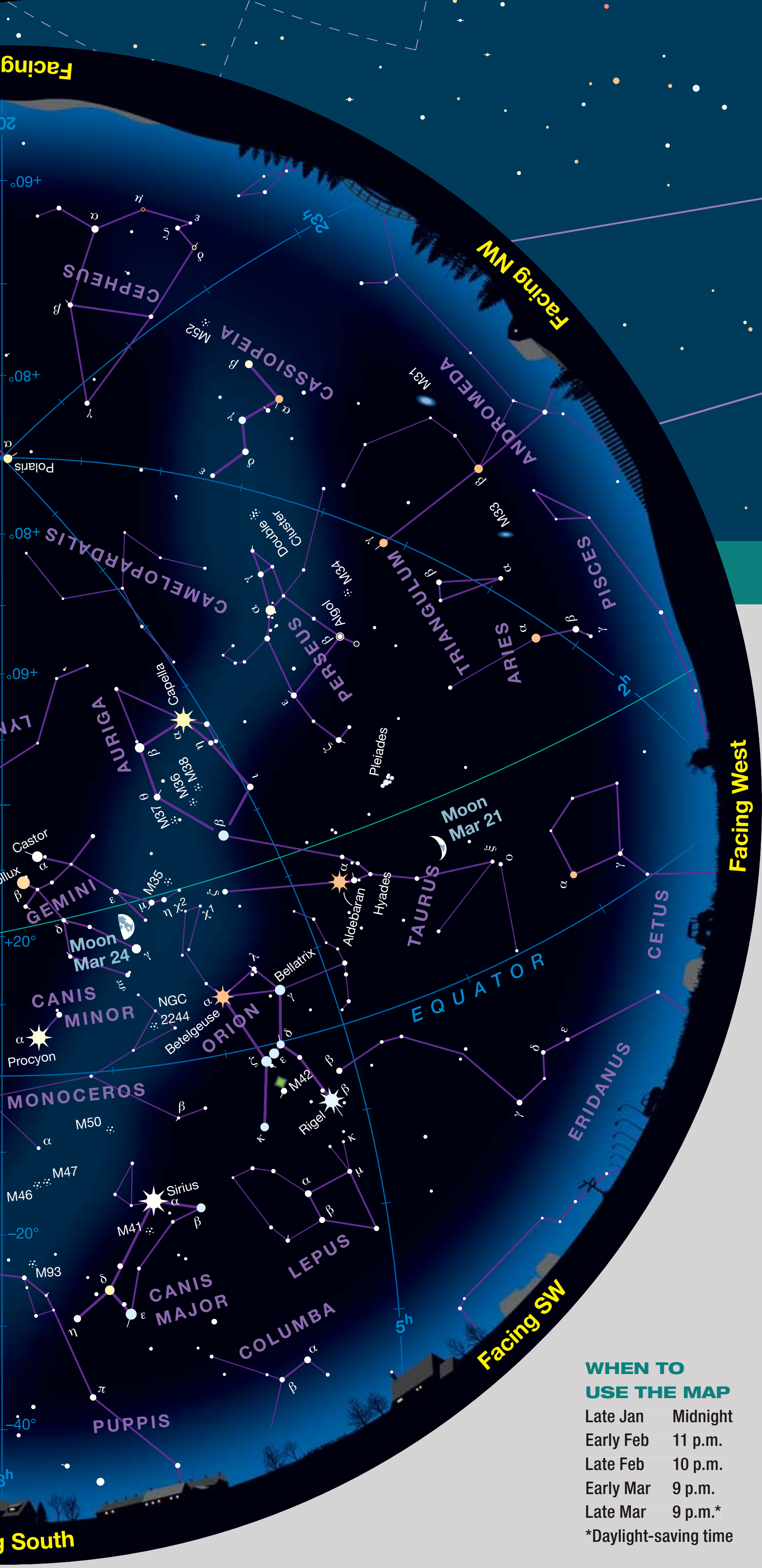
Apogee	March 11, 09^h UT
404,678 km	Diameter 29′ 32″
Perigee	March 26, 17^h UT
369,106 km	Diameter 32′ 22″

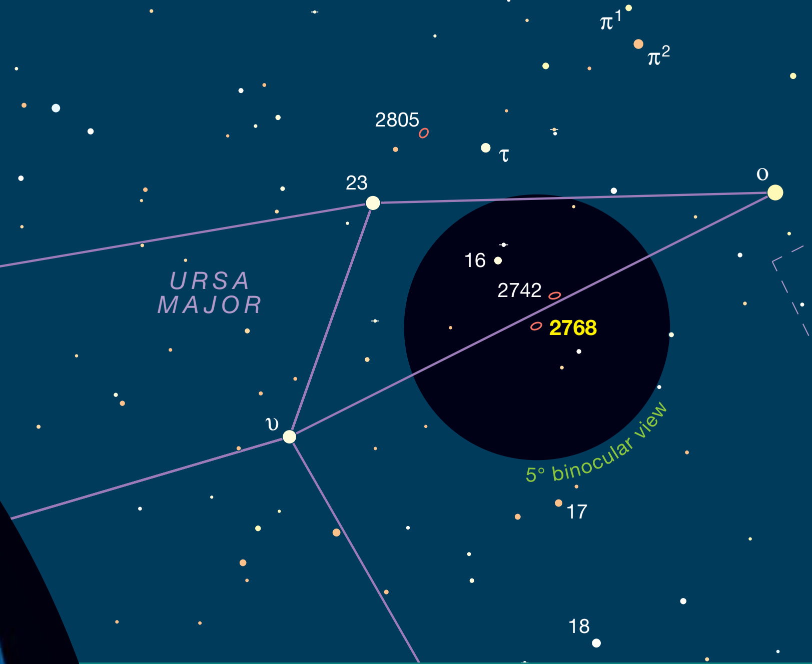
FAVORABLE LIBRATIONS

• Lyot Crater	March 2
• Demonax Crater	March 3
• Baade Crater	March 13
• Mare Australe	March 31

Planet location shown for mid-month

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





WHEN TO USE THE MAP	
Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early Mar	9 p.m.
Late Mar	9 p.m.*

*Daylight-saving time

Binocular Highlight by Mathew Wedel

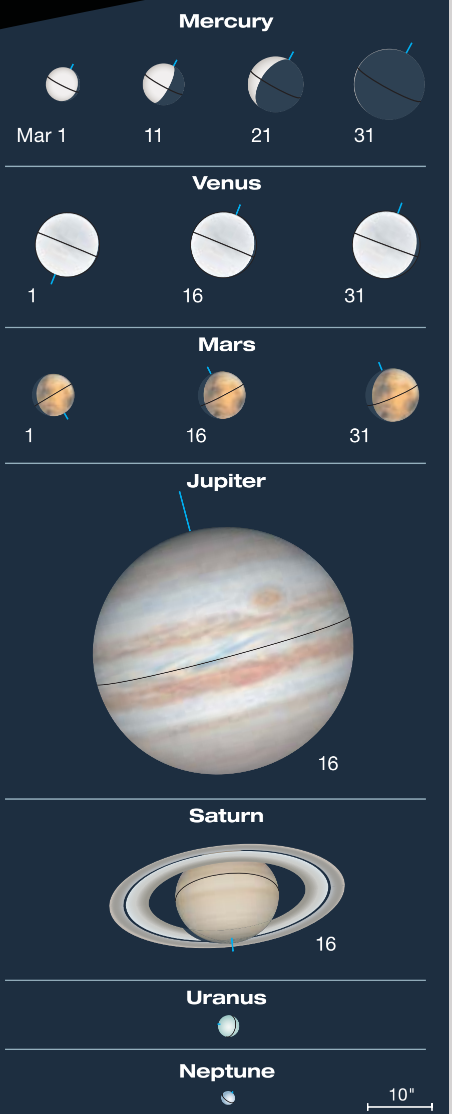
Turning Point

I admit up front that the lenticular galaxy **NGC 2768** isn't an obvious choice for a binocular highlight. It's stashed away in the western reaches of the Great Bear, about 1.5° south of 16 Ursae Majoris. If you've roamed out that way, chances are you're a galactophile, or you're working through the Herschel 400, or both. Just under 10th magnitude, the galaxy's barely-more-than-stellar glow is also not terribly bright (you may be thinking the same thing about me right now).

So what's the story — what does NGC 2768 have to offer? The galaxy does have one felicitous property: It lies 65 million light-years away. Or at least it did when the light that we see now left it. Within the confidence bands allowed by terrestrial dating and astronomical measurements, that's right about the time that a big hunk of rock from space plowed into the Yucatan Peninsula, threw up enough dust to crash the biosphere, and precipitated the extinction of all the dinosaurs that weren't already birds. We mammals had spent the previous 160 million years — the first two-thirds of our time on Earth — living in trees and holes and never, ever getting bigger than a modern badger. Without that impact, you and I would probably still be tree shrews.

NGC 2768 doesn't have any direct connection to the dinosaur-killer, other than its light being the same age just now, "now" being the point in cosmic history when we, the beneficiaries of the impact, have gained the intelligence and built the tools — handheld tools, even, the reason for this column — to look back 65 million light-years, to maybe the most important turning point in our history. As a paleontologist-astronomer, I may be biased, but I think that's worth a look.

■ **MATT WEDEL** enjoys crossing the streams of his professional and amateur careers, and he has not triggered any catastrophes so far.



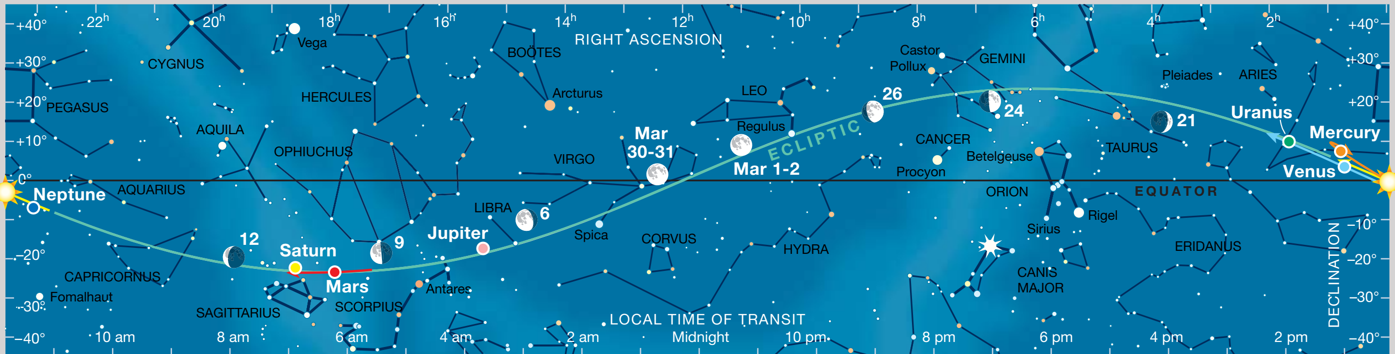
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury: visible at dusk, best evening apparition of the year • **Venus:** visible at dusk • **Mars:** rises early morning, highest at dawn • **Jupiter:** rises before midnight, visible until sunrise • **Saturn:** rises early morning, highest at dawn

March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h 46.5^m$	–7° 47′	—	–26.8	32′ 17″[2]	—	0.991
	31	$0^h 36.7^m$	+3° 57′	—	–26.8	32′ 02″	—	0.999
Mercury	1	$23^h 24.6^m$	–4° 45′	10° Ev	–1.3	5.3″	93%	1.262
	11	$0^h 25.2^m$	+3° 56′	17° Ev	–0.9	6.5″	64%	1.037
	21	$0^h 55.6^m$	+9° 17′	17° Ev	+0.8	8.7″	23%	0.771
	31	$0^h 43.3^m$	+8° 03′	4° Ev	+5.3	11.0″	1%	0.608
Venus	1	$23^h 33.9^m$	–4° 19′	12° Ev	–3.9	10.0″	98%	1.663
	11	$0^h 19.3^m$	+0° 48′	15° Ev	–3.9	10.2″	97%	1.640
	21	$1^h 04.6^m$	+5° 55′	17° Ev	–3.9	10.3″	96%	1.613
	31	$1^h 50.5^m$	+10° 49′	20° Ev	–3.9	10.5″	94%	1.581
Mars	1	$17^h 16.6^m$	–22° 47′	80° Mo	+0.8	6.7″	89%	1.402
	16	$17^h 54.7^m$	–23° 25′	86° Mo	+0.6	7.4″	88%	1.258
	31	$18^h 31.6^m$	–23° 33′	93° Mo	+0.3	8.4″	88%	1.118
Jupiter	1	$15^h 23.1^m$	–17° 21′	107° Mo	–2.2	39.1″	99%	5.046
	31	$15^h 20.6^m$	–17° 07′	138° Mo	–2.4	42.5″	100%	4.636
Saturn	1	$18^h 30.6^m$	–22° 22′	63° Mo	+0.6	15.9″	100%	10.476
	31	$18^h 37.3^m$	–22° 17′	91° Mo	+0.5	16.6″	100%	9.992
Uranus	16	$1^h 38.7^m$	+9° 41′	31° Ev	+5.9	3.4″	100%	20.738
Neptune	16	$23^h 02.9^m$	–7° 05′	11° Mo	+8.0	2.2″	100%	30.919

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



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

Colors and Clusters

You don't have to wait for summer nights to see a pleasingly colored double star.

Last month in this column, I began an exploration of Canis Major, the Big Dog. I discussed three of its 2nd-magnitude stars, the ones that form what I call the Southern Canis Triangle. But there's more to say about one of those three, and about several others of the Big Dog's remarkable stars and star clusters.

The warm-up for the pup and the dog star's announcer. One of our main topics in last month's column was Epsilon (ε) Canis Majoris, or Adhara. Even though at magnitude 1.5 it's the brightest of all 2nd-magnitude stars, Adhara is 15 times (almost 3 full magnitudes) dimmer than radiant Sirius. Interestingly, however, Adhara has a faint, close companion that makes it a challenging warm-up for any attempt at detecting Sirius B ("the Pup"), the famous white dwarf companion of Sirius. Adhara's companion shines 8″ away from the primary star, which is 6 magnitudes brighter. Sirius B this year is about 10″ from Sirius, which is 10 magnitudes brighter.

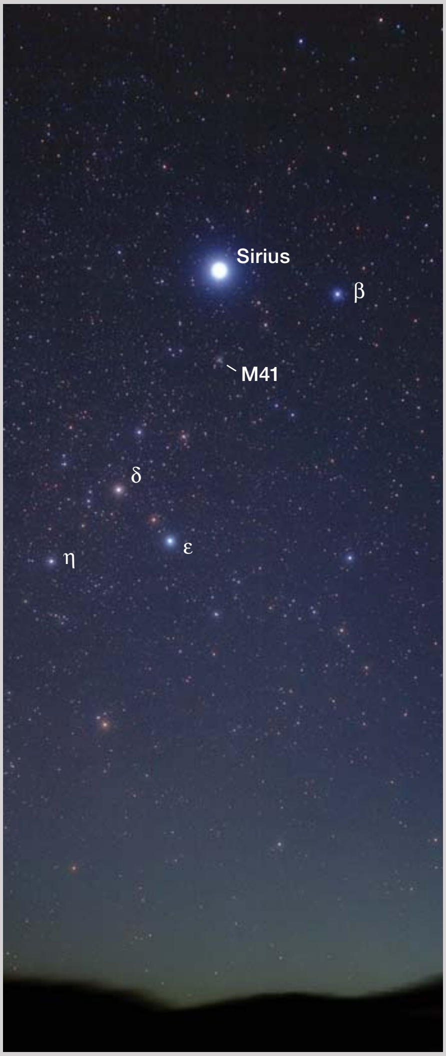
Another Canis Major star with a special relationship to Sirius is a 2nd-magnitude sun that's not part of the Southern Canis Triangle of Adhara, Delta (δ) Canis Majoris (Wezen), and Eta (η) Canis Majoris (Aludra). This is Beta (β) Canis Majoris, also known as Mirzam or Murzim. (Murzim is the name I grew up using, but star-name expert Paul Kunitsch apparently shows a preference for Mirzam.) The same title (the "herald") was applied by the early Arab astronomers to Beta (β) Canis Minoris (Gomeisa) and Gamma (γ) Orionis (Bellatrix) for their role in "announcing" (that is, rising just before) Procyon and Betelgeuse, respectively.

Today's Mirzam (our Beta Canis Majoris) is the announcer of the greatest star of them all, Sirius, though an earlier announcer of Sirius for observers around 40° North latitude is Canis Minor's 1st-magnitude luminary Procyon. Procyon is certainly very much brighter than Mirzam. Although the latter is known as Beta Canis Majoris, it's not the second-brightest star of the Big Dog but rather the fourth-brightest. Even so, Mirzam burns at magnitude 1.98, making Canis Major the only constellation with exactly four stars of magnitude 2.0 or brighter. Orion is the sole constellation that, with five, has an even greater number of stars brighter than 2.0.

The winter Albireo. In recent years one of the finest deep-sky objects in Canis Major has finally started receiving the greater attention it deserves.

I'm speaking of what may be the loveliest of all color-contrast doubles visible in the winter constellations: 145 Canis Majoris, also known as h3945 (Herschel 3945), but perhaps best known today as the Winter Albireo. This last title was given to it by long-time astronomy writer and deep-sky authority James Mullaney, who first started publicizing this double star. It appears as a magnitude-4.5 point of light to the naked eye, but even the lowest telescopic powers split it into a 4.8- and 6.8-magnitude pair of stars 27″ apart. The summer star Beta (β) Cygni (Albireo) is, of course, the most famous colored double in all the heavens. Some people apparently see the hues of h3945 as quite similar to the gold and blue of Albireo. I see the tints somewhat differently — what do you think the colors are?

The classic beauty of M41. As famous as the big, bright open cluster M41 is, it still seems to me that it is under-observed and underappreciated. After all, where in the heavens do we find a more amazing and delectable circumstance than having a naked-eye star cluster only about 4° south of the night's brightest star? Possibly the first mention of M41 was in 325 BC by none other than Aristotle himself. Its overall magnitude-4.5 glow has near its center the cluster's brightest star, a magnitude-6.9 star of definite ruddiness. As a whole, the cluster is circular with a diameter of about 38′, but its brighter members form a butterfly pattern.



AKIRA FUJII

■ **FRED SCHAAF** notes that he talks a lot about Vega, but Sirius is definitely his favorite star.

The Return of the Planets

March ushers in all five bright planets, and if you're lucky, you might be able to spot Uranus at the end of the month.

Two planets, Venus and Mercury, spend much of March together low in the west at dusk, as Mercury puts on its best evening show of 2018 for observers at mid-northern latitudes.

Two other planets, Mars and Saturn, move closer and closer together throughout the month in the hours before dawn.

The last of the bright planets, Jupiter, rises in late evening, reaching its highest in the south a few hours before sunrise.

DUSK

Venus and **Mercury** are only about 1½° apart on March 2nd. They are closest, slightly more than 1° apart, on March 3rd, when Mercury shines almost directly right of very bright Venus. On those dates, telescopes show both planets nearly fully lit, but with Venus about twice as wide as Mercury. Both planets set less than an hour after the Sun. For the next two weeks, however, Venus and especially Mercury keep appearing higher, Mercury moving ever farther to Venus's upper right.

For observers around 40° north latitude, Mercury reaches its peak height at mid-month, attaining a greatest elongation of 18° from the Sun on March 15th. By then, Mercury's magnitude has dimmed in two weeks from –1.3 to –0.4, and its phase has shrunk to just less than half-lit.

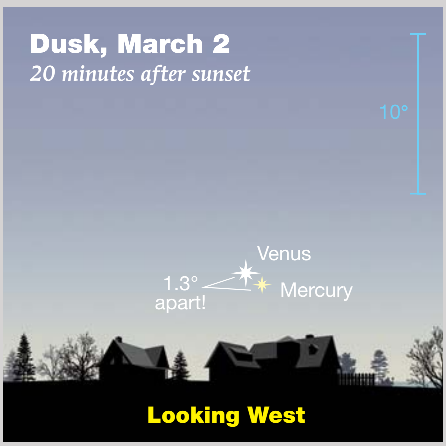
As Mercury starts getting lower after mid-month, it draws back closer to Venus again — though this time only to about 3½° separation on March 18th — and drops to about the same height as Venus on March 20th. On this latter date, Mercury has dimmed rapidly to magnitude +0.9 and soon after is too faint to see with the naked eye in the bright twilight. Venus, blazing at magnitude –3.9 all month, appears a little higher each day, the interval between sunset and Venus-set increasing from about 1 hour to more than 1½ hours.

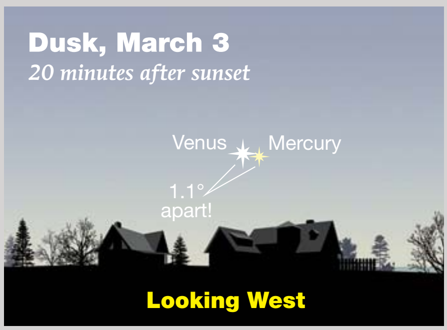
Uranus has an extremely close conjunction with Venus on the American evening of March 28th, when the 6th-magnitude ice giant is only 4′ slightly above and to the right of Venus. It's challenging to see even with a sizable telescope in twilight skies.

Neptune is at conjunction with the Sun on March 4th and therefore not visible this month.

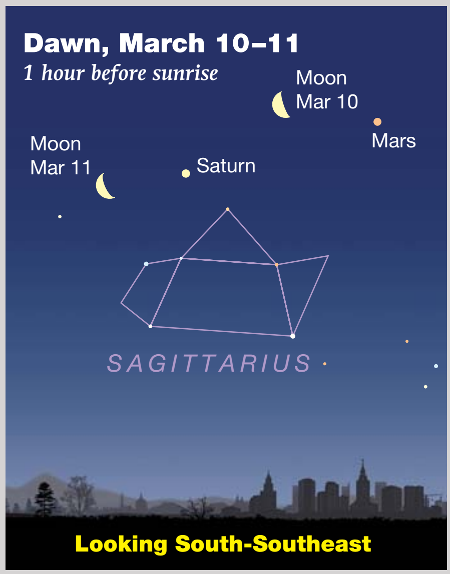
ALL NIGHT

Jupiter rises some 20 minutes before midnight on March 1st and about one hour earlier by month's end. The kingly





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



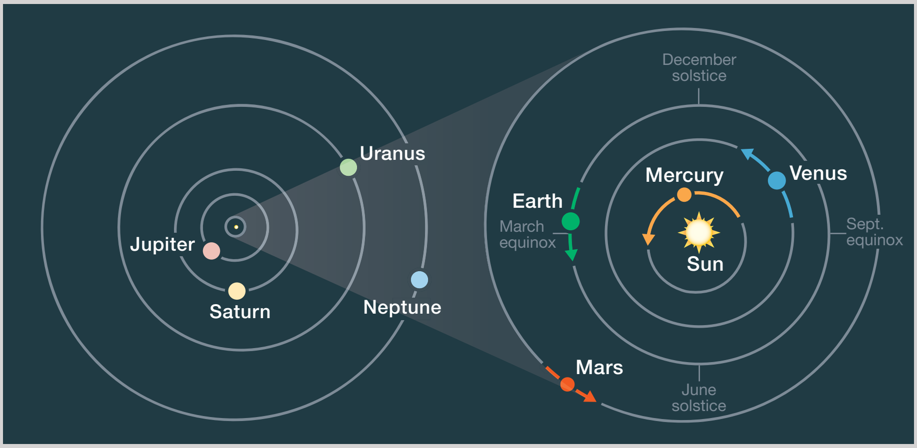
● To find out what's visible in the sky from your location, go to skypub.com/almanac.

planet reigns in lone splendor in dim Libra, brightening from magnitude –2.2 to –2.4. Jupiter halts its eastward movement in right ascension on March 9th, and then begins retrograde motion. The angular diameter of the huge world grows from about 39″ to almost 43″ during the month.

Mars and **Saturn** begin the month rising about 70 minutes apart, but end it rising only about 1 minute apart. As March opens, Mars comes up around 2 a.m. local time, shining at magnitude +0.8 in Ophiuchus. Saturn, at magnitude +0.6, rises in Sagittarius. Before mid-month, Mars crosses into Sagittarius and brightens to +0.7, while Saturn nudges to +0.5. Mars continues to kindle, equaling and then surpassing Saturn's brightness, hitting magnitude +0.3 by month's end. The two planets start the month as much as 17° apart, but by month's end are less than 2° apart, on the verge of their close conjunction on April 2nd.

Mars catches up with Saturn just to the upper left of Lambda (λ) Sagittarii, the star at the top of the Teapot of Sagittarius. Telescopes will show the Red Planet above the great globular star cluster M22. Mars doesn't climb to its highest, on the meridian, until about sunrise each day.

The globe of Mars swells from 7″ to almost 8½″ wide this month — still not big enough to show details in most telescopes on most nights — and the globe of Saturn from slightly less than 16″ to a little more than 16½″. The two planets reach west quadrature (90° west of the Sun) within five days of each other (Mars on March 24th and Saturn on March 29th), and these positions have notable observational consequences. In the case of Mars, the planet displays its largest phase effect, a shadowed edge that makes it appear gibbous. For Saturn, west quadrature means the shadows of the planet's ball and rings are cast farthest to the side, giving the system a particularly three-dimensional appearance.

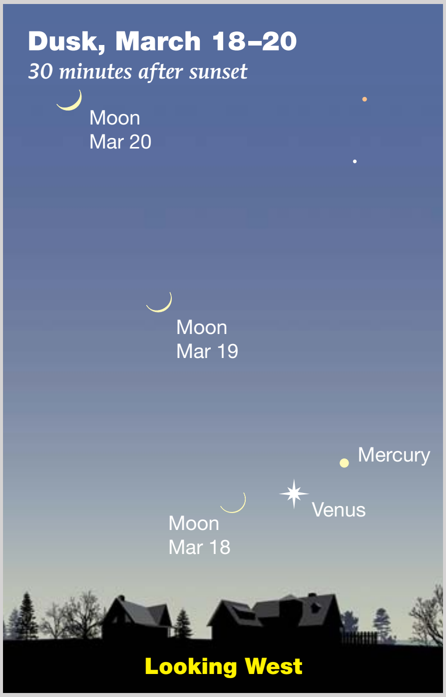


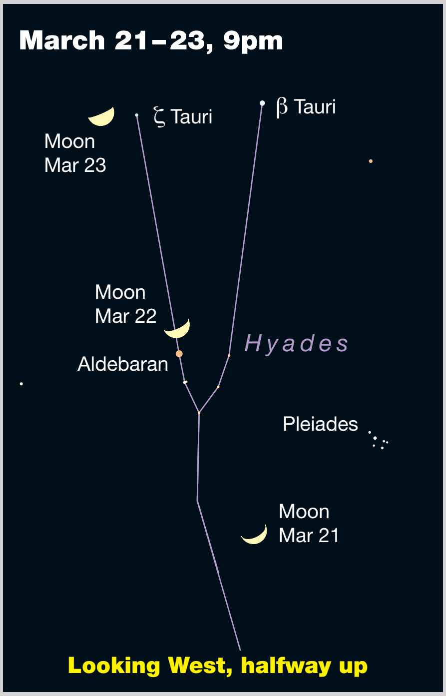
ORBITS OF THE PLANETS
The curved arrows show each planet's movement during March. The outer planets don't change position enough in a month to notice at this scale.

SUN AND MOON

The Sun reaches the March equinox at 12:15 p.m. EDT on March 20th, signaling the beginning of spring in the Northern Hemisphere and autumn in the Southern Hemisphere.

The Moon is full at 7:51 p.m. EST on March 1st (also, as in January, a second time in the month, at 8:37 a.m. EDT on March 31st). The waning gibbous Moon is 3° or 4° upper left of Jupiter on the morning of March 7th. The waning crescent Moon forms a long, flat triangle with Saturn and Mars at dawn on March 10th, and is left of Saturn the next morning. The very thin waxing Moon, Venus, and Mercury form a beautiful, gentle arc about 5° long low in the west about 30 minutes after sunset on March 18th. The waxing lunar crescent shines just above Aldebaran on the evening of March 22nd.





■ **FRED SCHAAF** had the 10-mile-wide asteroid 7065 Fredschaaf named after him in November 2016.

Mercury in the Month of Mars

March may be named for Mars, the Roman god of war, but Mercury, god of commerce and thieves, steals the show this month.

NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / CARNEGIE INSTITUTION OF WASHINGTON

The rayed impact crater Hokusai was first detected in 1991 through Earth-based radar observations from Goldstone Observatory. This mosaic of images sent back by NASA's Messenger spacecraft offers a dramatic view of the crater's rays, some of which stretch 1,000 km (more than 600 miles) across Mercury's surface.

It's not difficult to find amateur astronomers who've never spotted the mighty mite of planets. Mercury never strays far from the Sun, so you have to catch it at the edges of the day, when many of us are suffering through morning or evening commutes. And this little one moves quickly, orbiting the Sun once every 88 days. This means that when you've finally made plans to leave work early and hit the horizon with a pair of binoculars, Mercury's already begun its dash past the Sun and disappeared from view. Mercury returns to the evening sky around March 1st this year and slips away before month's end. So don't bother marking the calendar, just grab your binos and head outside at the first opportunity.

The closest planet to the Sun, Mercury always hews very closely to the ecliptic, the path our star appears to follow across the sky during the year. At this time of year, when we're approaching the spring equinox, the ecliptic is tipped up at a steep angle in relation to the western horizon. This sharp slope creates ideal conditions for observing Mercury even when its angular separation from the Sun isn't exceptionally large. On March 15th Mercury reaches a greatest eastern elongation of 18° — a fair distance, but short of the maximum possible 28°.

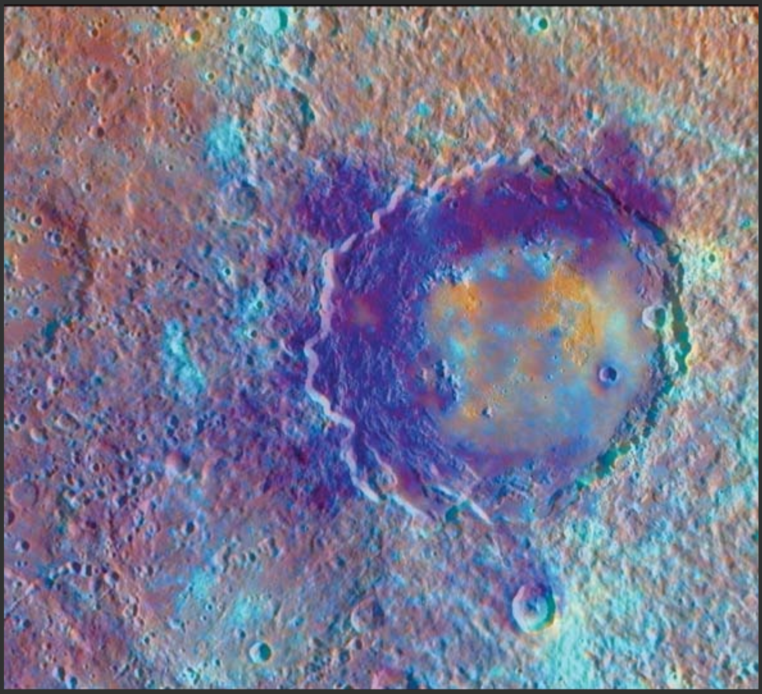
Mercury shines brightest in the fortnight leading up to greatest elongation: It's a lustrous –1.3 on the 1st and dimmer –0.4 on the 15th. However, it's highest between the 12th and 15th, when it stands at 12° about 30 minutes after sunset. Under clear, transparent skies, Mercury should be visible as deep into the calendar as March 25th, but you've a much better chance at finding it on the earlier dates. If you're having trouble spotting it, use Venus, beaming at magnitude –3.9, as a guide. Mercury begins this apparition lower right of Venus before climbing above and right of its brilliant neighbor. If you can keep Mercury in sight after the 15th, you'll see it sink toward the horizon once more.

▲ London-based astrophotographer Roger Hutchinson captured this image of Mercury during the September 2017 apparition with his 11-inch Schmidt-Cassegrain with a 685 nm IR pass filter.

The god of thieves doesn't look like much in binoculars, but even moderately sized telescopes can reveal its phases. On the 1st Mercury's phase is fat and gibbous, showing a face 93% lit, but it rapidly thins to a slender crescent. On the 15th, the planet is only 47% lit, and by the time Mercury flees the night sky to head toward morning, it's only 10% lit. Track Mercury's motion and phases for a few months and you'll get a good sense of the innermost planet's quick, tight orbit around the Sun.

A Dark Story

Mercury might appear as a bright light in your binoculars, but the planet turns out to be much darker than it should be based on its elemental composition. Mercury reflects much less sunlight than does the Moon, whose shine is amplified by iron-rich minerals. One explanation for Mercury's low reflectance may be the presence of an unusual amount of carbon at its surface. But how did this carbon find its way to Mercury's uppermost layers? In 2016, scientists from Johns Hopkins University Applied Physics Laboratory, Carnegie Institution of Washington, and Columbia University drew on data returned from NASA's Messenger spacecraft to offer a new explanation for its presence. The carbon probably originated in the graphite crust of an early magma ocean. Fragments of the ancient layer surfaced during comet impacts and mixed with the overlying volcanic materials. The end result of this cataclysmic process was the darkening of Mercury's topmost layer.



▲ This enhanced color view of Mercury's Derain Crater highlights the different types of rocks in the volcanic basin. The dark blue areas show the locations of low-reflectance material that may have originated in an ancient magma ocean. The red and orange areas represent brighter, newer regions of volcanic fill.

CRATER: NASA / JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY / CARNEGIE INSTITUTION OF WASHINGTON

Asteroid Occultations

VERY EARLY on the morning of March 14th, the faint asteroid 51 Nemausa will black out an 11.5-magnitude star in the constellation Sextans. The star will appear to dim to 10.2 (the magnitude of Nemausa) for up to 15.7 seconds for viewers along a path running from New Jersey across western New York and Lake Ontario to Nunavut. The occultation for observers in the United States will happen within a minute or two of 4:43 UT (12:43 a.m. EDT) on the 14th.

On the morning of March 26th the very faint asteroid 88 Thisbe will occult a 12th-magnitude star in Sagittarius. Though the event track stretches across North America, the Sun will be well up for the eastern United States by the time the occultation occurs, so this one is for viewers in the American West. The occultation will begin within a minute or so of 12:59 UT (5:59 a.m. PDT) and will last at most 7.7 seconds.

About a week before both events, more precise predictions and path maps will be available from Steve Preston's asteroid and minor-planet occultation website (**asteroidoccultation.com**). For advice on timing occultations and reporting observations, see **asteroidoccultation.com/observations**.

GET INVOLVED

If you'd like to learn how to time asteroid occultations, start by downloading the free ebook *Chasing the Shadow: The IOTA Occultation Observer's Manual* from Derek Breit's occultation page (**poyntsource.com/IOTAmanual**).

Minima of Algol

Feb.	UT	Mar.	UT
2	4:30	2	20:43
5	1:19	5	17:32
7	22:09	8	14:22
10	18:58	11	11:11
13	15:47	14	8:00
16	12:37	17	4:50
19	9:26	20	1:39
22	6:15	22	22:28
25	3:05	25	19:17
27	23:54	28	16:07
		31	12:56

These geocentric predictions are from the heliocentric elements Min. = JD 2452500.179 + 2.867335**E**, where **E** is any integer. For a naked-eye comparison-star chart and more information about Algol and its history, see **skyandtelescope.com/algol.**

Aldebaran Afternoon

THE MOON will be a waxing crescent, 31% lit, when it occults Aldebaran on the afternoon or evening of Thursday, March 22nd. Observers in the northwestern United States and western Canada can try to spot the 1st-magnitude star as it disappears behind the Moon's dark limb and reappears at the bright limb some 30–35 minutes later. Observers along the southern edge of the path should be alert and look for a graze along the southeastern lunar limb.

Complete timetables for the event are available from the International Occultation Timing Association (**lunar-occultations.com/iota/bstar/bstar.htm**), but these will get you started:

Anchorage, *disappearance* 5:43 p.m., *reappearance* 6:43 p.m. AKDT; **Vancouver, BC,** *d.* 2:50 p.m., *graze* 3:02 p.m., *r.* 2:38 p.m. PDT; **Seattle,** *d.* 2:53 p.m., *gr.* 3:04 p.m., *r.* 3:20 p.m. PDT; **Edmonton,** *d.* 4:05 p.m., *gr.* 4:20 p.m., *r.* 4:46 p.m.

Action at Jupiter

JUPITER LINGERS in Libra this spring. The gas giant reaches its easternmost stationary point at 10^h UT March 9th, then begins retrograde motion, on its way to a May 9th opposition. Jupiter brightens from magnitude –2.2 to –2.4 during the course of the month and broadens in equatorial diameter from 39″ to more than 42″.

Any telescope shows Jupiter's four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them at any date and time.

All of the March interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

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

March 1, 9:34, 19:30; **2,** 5:25, 15:21; **3,** 1:17, 11:12, 21:08; **4,** 7:04, 16:59; **5,** 2:55, 12:51, 22:46; **6,** 8:42, 18:37; **7,** 4:33, 14:29; **8,** 0:24, 10:20, 20:16; **9,** 6:11, 16:07; **10,** 2:02, 11:58, 21:54; **11,** 7:49, 17:45; **12,** 3:41, 13:36, 23:32; **13,** 9:27, 19:23; **14,** 5:19, 15:14; **15,** 1:10, 11:06, 21:01; **16,** 6:57, 16:52; **17,** 2:48, 12:44, 22:39; **18,** 8:35, 18:30; **19,** 4:26, 14:22; **20,** 0:17, 10:13, 20:08; **21,** 6:04, 16:00; **22,** 1:55, 11:51, 21:46; **23,** 7:42, 17:38; **24,** 3:33, 13:29, 23:24; **25,** 9:20, 19:16; **26,** 5:11, 15:07; **27,** 1:03, 10:58, 20:54; **28,** 6:49, 16:45; **29,** 2:40, 12:36, 22:32; **30,** 8:27, 18:23; **31,** 4:18, 14:14.

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

The listed times assume that the spot will be centered at System II longitude 287°. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 287° and 1²/₃ minutes later for each degree more than 287°.

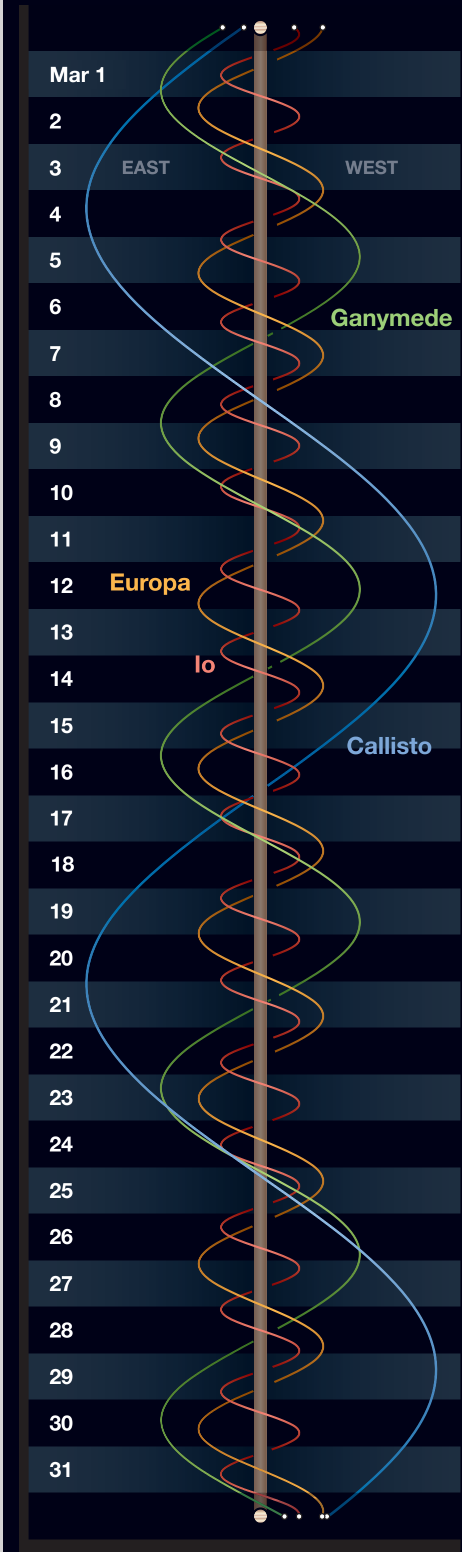
Features on Jupiter appear closer to the central meridian than to the limb for about 50 minutes before and after transiting. A light blue or green filter slightly increases the contrast and visibility of Jupiter's reddish and brownish markings.

Phenomena of Jupiter's Moons, March 2018

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

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

Jupiter's Moons



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

Velikovsky's Venus

A controversial 1950 book declared that our neighbor world was spawned by Jupiter 3,500 years ago and nearly struck Earth — twice.

As northern winter gives way to the longer daylight hours of spring, Venus returns to the evening sky for a long engagement. As the chart below shows, the planet doesn't get as dramatically high in the sky as it did back in 2015. But the Evening Star will remain in view through September.

Telescopically, Venus never offers much to see aside from its gradual change in apparent size and an attractive progression of phases. Observers have strained for centuries to glimpse any detail on its cloud-cloaked disk. We sometimes forget that astronomers knew very little about this neighbor world — so like Earth in size and mass — until powerful radar probing and spacecraft visits started to peel back the layers of mystery in the 1960s.

The first artificial satellites were still a decade away when, in 1946, Immanuel Velikovsky finished the manuscript for *Worlds in Collision,* a book that capitalized on our relative ignorance and put forward a theory of solar-system formation that goes beyond bizarre. Born in 1895 and a student variously of history, law, biology, and psychoanalysis, Velikovsky maintained that the inner planets only recently assumed the serene, stable orbits they have today.

Rather, in his scheme Venus took the form of a huge, rogue comet after being ejected by Jupiter not long before 1500 BC. It then hurtled sunward, sideswiping Earth twice and colliding with Mars before settling into the almost perfectly circular orbit it now occupies.

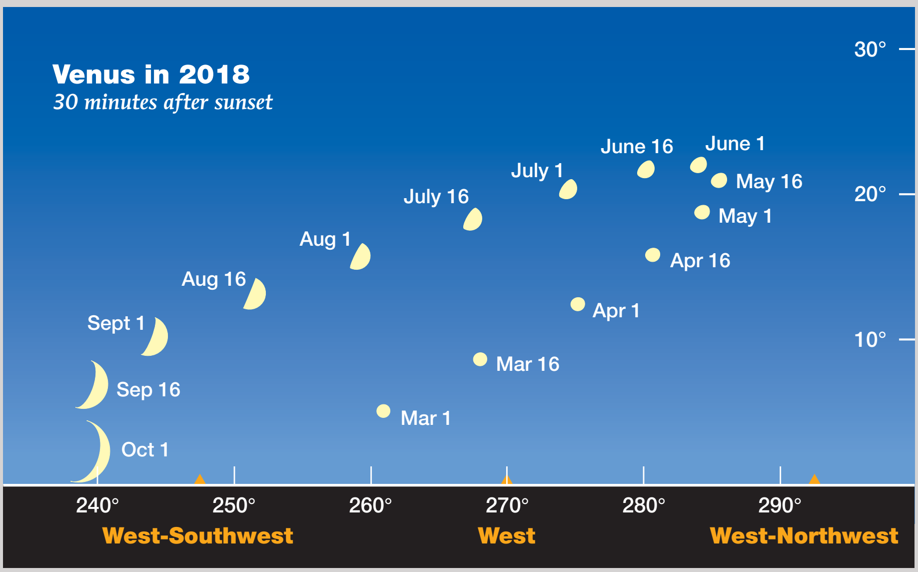
The basis for all this astounding, historically recent chaos wasn't a detailed computation of orbital motion but

◀ Immanuel Velikovsky (1895–1979), seen here in 1968, wrote controversial books about the history of Earth and the solar system.

rather Velikovsky's unwavering belief that Old Testament narratives and cosmological myths drawn from China, Central America, India, Assyria, and elsewhere were accounts of real events.

What got him started was the biblical story of Joshua commanding the Sun and Moon to stop moving for an entire day and invoking a devastating hail of stones from the sky during his battle with the Amorites. Velikovsky was also seeking a physical reason for the plagues inflicted on the Egyptians in Exodus.

Venus provided all the answers. That long tail it trailed after leaving Jupiter had also created all kinds of havoc for Pharaoh as Earth passed through it not once but twice. And although we escaped an outright collision, the proximity of Venus caused Earth's orbit and axial tilt to change, a magnetic reversal, and worldwide floods, hurricanes, and volcanic eruptions — all within recorded history. None of this catastrophism was chronicled by our



▲ Venus spends much of this year lingering in the west after sunset. It reaches greatest eastern elongation in mid-August but isn't its brightest until late September. Disks are enlarged for clarity.

FURTHER READING: You'll get a good grounding in Velikovsky's controversial publications by perusing the essays in The Skeptic's Dictionary (**skepdic.com/velikov.html**), by Stephen Jay Gould (**https://is.gd/OlkXye**), and by Paula Findlen (**https://is.gd/9SmAGW**).

PHOTO: BETTMANN / GETTY IMAGES, DIAGRAM: *SKY & TELESCOPE*

Venus mimics all the phases of the Moon as it circles the Sun inside Earth's orbit, as shown in this near-ultraviolet sequence recorded in 2007.

ancestors, Velikovsky asserts, because they suffered from a "collective amnesia" that repressed all memory of these occurrences. As further proof, he details how Venus is conspicuously absent from various historical tabulations of planets prior to about 2000 BC.

Velikovsky acknowledged that his scenario was at odds with established physics. But any inconsistencies weren't due to his myth-as-fact interpretations; instead, he pointed to the "need for a new approach to celestial mechanics" in which electrical forces and magnetism trumped the power of gravity.

Understandably, astronomers of the day were outraged by all of this. It took Velikovsky four years to get *Worlds in Collision* published, finally getting a green light from Macmillan in part because a sympathetic Gordon Atwater, then head of astronomy at New York's American Museum of Natural History, promised to create a show for Hayden Planetarium to depict the book's planetary pinball. But Atwater was summarily fired before that could happen. Strenuous objections by Harvard's Harlow Shapley, Cecelia Payne-Gaposchkin, and other academics — including a boycott of Macmillan's astronomy textbooks — caused the publisher to jettison this literary hot potato to Doubleday. The book and its author merited a blistering editorial in *Sky & Telescope*.

A Curious, Believing Public

Remarkably, *Worlds in Collision* became phenomenally popular in the summer of 1950, especially among the New York literati. Advance articles about the forthcoming book in *Harper's*, *Collier's*, *Reader's Digest*, and elsewhere whetted the public's appetite. Once in print, the book rocketed to the top of the *New York Times'* best-seller list and remained a top-ten pick for five months.

Although pilloried almost universally by professional astronomers, Velikovsky remained a frequent acquaintance of Albert Einstein. More than a decade later he gained a modicum of support thanks to Princeton physicist Valentine Bargmann and Columbia astronomer Lloyd Motz, whose letter in *Science* (December 21, 1962) pointed out Velikovsky's successful predictions that Jupiter was a source of radio energy and that Venus must be very hot.

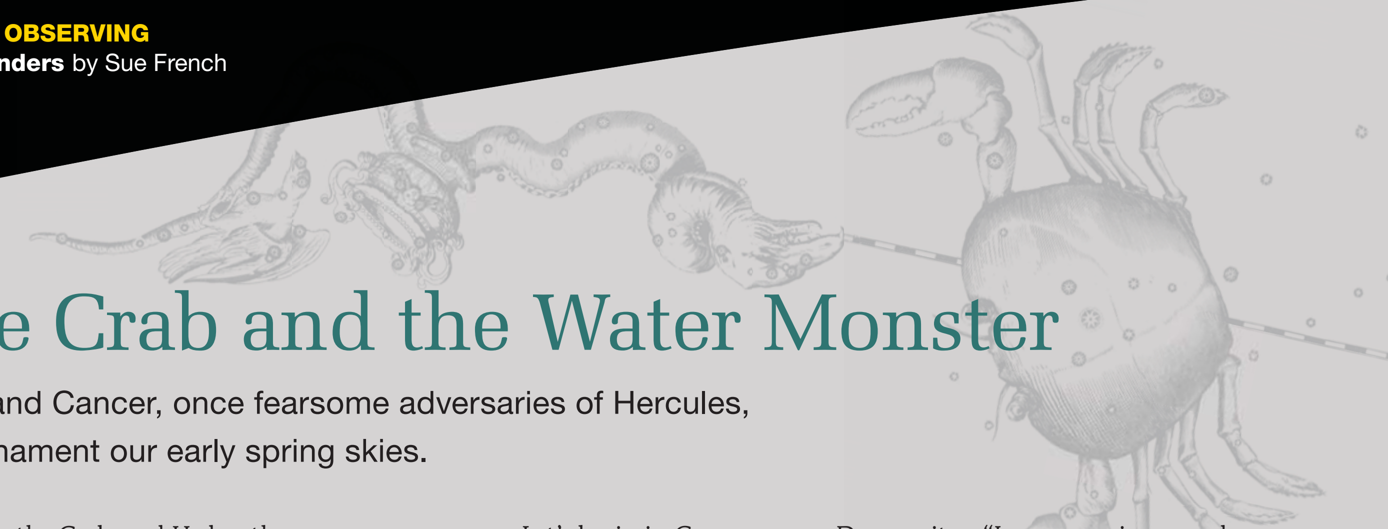
Still, one has to wonder why the outlandish premises of *Worlds in Collision* got so much traction in the first place. Science historian Stephen Jay Gould wrote, "The Velikovsky affair raises what is perhaps the most disturbing question about the public impact of science. How is a layman to judge rival claims of supposed experts? Any person with a gift for words can spin a persuasive argument about any subject not in the domain of a reader's personal expertise." Advocate-turned-critic Leroy Ellenberger notes, more pointedly, "The less one knows about science, the more plausible Velikovsky's scenario appears."

Six decades later, *Worlds in Collision* is rapidly disappearing in the rearview mirror of history, yet our human penchant for intriguing but outlandish scientific claims remains.

▲ Normally featureless to the eye, Venus revealed subtle atmospheric features when captured in near-infrared light (610 nm) during its apparition before dawn in mid-2017.

SIMON KIDD; VENUS SEQUENCE: SEAN WALKER

■ Senior Editor **KELLY BEATTY** keeps close watch on Venus just to make sure it doesn't suddenly sprout a tail and careen toward Earth.



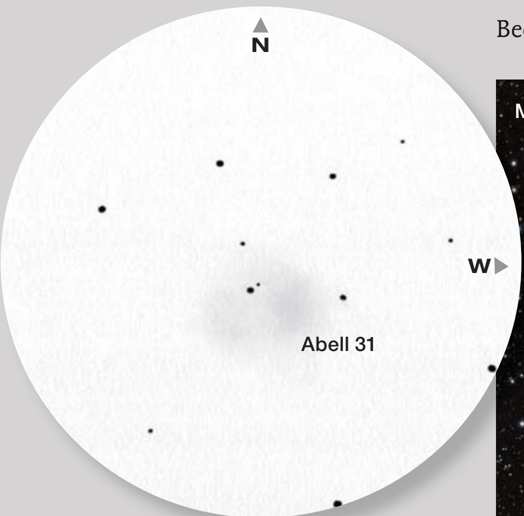
The Crab and the Water Monster

Hydra and Cancer, once fearsome adversaries of Hercules, now ornament our early spring skies.

Cancer, the Crab, and Hydra, the Water Monster, are mythologically tied. They battled the great hero Hercules during the second task of his 12 legendary labors, but the tremendous crab and multi-headed beast were slain by the mighty demigod. Their constellations are joined in the sky as well, with Hydra's head resting close beneath Cancer's legs. Now well placed for observing in the evening sky, these foes of Hercules will be the site of our deep-sky explorations.

I very much enjoy the observations other amateur astronomers send me, and I'd like to showcase some that have come my way. Let's begin in Cancer, which is shown as an upside-down Y on the all-sky chart at the center of this magazine. The star at the Y's fork is called Asellus Australis, the Southern Donkey, while the star above it is Asellus Borealis, the Northern Donkey. In a dark sky, you'll see a hazy patch halfway between and a shade west of these stars. This is the large and beautiful star cluster **Messier 44**. It's sometimes called Praesepe, the "manger" where the Donkeys feed. Figuratively, this Latin word also means a bee's hive, and M44 is more commonly known as the Beehive Cluster.

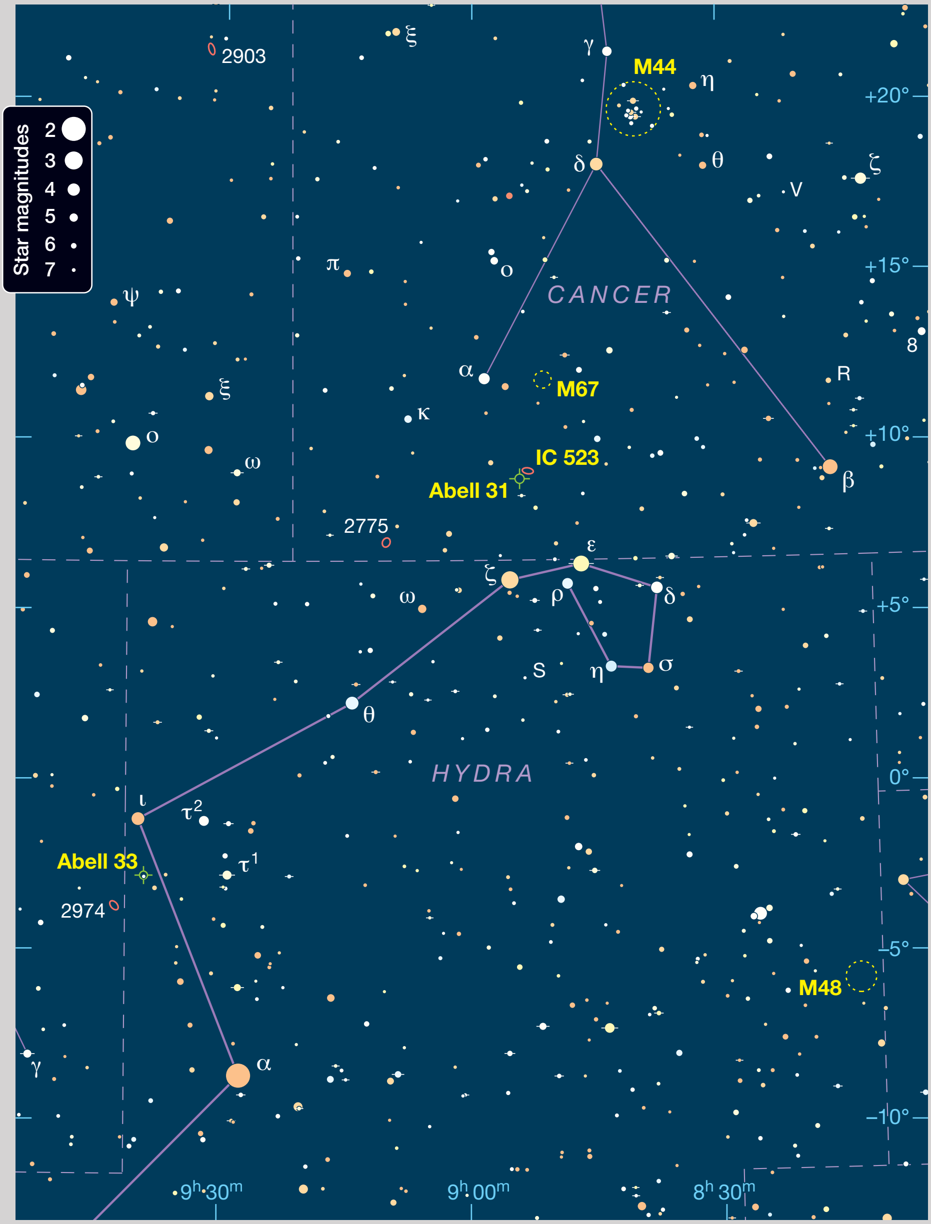
Doug and Janet Adams observed the Beehive under dark skies in Australia. Doug writes, "I was more impressed with the naked-eye view! Something I don't get from Melbourne is just what an eerie nebulous patch it is. Our view to the north was partially blocked by surrounding gum trees, and I didn't know what it was until I worked out what patch of the sky we were looking at." He also described the view through their 101-mm scope: "The telescope view exploded into a large patch of bright stars. It was framed well at 23× in the refractor." Even my 12×36 binoculars reveal a swarm of about 20 bright bees, nine of them flying in a V formation and four tinted yellow-orange. Fainter members double the count and spread across 70′.



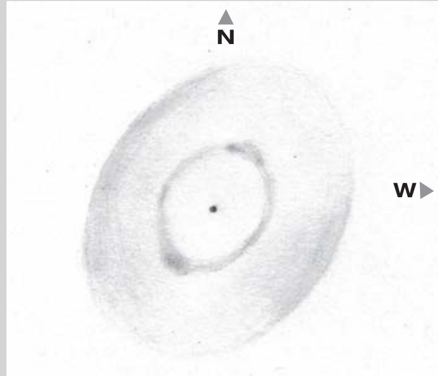
▲ Use an O III filter to search for the extremely faint, diffuse planetary nebula Abell 31; an H-beta filter might also help. Even with filters, this is a challenge object that will require dark skies and (realistically) at least 8 inches of aperture.

▶ In dark skies, the open star cluster M44 is visible to the naked eye. This image was created with a total of 1 hour exposure time with an f/4.9 astrograph.

SKETCH: JAAKKO SALORANTA; IMAGE: CHAD QUANDT



SUE FRENCH



▲The author captured this view of the planetary nebula NGC 3242, commonly called the Ghost of Jupiter, with her 10-inch Newtonian reflector at 308× while observing at the Winter Star Party in the Florida Keys.

The star-packed open cluster **Messier 67** also resides in Cancer, 1.7° west of Alpha (α) Cancri. Doug and Janet Adams shared their experience with this object as well. Doug says, "It's very easy to find from dark skies with the *Pocket Sky Atlas*. You can virtually see every star plotted with the naked eye — position the scope and boom! You've got it. Nice, rounded cluster with around 20 stars instantly resolved at low power, and one orange member very evident. My wife said it resembled Pacman, and I could see it once she'd said it. It has a concave shape to the cluster, as if it's gobbling stars ahead of it." Also observing with a small refractor, Ireland's Kevin Berwick says that M67 "is very rich and bright, and to the east there's a very bright star. It's quite compact and very similar to M37 in many ways. There's a bright fountain of stars in the cluster and at the top of the fountain is a rusty orange star." The cluster teems with about 80 faint stars spanning 22′ through my 105-mm refractor at 87×. The conspicuous orange star tacks the group's northeastern rim, and Berwick's sparkling fountain might also be fancied as a celestial tree.

A considerably more taxing target, the 16.2′ planetary nebula **Abell 31** lies 3.0° south-southeast of M67 and 25′ southeast of two colorful stars: orange, 8.5-magnitude HIP 43582 and yellow, 8.6-magnitude HIP 43618. Abell 31 is dominated by lines of doubly-ionized oxygen (O III) in its central region. With the help of an O III filter, experienced observers under dark skies have nabbed parts of the interior in scopes as small as 80 mm in aperture. Despite this impressive feat, Abell 31 is still no cakewalk in larger instruments.

After observing with friends, New York's Joe Bergeron wrote, "I didn't see a trace of it with my Stowaway [90-mm refractor], though Jenn Polakis immediately saw something in the correct location. We then looked with Tom Polakis's 10-inch f/5.5 at 40× with an O III filter. Now we could all barely see a vague circular glow, about half the size of the parallelogram of stars with which it's involved. Quite a challenge."

Steve Amerongen of Australia was able to detect some detail with his 25-inch scope at 144×, and he describes Abell 31 as a "very large, diffuse glow; fairly faint PN, with very ill-defined, soft edges; subtle mottling is visible throughout disk; also, the galaxy **IC 523** is visible about 21′ (from the center of the nebula) to the northwest; seeing was very good but transparency was average." His view was greatly enhanced with the use of an O III filter.

Much easier game, the splashy open cluster **Messier 48** dwells in Hydra, 3.0° south-southeast of the yellow,

Treasures in Cancer and Hydra

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 44	Open cluster	3.1	70′	8^h 40.4^m	+19° 40′
Messier 67	Open cluster	6.9	25′	8^h 51.4^m	+11° 49′
Abell 31	Planetary nebula	12.0	16.2′	8^h 54.2^m	+8° 54′
IC 523	Spiral galaxy	13.1	56″ × 35″	8^h 53.2^m	+9° 09′
Messier 48	Open cluster	5.8	30′	8^h 13.7^m	–5° 45′
Abell 33	Planetary nebula	12.6	4.5′	9^h 39.2^m	–2° 49′
NGC 3242	Planetary nebula	7.3	45″ × 36″	10^h 24.8^m	–18° 39′

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

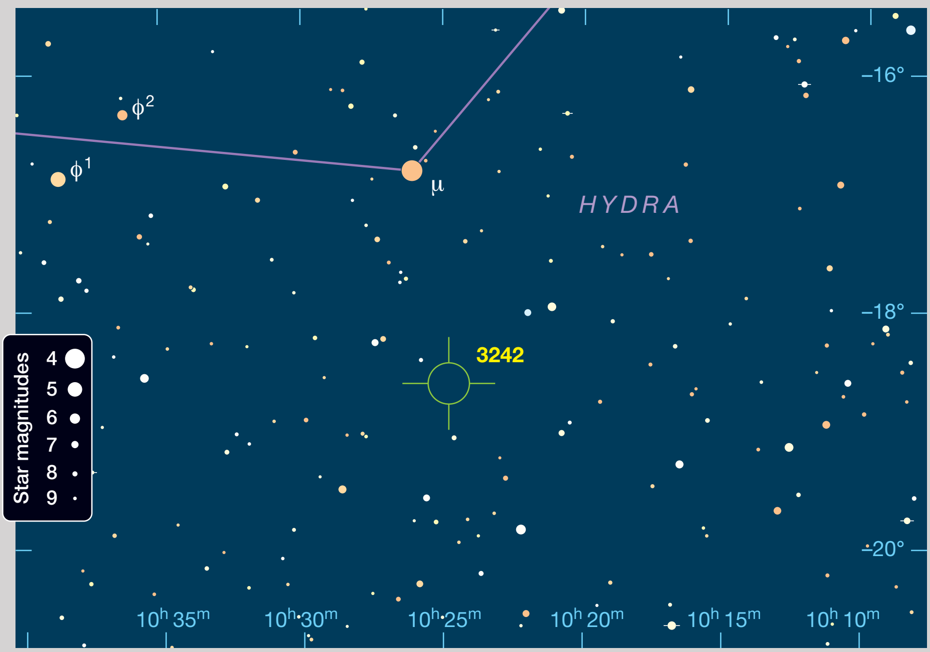
4.4-magnitude star Zeta (ζ) Monocerotis. As viewed in his small refractor, Kevin Berwick considers M48 an impressive group, and he reports, "There are quite a lot of bright stars in this cluster and a strong grouping towards the center, although not globular-like. There's a tight V of stars at the center of the cluster." Magda Streicher, an accomplished observer and astronomy author from South Africa, described the view through her 12-inch Schmidt-Cassegrain at 95×. She notes, "Caroline [Herschel] and Messier independently discovered this large, bright, and loosely expanded cluster displaying circles, pairs, and triplets. A prominent, uneven string of stars runs through the cluster in a north to south direction." Through a small scope at 50×, M48 spans 30′ and boasts about 60 stars, 8th magnitude and fainter.

Now we'll sweep over to the 3.9-magnitude, yellow-orange star Iota (ι) Hydrae and then drop 1.7° south to 4.5′ planetary nebula **Abell 33**. With his 25-inch scope at 187×, Steve Amerongen saw Abell 33 as an "oblong patch of nebulosity; it's slightly darker in the middle; very slight uneven surface brightness and mottling are visible in the disk; it has ill-defined/soft edges; the central star is easily visible; the nebula's invisible without the O III filter."

Spotting Abell 33 doesn't require a big telescope, but you'll need the O III filter. When I observed the planetary with my 10-inch and 15-inch scopes, it looked quite faint and vaguely annular. A 7.2-magnitude star (HIP 47369) rests just off the southwestern edge, and two faint stars pin the north-northwestern edge. A few years later, I swept up the star field that contains Abell 33 with my 130-mm refractor at low power, and I was surprised I could spot it immediately before checking its exact position. This time, I had the advantage of seeing the planetary 25° higher in the sky from a location in the Florida Keys. Abell 33 has also been captured in apertures as small as 80 mm.

We'll end our tour with the exceptionally beautiful planetary nebula **NGC 3242**, also known as the Ghost of Jupiter or the Eye Nebula. It lies much farther along Hydra's sinuous body, 1.8° south of yellow-orange Mu (μ) Hydrae and 27′ north of yellow-white, 8.1-magnitude HIP 50966. Steve Amerongen avers that this nebula is "an absolutely fantastic object; very beautiful; it has a vivid blue color; excellent at high powers; two distinct shells are visible; the central star is easily visible." He observed the nebula through his 25-inch scope, at 144× to 530×.

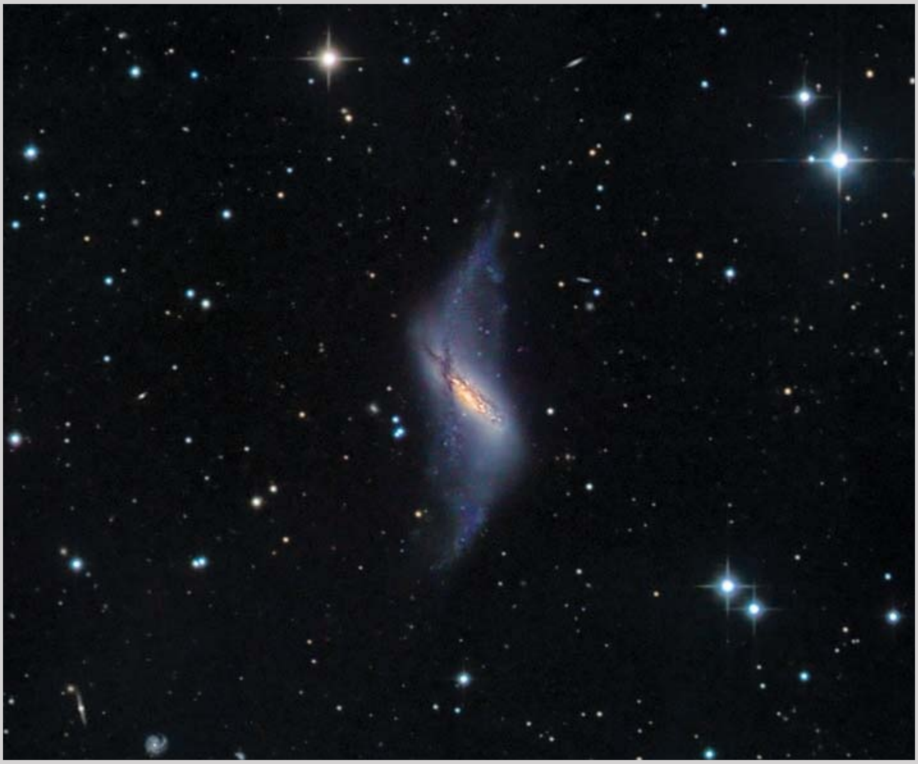
While the view through a large scope is spectacular, the vivid blue color can be appreciated even in a 4-inch scope, and a 10-inch scope at high power can reveal considerable detail. If you'd like a little music while observing NGC 3242, New York's John McMahon suggests "Ghost of Jupiter" by Lettuce, which you can listen to on YouTube.

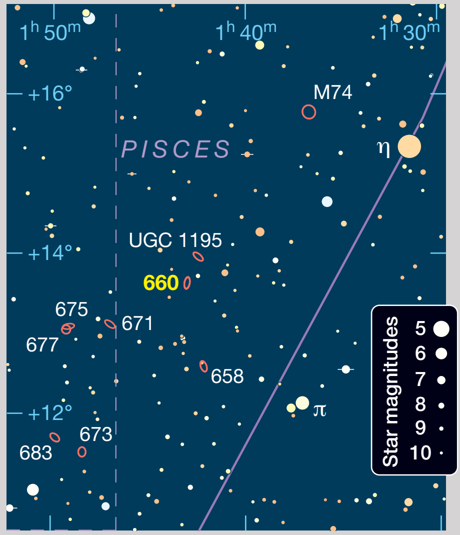


■ Contributing Editor **SUE FRENCH** welcomes your comments **scfrench@nycap.rr.com**.

Ancient Photons from AGNs

Light from these faraway galaxies has traveled for millions to billions of years, crossing vast expanses of space.





◀ **NGC 660** Situated some 43 million light-years away, this Seyfert is a fine example of a polar-ring galaxy. It's not yet known how these objects came to be: One scenario postulates the merging of two galaxies at a right angle, while another has the host galaxy tidally stripping a passing gas-rich spiral galaxy. Only a handful of these objects are known to date.

FRANK COLOSIMO

If you're a deep-sky aficionado who's always looking for another challenge to "go deep," try the Active Galactic Nuclei (AGN) Observing Program of the Astronomical League (**https://is.gd/al_agn**). Although there are several classes of AGNs, only three will be addressed here: Seyfert galaxies, BL Lacertae objects (BLL), and quasars — see the website above for a summary of their characteristics. In general, AGNs are very energetic and active objects powered by supermassive black holes, and their complex natures can give rise to very different outputs of radiation.

Let's take a closer look.

Seyfert galaxies are mostly spiral galaxies with less luminous AGNs, thereby making the host galaxy visible. Many of you have observed or imaged several AGNs, perhaps not realizing that they were in this category. Popular Seyfert galaxies include M61, M81, and M104, along with a host of Herschel objects. There are 30 such galaxies brighter than magnitude 13.8, and their distances are measured in the tens to several hundred million light-years.

BLL are hosted in massive galaxies. Try this type of variable AGN if you want to go deeper. They're more distant, situated between 0.5 to 10 billion light-years away, and as such, tend to be dimmer, ranging in magnitude from about 13 to 17.

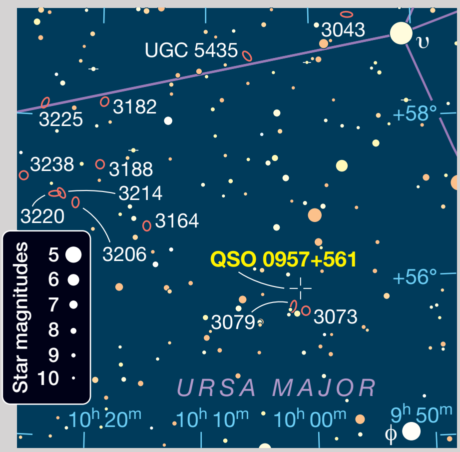
Quasars are extremely bright AGNs that overpower their host galaxy. They are at distances listed in the millions to billions of light-years. The brightest, with a magnitude of 12.9, and perhaps best known is 3C 273 in Virgo at a distance of slightly more than 2 billion light-years. Interestingly, Markarian 509 in Aquarius is much closer at 490 million light-years and shines at magnitude 13.1. More awe-inspiring are the sub-types of quasars: gravitationally lensed and double, or binary, quasars. The former are quasars whose light has been gravitationally distorted around a massive foreground object and may be split into two or more points of light with identical spectra. The latter are two distinct quasars in close proximity in the sky, possibly gravitationally bound (not to be confused with the Twin Quasar, see below) and, consequently, having different spectra.

Plan of Attack

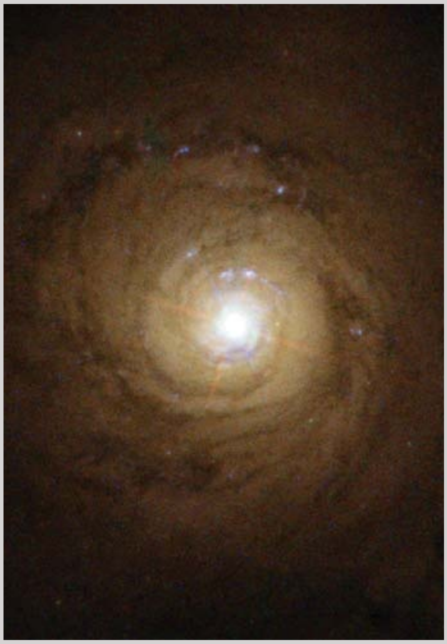
As with any observing endeavor, preparing ahead of time will enhance the experience. Those of you with Go To capabilities can prepare a list of AGNs to upload into your device. Whether using Go To or star-hopping from a nearby object to your target, having a detailed sky chart will help you differentiate the AGNs from any foreground stars in the eyepiece. *Observing Variable Galaxies* by Alvin Huey (**https://is.gd/huey_ovg**) can well serve this purpose for the 65 objects he lists. Several online lists are available in addition to those on the Astronomical League website, such as the one provided by Wolfgang Steinicke, **https://is.gd/steinicke**. High magnification is a key factor in your success, as is better-than-average seeing and transparency from dark skies. Jotting down the distance of your object beforehand adds to the joy once you've captured it with your eye or digital-imaging setup. Published redshifts (*z* values) can be converted to light-years with online calculators; note that the resulting distance depends on which cosmological model is adopted.

What You Might See

Below is a sampling of my observing notes on the more than 80 AGNs that



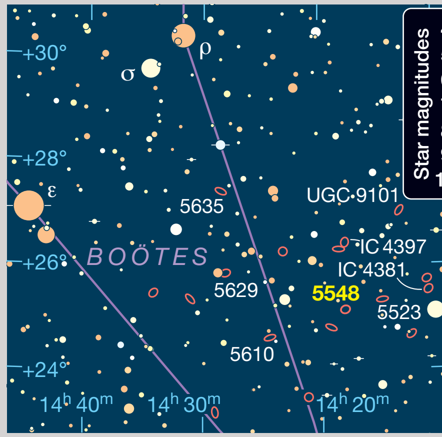
▶ **DOUBLE VISION** Astronomers observing QSO 0957+561, or the Twin Quasar, were suspicious of the two objects' similarity. When they discovered that the two sources had identical spectra, they soon realized they were witnessing gravitational lensing — light from the distant quasar was being gravitationally distorted by a massive foreground object.



were seen visually. I relied mostly on 20- and 22-inch reflecting telescopes.

Seyfert Galaxies

NGC 660, an 11th-magnitude polar-ring galaxy located a mere 43 million light-years away in Pisces, was best seen at 77× with a galaxy-contrast-enhancement (GCE) filter. The nucleus appeared stellar or mottled. I found this hazy glow in the middle of a triangle



◀ **NGC 5548** As with all AGNs, a supermassive black hole is responsible for powering this Seyfert galaxy. Turn your telescope toward this object in March — you won't see the black hole, but you will observe photons that have traveled 230 million years. For clarity, galaxies have been omitted in the top left of the chart.

formed by two pairs of wide double stars and a single star.

NGC 5548 in Boötes, the Herdsman, is 230 million light-years distant and showed as a slightly elongated galaxy with a central brightening.

BLL

1ES 2344+51.4 in Cassiopeia was easy to find, but I needed 416× to recognize the star field that resembled the one found in the printed chart. This BLL, at some 615 million light-years distant, was small yet relatively bright. Since it was adjacent to a field star, the pair looked like a double star, oriented southeast-northwest, at first glance.

3C 66A in Andromeda, with a *z* of 0.444 corresponding to a distance of 4.8 billion light-years, was stellar in appearance. It makes a right triangle with a field star and **UGC 1841** (also known as 3C 66B), a foreground Seyfert galaxy at 300 million light-years. A veritable two-for-one special!

Quasars

KUV 18217+6419 in Draco was a faint dot whose light has traveled some 3.5 billion light-years. Nearby, the planetary nebula PK 94+27.1 was undetectable in any filter.

PG 1718+481 in Hercules was rela-

GALAXY: ESA / HUBBLE / NASA; TWIN QUASAR: ROBERT GENDLER

Flavors of AGN

Object	Type	Redshift (z)	Distance (million l-y)	Mag(v)	Size	RA	Dec.
NGC 660	Seyfert	0.003	43	11.2	8.3′ × 3.2′	$01^h 43.0^m$	13° 39′
NGC 5548	Seyfert	0.016	230	12.6	1.4′ × 1.3′	$14^h 18.0^m$	25° 08′
1ES 2344+51.4	BLL	0.044	615	15.5	36″ × 28″	$23^h 47.0^m$	51° 42′
3C 66A	BLL	0.444	4,800	15.2	–	$02^h 22.7^m$	43° 02′
UGC 1841	Seyfert	0.021	300	14.0	3.3′ × 2.3′	$02^h 23.2^m$	43° 00′
KUV 18217+6419	Quasar	0.297	3,500	14.2	–	$18^h 22.0^m$	64° 21′
PG 1718+481	Quasar	1.083	8,300	14.6	–	$17^h 19.6^m$	48° 04′
QSO 0957+561	Lensed quasar	1.41	9,300	16.9	–	$10^h 01.3^m$	55° 54′
QSO 2237+0305	Lensed quasar	1.695	10,000	16.8	39″ × 22″	$22^h 40.5^m$	03° 22′
J014709+463037	Lensed quasar	2.341	11,000	–	–	$01^h 47.2^m$	46° 31′

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

tively easy to find. The star-like object, situated at 8.3 billion light-years, formed a small arc with two foreground stars.

The first lensed quasar was discovered in 1979. **QSO 0957+561**, or the Twin Quasar, is in Ursa Major and can be found easily by star-hopping less than ½° northwest from NGC 3079 via asterisms shaped like a triangle, a pentagon, and finally a trapezoid — the quasar is located off the top-right corner of the trapezoid. I made two attempts to observe this object, the first under excellent skies (NELM 6.3) at Cherry Springs State Park, Pennsylvania. However, I wasn't able to split it. Six years later, I made a second attempt from another dark-sky site (NELM 5.9). This led to success; the split was easily observed. The light from this quasar, traveling 9.3 billion light-years, is gravitationally lensed by a foreground galaxy, YGKOW G1, a mere 4 billion light-years away. Why could I not split the lensed quasar the first time? Looking back at my notes it appears that the object was quite low in the sky the first time and more favorably placed the second.

The capstone object for me was **QSO 2237+0305**, also known as the Einstein Cross in Pegasus, that I observed twice over several attempts. Again, looking back at my notes, I can see that success depended upon high magnification, steady seeing, and good transparency. Initial views showed granularity, while observing it for several minutes revealed the four points of light. The foreground galaxy CGCG 378-15 (PGC 69457) presented itself variously as a small, elongated glow; a hazy glow with a stellar nucleus; or as a compact and solid-looking galaxy, depending upon sky conditions, aperture, and location. If you detect a stellar nucleus, try higher magnification to snag these ancient photons from nearly 10 billion light-years away.

More recently, the lensed quasar **J014709+463037** was discovered serendipitously by PanSTARRS and shortly thereafter given the moniker Andromeda's Parachute by Kate H. R. Rubin (San Diego State University) and others. Three of its four components, with *grizy* magnitudes between 14.9 and 18.1, lie in a small arc with an even fainter fourth component underneath. Several amateurs have observed one or more of the components. I viewed the two brightest components, split in brief moments of steady seeing, at 770×. Its redshift translates into a distance of around 11 billion light-years!

FINDER CHARTS

For more finder charts on the AGNs covered here, visit **https://is.gd/ch_agn**.

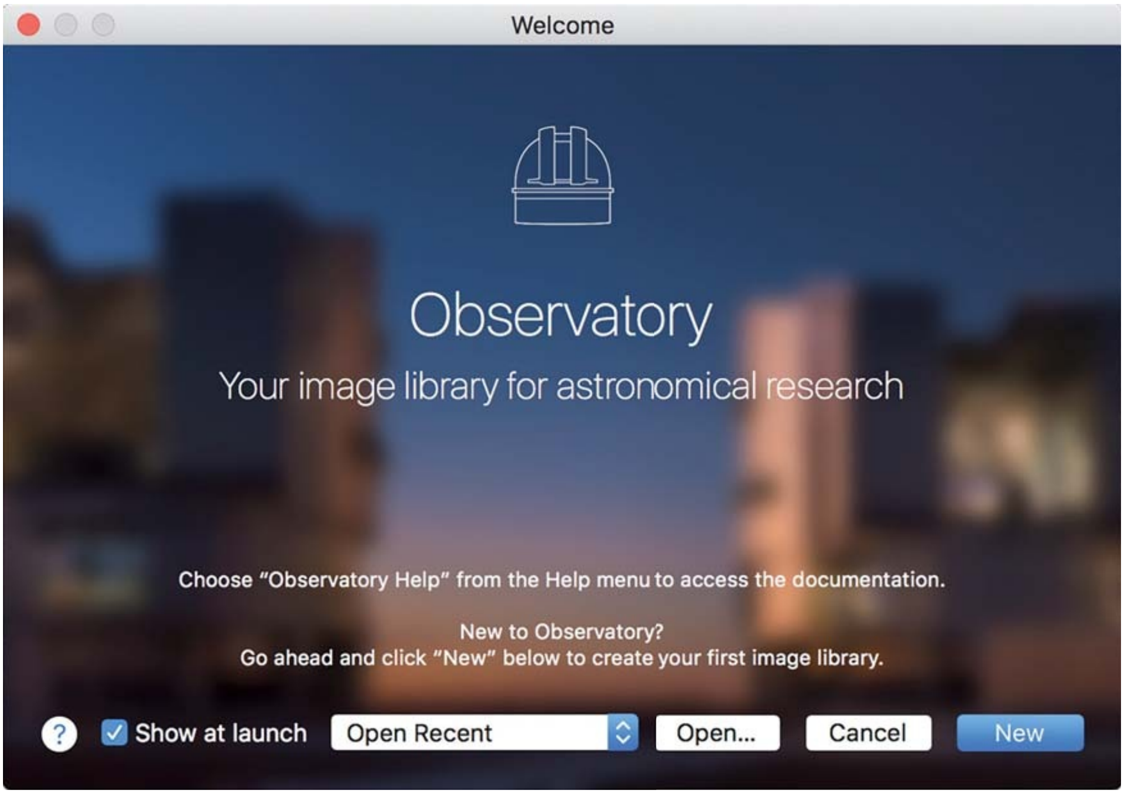
Final Words

The Big Bang occurred over 13 billion years ago. Imagine capturing light that's been traveling through space for over half that time. Imagine as well how unique it is to have that light stimulate your retina or imaging chip. Those thoughts can be mind-numbing and humbling. The endeavor also makes you appreciate ever more so the wonders that are up there just waiting for you to capture them. So how deep and far back in time can *you* go?

■ **AL LAMPERTI** has been going deep since 1985 when he acquired his first light bucket. He and other members of the Delaware Valley Amateur Astronomers developed the AGN Observing Program for the Astronomical League.

Managing Images with Observatory

This program for Mac computers helps you to organize your image data, and more.



▲ *Observatory* is an astronomical-image management program for Mac computers running OS X 10.11 or later, with a 64-bit processor.

Observatory 1.1.1 By Code Obsession

U.S. Price: $79.99
codeobsession.com

What We Like:

Finder Previews
Online database searches
Overlays for plate-solved images

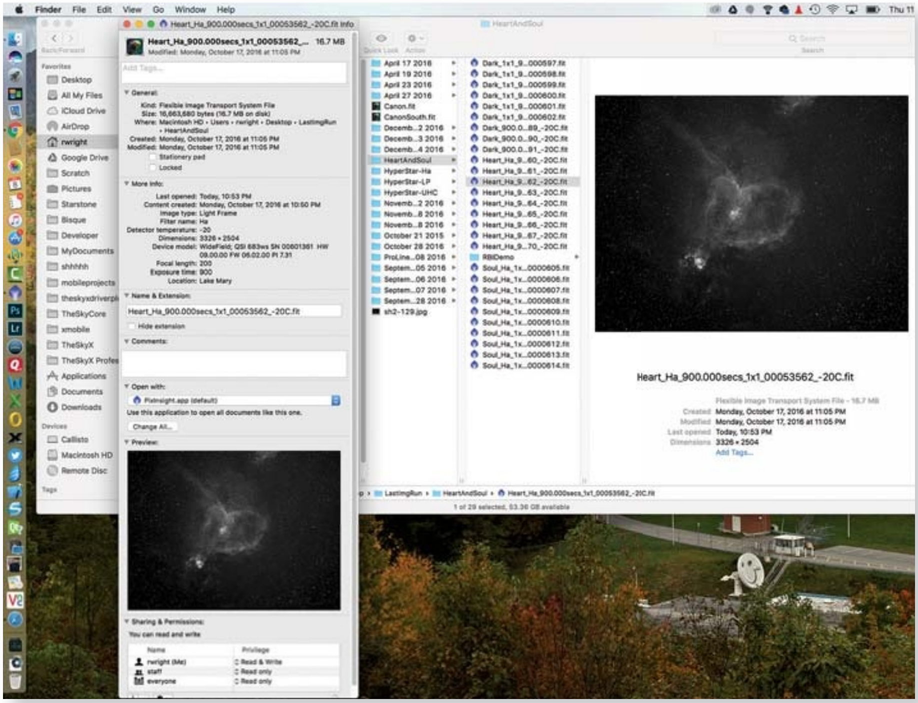
What We Don't Like:

Interface not always intuitive
Plate solving was tricky
Extraneous features

FOR SOME, astrophotography is a hobby, a pastime that keeps us busy and out of trouble. For others, it's a passion, maybe even an all-consuming passion. For those latter people, among whom I include myself, tend to accumulate a lot of data. Years of imaging every clear night will generate a lot of FITS files (FITS is the standard image file format for astronomical images). Hard-drive storage is cheap these days, so it's not unreasonable that some seasoned astrophotographers may have hundreds of gigabytes or even terabytes of astronomical data amassed over the years.

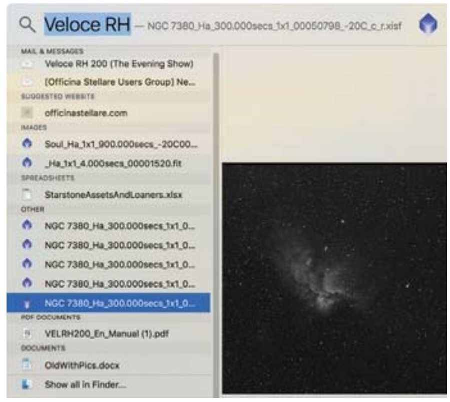
How on earth do you keep track of it all, or find anything? For those who think hierarchically, there are folders upon folders based on objects or regions of the sky. Or perhaps you organize by camera/optic, or maybe just by date-based folders. For "normal" photographers there are myriad tools for organizing photo shoots or projects. My smartphone can show me all the photos I've ever taken with dogs in them, and I never even tagged any of them with "dog." We live in the future. None of these tools, however, would know what to do with FITS files, much less try and create a system whereby they can be searched easily. But now there is finally such a tool, and it's called *Observatory*.

With so much astronomical software being only available for Windows, it's nice to see a high-quality tool available for the Mac. Since I prefer to use a Mac on a day-to-day basis myself, I was especially keen to see what *Observatory* had to offer.



◀ *Observatory* adds functionality to your Mac. After installation, your desktop's Finder will display a preview of FITS images as it does for any other common image type. You can also access useful FITS metadata via "Get Info".

▼ The program also enables the MacOS *Spotlight* feature to locate FITS files based on keywords in the FITS header. For example, you can search for all images taken with a specific telescope or camera.



Shell Extensions

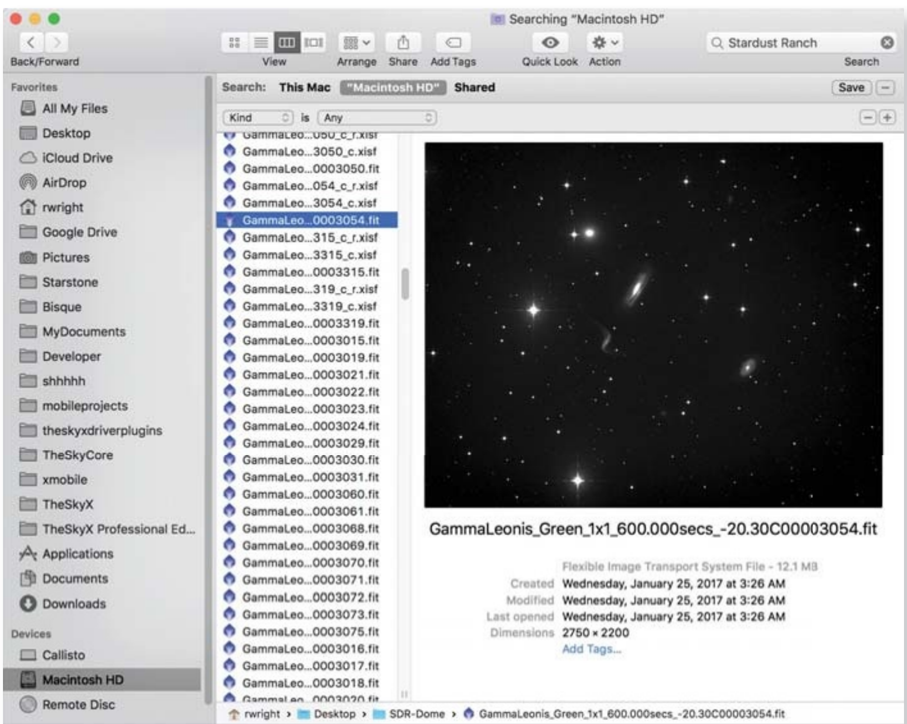
The most exciting two features of the software to me actually aren't part of the main application at all. Simply installing the program extends the Mac user environment by adding image preview support in *Finder*, and *Spotlight* support for FITS headers.

Preview support is fantastic. When navigating your files with the Mac's *Finder*, a nice auto-stretch is applied to your astronomical images, and they can be previewed just like you'd expect any image format to be, such as JPEG or TIFF. When you install *Observatory*, this support includes both the FITS format, which is standard with most astro-imaging software, and the *PixInsight* native format XSIF, as well as the SBIG native formats for *CCDOPS* users. It's also amazingly fast, even for large image files.

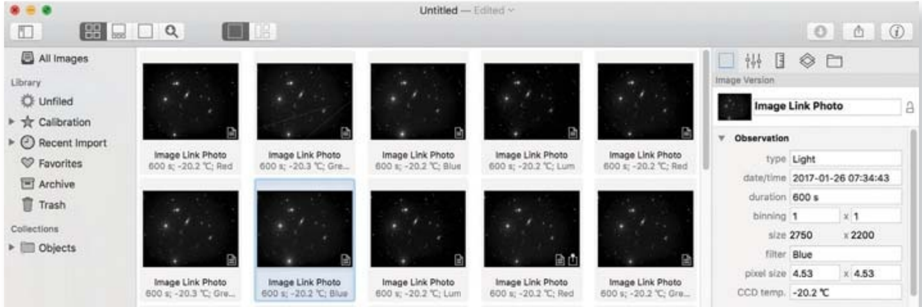
In addition to an image preview, "Get Info" will display some of the most pertinent information from the FITS header, such as image type, filter name, exposure, etc. How many times have you had to open a FITS file just to inspect the header for some of these items?

While this is quite useful, even more amazing is that *Spotlight* can now extend its search to the FITS headers in the images on your hard drive. This includes all the FITS files on your system, not just the ones managed by *Observatory*! Be advised this doesn't happen instantly; it takes some time (potentially days) for *Spotlight* to catalog all your images in the background.

Spotlight is one of my favorite features of the Mac to begin with. If I can remember just a scrap of information about some document or email, *Spotlight* can find it for me. It will locate almost instantly Word documents, emails,



▲ Searching your hard drive for a specific location will now not only turn up documents with that keyword, but also FITS files with that keyword in the header.



▲ Much like other photo organizers, *Observatory* presents all your astronomical images as thumbnails. Because FIT files are linear and dark before post-processing, an auto-stretch is automatically applied to the preview, allowing you enough information to recognize the field.

and even a website I've visited from my browser history. It's my habit to set up the *TheSkyX*'s camera control so that my FITS images are tagged in the header with not just the essential camera and filter settings, but also my location and the optic and camera I used. Do I want to find all the images I shot with an Officina Stellare RH-200 using a Finger lakes Instrumentation ML16200 camera, or maybe just images taken at a specific star party? It's no problem!

All FITS keywords aren't stored, but many of the more useful ones are. For example, ORIGIN is indexed, so I can almost instantly locate all files taken at my Stardust Ranch observatory.

The Library

The core purpose of *Observatory* is to serve as an organized library of your FITS archives. Somewhat like the application *Photos* on the Mac, you can preview all the images in your collection and organize them by albums based on object types. When you first start *Observatory* it will ask you if you want to start importing images or add a source folder.

To get started, you have to add a source folder and then import the images into it. The rationale for this two-step process at first eluded me.

The library file you can save here does not contain all the images, but only the metadata for where the images are. I could, for example, add other images to this collection, say from other imaging runs or of the same object using different telescopes and cameras. I could also add reference images here from one of a number of online image archives.

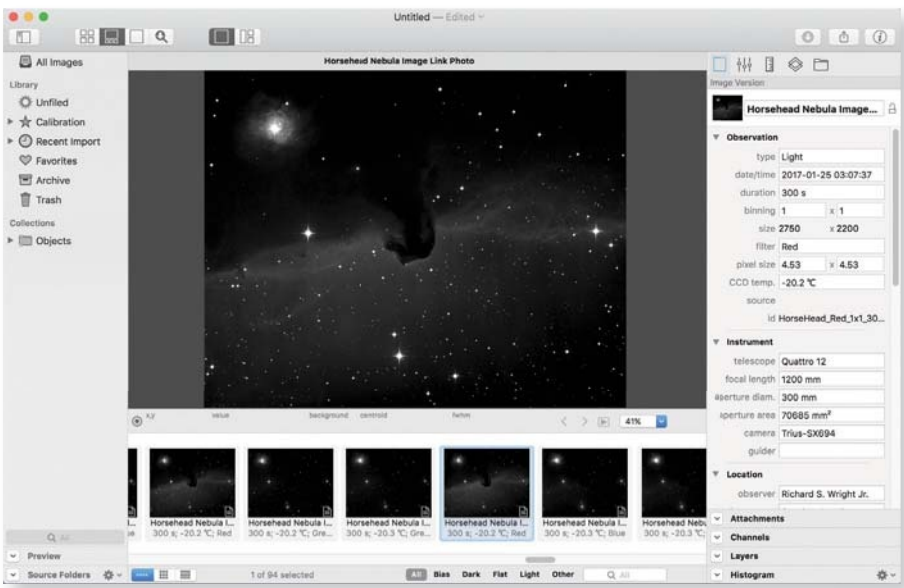
Once you've set up a folder full of FITS files, *Observatory* will apply a screen stretch (which does not alter the actual files) and display them as thumbnails. Double-clicking an image or changing the view mode will display an "editor" for more detailed image inspection. Moving the mouse around over the image displays information like the background counts, as well as the centroid and FWHM values for stars in the field.

Observatory also features "Smart Folders" and will use object names and metadata to try and categorize your images to things like dark or emission nebula, or galaxies. I found this feature to be mostly hit or miss (not quite as accurate as my iPhone's "dog" filter, but give it time), so I prefer to assign objects to the smart folders myself.

The Virtual Observatory

Another major feature of *Observatory* lets users add images from a number of online sources. Searching with the Virtual Observatory feature will teach you a great deal about the professional community and the kinds of data being produced by the world's astronomical institutions for research. Some of it, I should stress, is very useful for imagers looking for interesting source data. All of it is of course useful or interesting for analysis if your imaging goals are more science-related, though a fast internet connection is recommended. Searching is easy enough — type in the name (common or astronomical) or the coordinates of your desired target and off it goes to search any of the 11 available repositories you have selected.

A browser window lists the images found and other useful information, including the date the image was acquired, instruments used, coordinates, and image scale. You can scroll down through the list, and many of the images will have previews available that are displayed in the lower left of the window. Clicking the small preview will bring up a larger version of the image, and you can also transfer the image to *Preview* (the Mac default image viewing program), and of course import it into your own library.



▲ Double-clicking any thumbnail in *Observatory* opens a larger preview and displays additional image details from the file's metadata, such as FITS headers when selecting FITS files.

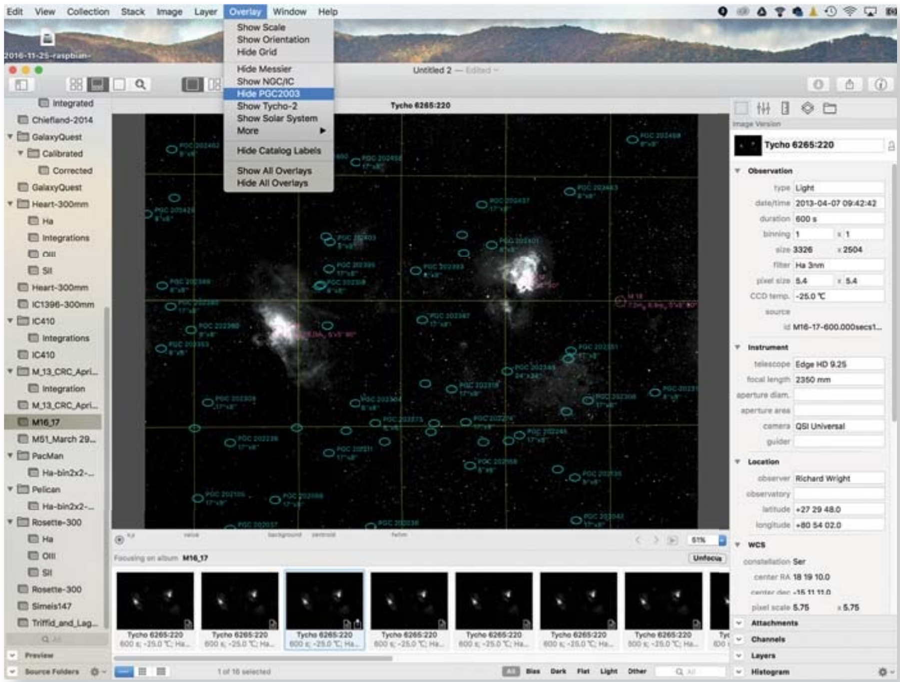
Wait, are you serious? Is that a 14,400 × 10,800 pixel Hubble image at a scale of 0.05 arcseconds per pixel?! A little Curves in *Photoshop* and look Ma, I can process Hubble data too! In fact, this is probably the easiest way I've come across to find raw Hubble data in a usable form for us mere mortals.

Matching Images

Observatory calls plate solving (providing an astrometric solution) "Matching" the image. Honestly, I was only able to make this work once, even after adding the optional 9-gigabyte USNO UCAC4 dataset. There are a number of hints, and one of the prerequisites is knowing the RA/Dec of the field for a starting point (which can automatically be extracted from the FITS header). Fortunately, whether you use *Image Link*, *PinPoint*, or Astrometry.net to plate solve, the embedded WCS (World Coordinate System) stored in the FITS headers is recognized by *Observatory*, so there are a number of other readily available ways to achieve this goal.

Having an image "matched" enables another of my favorite features: overlays. There are a number of nice overlays available — Messier objects, PGC galaxies, Tycho-2 star designations, solar system objects, and RA/Dec Grid, an orientation arrow, and image scale.

The overlays, along with some information about the image including your own added notes, are displayed when you export the image to a PDF, which I thought was another nice and time-saving feature.

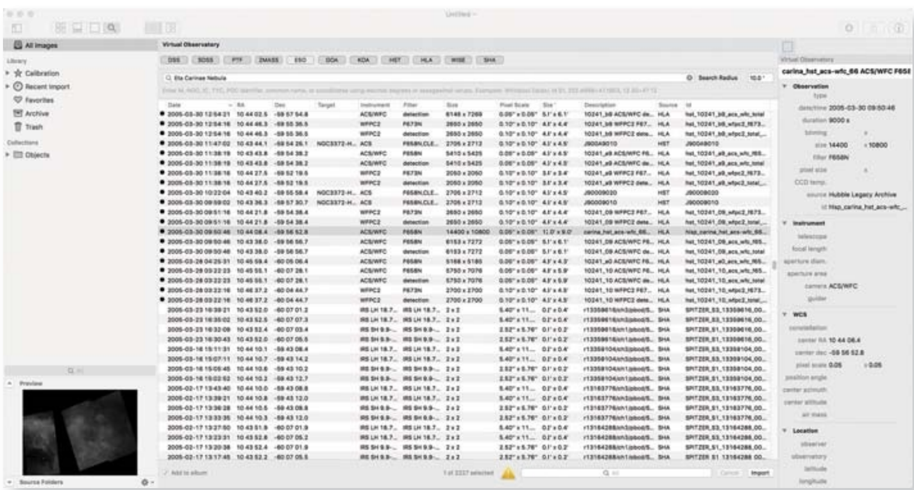


▲ Another of the program's excellent features is its ability to create custom overlays with labels and coordinate information. This works once an image has been plate-solved, or "matched".

Conclusion

This is a tremendous set of features, and I would recommend *Observatory* to any Mac-loving astrophotographer based on these alone. *Observatory* also offers the ability to calibrate and stack images in the library. I haven't focused on these features because I honestly question their presence, as I feel they distract from the core strengths of the application. There is so much more to preprocessing than simply calibration and stacking, and I wonder where the author is headed. Better in my opinion to keep *Observatory* focused on managing my collection, and offer another product if the desire is to begin competing in the image-processing market. On the other hand, I must admit getting your subs calibrated, stacked, and ready for additional work is also a compelling factor, and for the price of *Observatory* you do get a decent native calibration and stacking program for MacOS.

While the user interface seemed a bit counter-intuitive to me at times, it is a fantastic image management tool and great for online data mining. My only critique is I'd rather see the author focus more on the core strengths and utilities of the program, and leave processing to other packages, or break this functionality out into a complementary product.



▲ Browsing online data sources with Virtual Observatory could not be made much easier than this. You can easily get lost in the treasure trove of online images available from many professional observatories, including raw data from the Hubble Space Telescope.

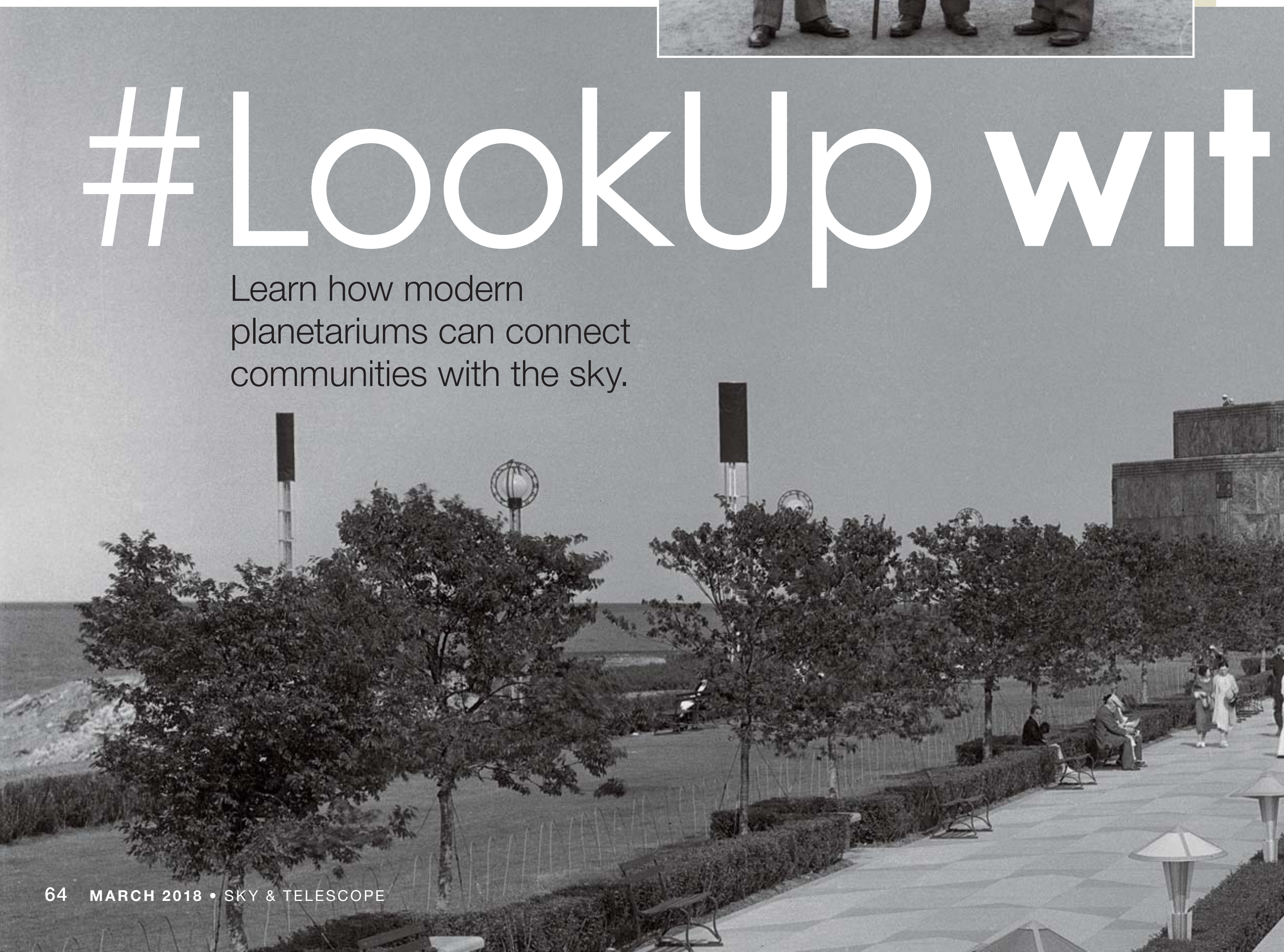
■ **RICHARD S. WRIGHT, JR.** is a software developer for Software Bisque. He writes a monthly blog on astrophotography at **https://is.gd/3yZO2K**.

In 1928, two Chicagoans boarded a ship to Jena, Germany, with stars in their eyes.

Max Adler, a vice president for Sears, Roebuck and Co., was on a mission to bring the night sky home to Chicago. In the years before the trip, he had been looking for a way to contribute to a city that was growing and changing, constructing institutions that would allow its citizens “to live a life richer and more full of meaning than was available for the citizens of yesterday.” Then, he found his opening in the universe. A new device that could project the stars onto a dome — a “planetarium” — had debuted in Germany a few years earlier, and the result was awe-inspiring.

Accompanying Adler was Ernest A. Grunsfeld, Jr., a renowned Chicago architect who would help Adler design a facility to showcase this modern wonder on Chicago’s lakeside. Grunsfeld, whose name may sound familiar, is the grandfather of NASA astronaut John Grunsfeld. The astronaut’s repair work on the Hubble Space Telescope would later contribute to the vision of his grandfather and Adler by enabling the telescope to capture stunning images of the

DÜSSELDORF TRIO: ADLER PLANETARIUM; PLANETARIUM: HEDRICH-BLESSING COLLECTION / CHICAGO HISTORY MUSEUM / GETTY IMAGES; TICKET: ADLER PLANETARIUM



#LookUp wit

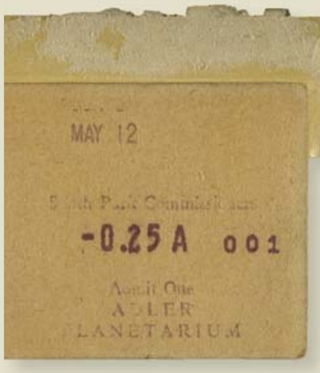
Learn how modern planetariums can connect communities with the sky.

cosmos that would captivate audiences on planetarium domes for generations to come. With his drive to build the first planetarium in the Western Hemisphere — America's first planetarium — Adler established a foundation for public engagement in astronomy that continues to this day.

Lighting the Way

When the Adler Planetarium first opened its doors on May 12, 1930, the public was ready to start exploring the universe. Perhaps because it was also Max Adler's birthday, or more likely as a sign of the times, people came dressed for an outing and waited in line to pay the $0.25 entry fee for a ticket to the stars. Embraced by the locals, the Adler quickly established itself as a pillar of Chicago's vibrant cultural landscape. Three years later, under Director Philip Fox, the Adler and the star Arcturus played a visible role in the opening of the Century of Progress International Exposition (Chicago World's Fair). Rufus C. Dawes, then-president of the World's Fair, set the stage with these opening remarks:

"We recall the great Columbian Exposition of 1893. Never will its beauty be surpassed. Never will there be held an exposition of more lasting value to this city. It was for Chicago a great triumph. We remind ourselves of that triumph tonight by taking rays of light that left the star Arcturus during the period of that exposition and which have traveled at the rate of 186,000 miles a second until at last they have reached us. We shall use these rays to put into operation the mysterious forces of electricity which will make light our grounds, decorate our buildings with brilliant colors, and move the machinery of the exposition."



▲ **BIG DAY OUT** The Adler Planetarium opened its doors on May 12, 1930, Max Adler's birthday. Excited patrons paid $0.25 for a single-admission ticket. The average daily attendance for the first two years was 1,704.

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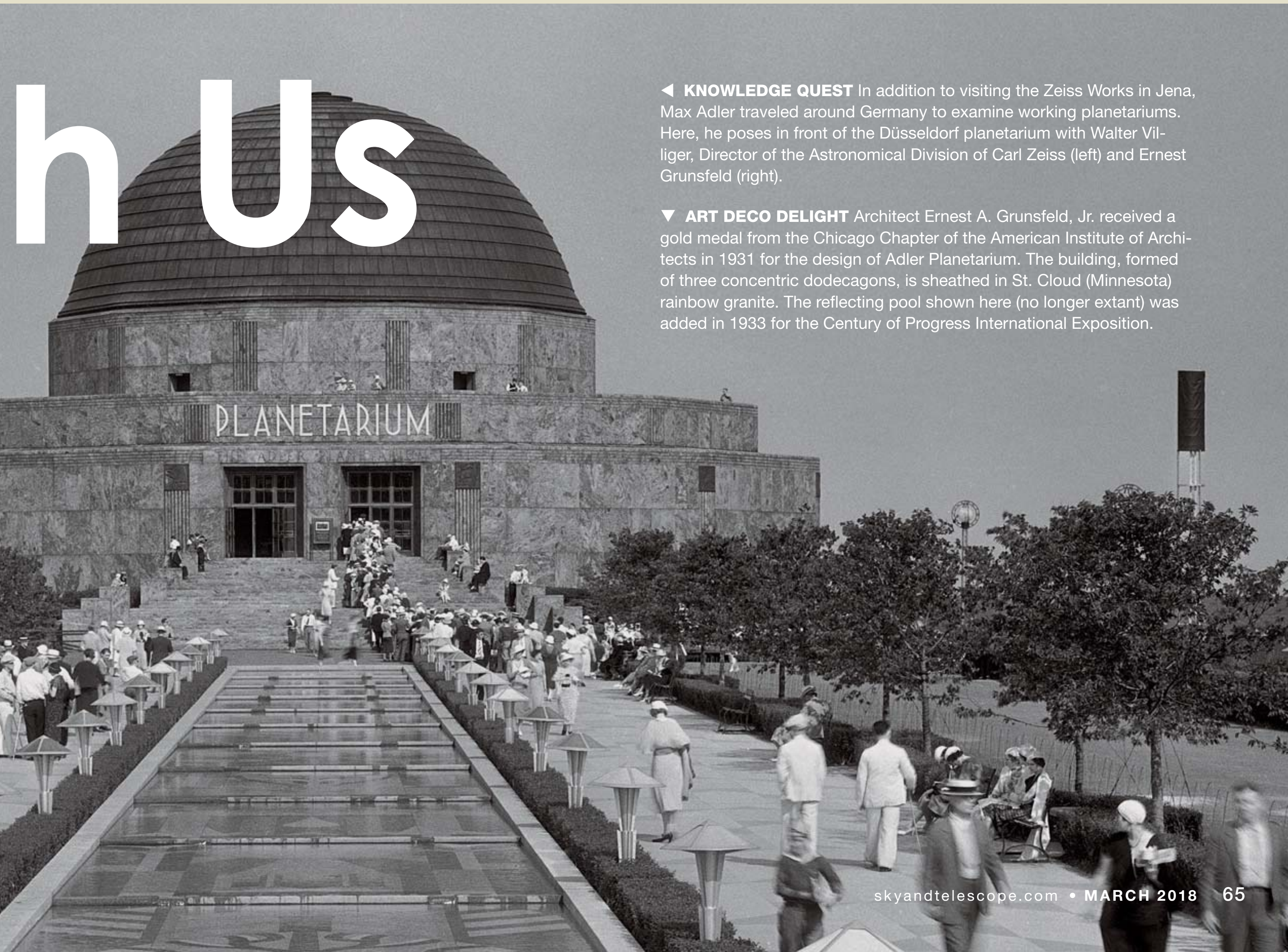


◀ **KNOWLEDGE QUEST** In addition to visiting the Zeiss Works in Jena, Max Adler traveled around Germany to examine working planetariums. Here, he poses in front of the Düsseldorf planetarium with Walter Villiger, Director of the Astronomical Division of Carl Zeiss (left) and Ernest Grunsfeld (right).

▼ **ART DECO DELIGHT** Architect Ernest A. Grunsfeld, Jr. received a gold medal from the Chicago Chapter of the American Institute of Architects in 1931 for the design of Adler Planetarium. The building, formed of three concentric dodecagons, is sheathed in St. Cloud (Minnesota) rainbow granite. The reflecting pool shown here (no longer extant) was added in 1933 for the Century of Progress International Exposition.

Fox followed with, “Harvard, are you ready? Yes. Is Allegheny ready? Ready. Illinois ready? Yes. Yerkes? Let’s go.”

Four sites across the country had trained their telescopes on the star Arcturus, which at the time was estimated to be at a distance of 40 light-years away, meaning that the arriving photons would have left the star in 1893 — the time of Chicago’s first big fair, the Columbian Exposition. Once Arcturus was in view, light was directed into photocells at the four sites, and the generated current travelled to Chicago to light up the World’s Fair. A Rube Goldberg-like chain of events for certain, but a grand demonstration of the hold astronomy has on the hearts and minds of the public — then and now.

At the Adler, we’re inspired by our founder’s vision — and our city’s response to that vision — to continue the legacy of community engagement. Thinking about the role of the planetarium in the modern era, we look to Adler and his founding words for guidance and translate them into modern vernacular through — what else? — hashtags! Adler said, “The popular conception of the Universe is too meager . . .” We say #LookUp! Adler said, “The planets and the stars are too far removed from general knowledge.” We say #AstroEverywhere.

▲ **CREATURE COMFORTS** Attendance at public observing events at Adler’s Doane Observatory skyrocketed, jumping from 400 visitors per year to 22,000 after a renovation project made the building more accessible and more comfortable.

ADLER PLANETARIUM

Eyeball to Eyepiece

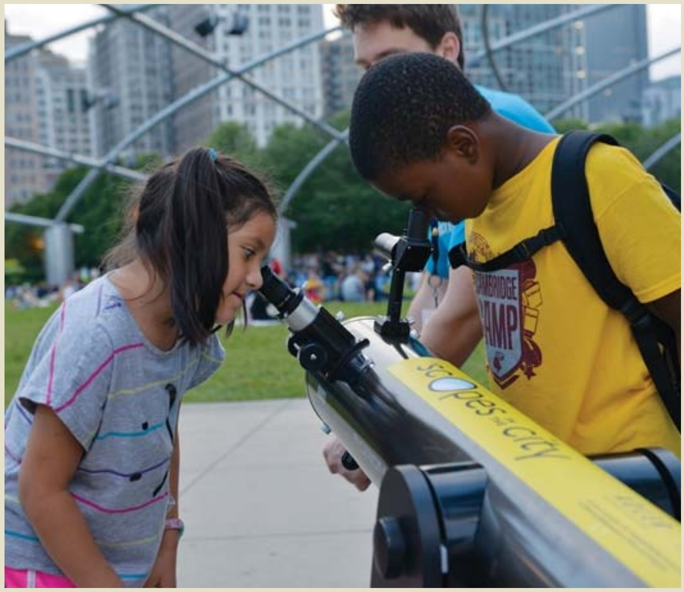
Today, the public is much more aware of the planets and stars than in Adler’s day. A steady stream of stunning imagery and frontier discoveries made by ground-based observatories, satellites in orbit around the Earth and travelling through our solar system, and facilities like the Laser Interferometer Gravitational-wave Observatory (LIGO) have secured a special place for astronomy in our imaginations. However, as any amateur astronomer knows, these technological breakthroughs are no substitute for interacting directly with the sky.

As an amateur astronomer myself, it’s been my experience that a telescope on a grassy patch or concrete corner is a great attractor. While color-balanced, high-resolution images from NASA’s finest are indeed stunning, putting one’s own eyeball to the eyepiece is an experience like no other.

After a 2014 renovation to make the Adler’s Doane Observatory more accessible and friendly to the public (think climate-controlled holding room and restrooms!), we have seen public interest in observing at the Observatory rise from 400 people per year to more than an astounding 22,000 per year in 2017. Despite Chicago’s urban, light-polluted skyscape, we enthusiastically observe the Sun and the Moon during the daytime, and our *Doane at Dusk* evening events offer stunning views of the Moon, Saturn, Jupiter, and a few other bright objects in the night sky.

Even without an observatory on site, planetariums can help the public #LookUp by recruiting telescope volunteers, often from a local amateur astronomy society, and by positioning a telescope or two outside their doors. They can even take telescope outreach a step further and leave the facility grounds altogether. That’s what we did in 2015 when we launched our *’Scopes in the City* program, which sends astronomers, volunteers, and telescopes to neighborhood parks, schools, libraries, and other public spaces across Chicago. The program grew out of an awareness that many of our neighbors face obstacles to visiting the museum — and our desire to share the eyeball-to-eyepiece experience with as many people as possible. Today, *’Scopes in the City* hosts free observing events in more than 25 neighborhoods and reaches more than 2,000 people per year.

◀ **SUN STUDY** An Adler Planetarium volunteer explains solar filters to a young visitor as part of the institution's public programming.



▲▶ **'SCOPES IN THE CITY** In an effort to bring the universe to those that may not be able to visit the planetarium, the Adler launched an outreach program in 2015 to bring telescopes to Chicago neighborhoods.

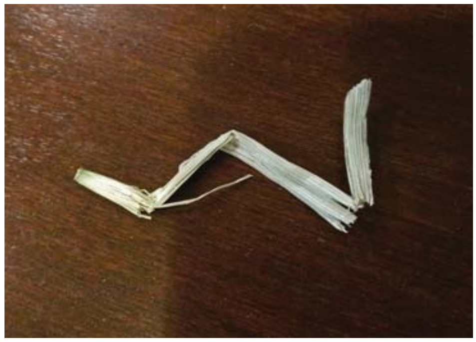
ADLER PLANETARIUM (4)

While little compares to facilitating someone's first "Saturn Moment," planetariums can also help the public #LookUp on the dome, where guests can learn and navigate the constellations or embark on a journey of wonder and discovery. Digital dome shows can connect us to our ancestors who also would #LookUp, ask questions, learn something, discover another unknown, ask more questions, and repeat, just like we do today. Planetariums are in a unique position to remind our audiences that we're human — we cannot help but explore.

It's powerful to share what we've learned about the universe and what we still don't know, and then to suggest that someone in this very room may be able to help figure it out. After inspiring people under the dome or at the telescope, we invite them to participate in scientific research through zooniverse.org, a citizen science platform that began as a partnership between the Adler Planetarium and Oxford University in the United Kingdom. More than 1.6 million *Zooniverse* volunteers around the world are classifying galaxies, hunting for exoplanets, and mapping the Milky Way. We work hard to make sure nobody leaves the Adler with a meager impression of our magnificent universe. I'm certain Max Adler would be proud.

#AstroEverywhere

Once again, taking inspiration from Adler, planetariums and astronomy groups are in a great position to feed a broad awareness of the cosmos through a variety of efforts we've labeled #AstroEverywhere. For example, in the modern age of social media, we invite you join the bandwagon of seeing and (hash)tagging astronomy all around you. Once you start looking, your eyes will be opened to astronomy in architecture, sculptures, and paintings, in song lyrics, beer labels, and wearables. The magic of our professional medium is that we all share one sky, and that connection is a useful outreach platform that can awaken the inner explorer as much as it can feed the inner child (a child who just wants to #AstroEverywhere-tag some Cassiopeia-shaped rabbit hay) — no matter your actual age!



▲ **ACCIDENTAL ASTERISM** The Adler encourages its social media followers to see the universe in everyday objects – like this piece of hay shaped like the W of Cassiopeia – and tag them #AstroEverywhere.

Our connection under a dome sky can be just as powerful as our connection under the real one. The planetarium dome can be viewed as a figurative big tent, and as planetarium dome operators, we're in a unique position to welcome everyone under it and deliver on our promise of #AstroEverywhere. While each planetarium has its own tent, collectively, we represent a carnival of sky-dome engagement, and by working together, we can pool our resources to connect with audiences worldwide. This is the idea behind the Adler Planetarium's Kavli Fulldome Lecture Series. With support from the Kavli Foundation, our visualization team works with frontier scientists to produce one-of-a-kind lectures under the dome. The experience allows the audience (and the scientist!) to fly through the data rather than simply stare at a graph of it.

To produce such an experience is time-consuming, and the investment of resources demands an audience larger than the 200 we can fit in our location alone. Therefore, we decided to take the carnival metaphor seriously and deliver each Kavli Fulldome Lecture as a simultaneous live broadcast to planetariums across the country and around the globe. Thus far, we've partnered with sites in 27 states and 6 countries for live fulldome lectures and audience Q&A with the scientists. Each lecture is also viewable live, in 360 degrees, with a Google Cardboard virtual-reality viewer and a smartphone (or simply on a flat screen) via YouTube. Through the YouTube channel, we're able to reach audiences without access to a planetarium dome, including patients in children's hospitals and students in rural communities and inner-city neighborhoods. #AstroEverywhere, indeed.

▲ **GOODBYE, MOON** Chicagoans gathered as a community on the grass outside the Adler Planetarium on the evening of September 27, 2015, to witness a total lunar eclipse.

That Adler's vision has evolved over these 88 years to include the engagement of audiences both near and far is a remarkable demonstration of the inspirational role planetariums can play in the modern age. Too often we're called upon to augment formal education when our greatest impact lies in complementing classroom instruction with the inspiration and wonder necessary to drive us to learn more. As informal educators, we must embrace our role to ignite a spark of discovery within, to awaken the inner explorer in everyone.

When our guests run out the front door begging for someone to teach them algebra because they have a planet to discover, we'll take it as evidence of a job well done. When we inspire someone to #LookUp and wonder, we facilitate a cosmic connection that will launch society into a promising future, one empowered citizen at a time. When we all #LookUp together, the sky's no longer the limit.

■ **MICHELLE B. LARSON** discovered astronomy in her 20s, when she pointed a pair of binoculars at the Moon. The stunning details visible on its craggy surface were a complete surprise, and the experience left her eager to find out what other secrets the sky had to offer. Now, as the President and Chief Executive Officer of the Adler Planetarium in Chicago, Larson leads a talented team that helps people of all ages explore and discover our universe.

ADLER PLANETARIUM (2)


NEW
CEM120, CEM120EC
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We created the iOptron CEM120 to respond to the growing demand for an accurate, stable equatorial mount with the versatility to carry larger instruments and complex imaging arrays.The mount offers the benefits of our revolutionary "center balance" design: stability, accuracy,and smooth mechanical operation with a large payload capacity of 115 lbs, (52kg).The natural stability of the center balance design is due to its focusing its payloads weight directly over the center of its pier or tripod.The CEM120's performance is demonstrated by its low +/- 3.5 arcsecond periodic error, which is further reduced to <0.15 arcsecond RMS in the CEM120EC model. Additionally, the CEM120 features an advanced cable management system consisting of several pass-through ports to prevent tangles and reducing the chance of split cables in cold temperatures. It also adds new features to the CEM family including built-in Wi-Fi and LAN for remote operation and easy to use clutches on both axes. The CEM120 will initially be available in two versions, the CEM120 and the CEM120EC which includes high-resolution encoders for real-time, nearly error-free tracking.
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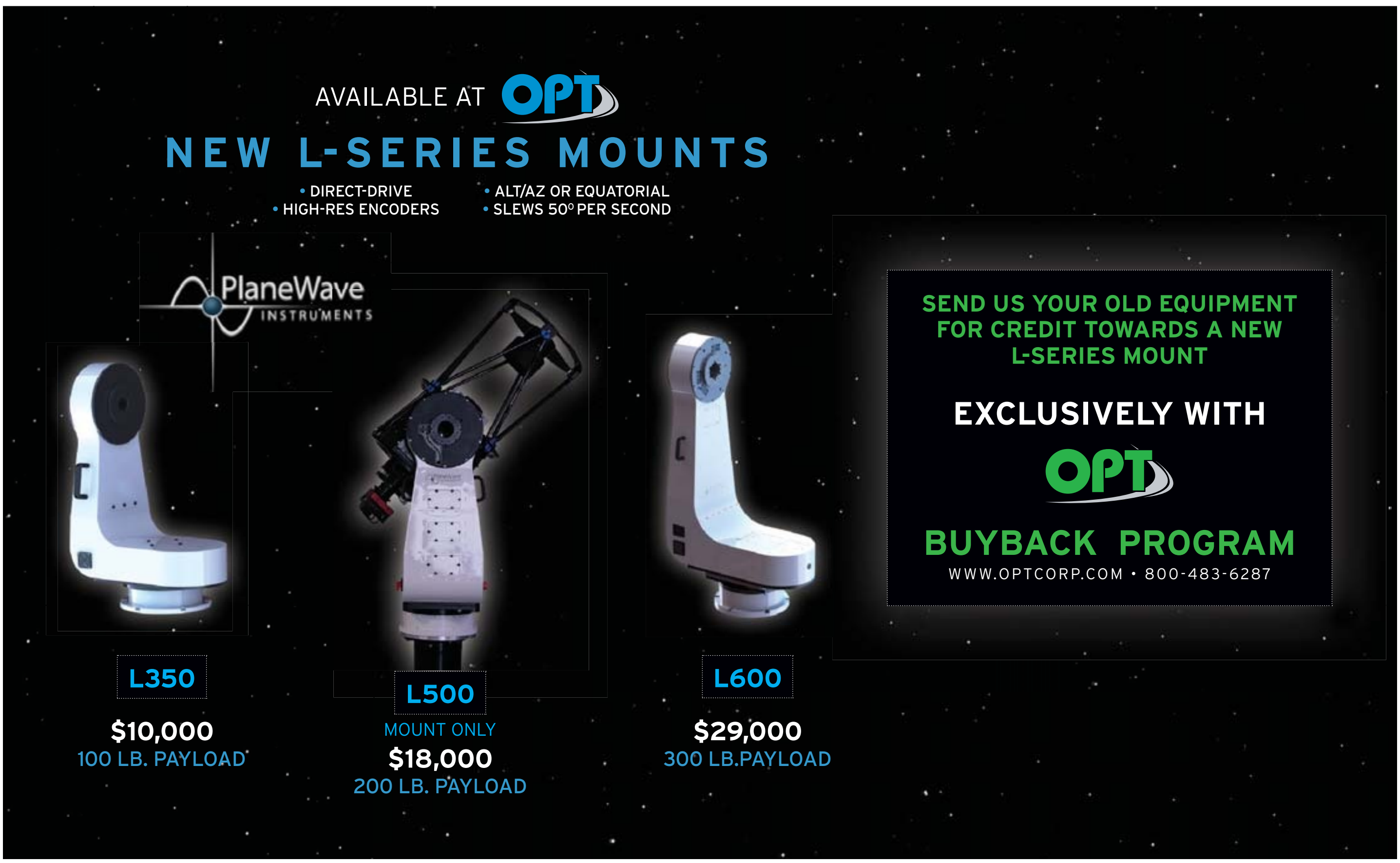
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A Stair-Climbing Scope Buggy

Stairs and stars can play nice after all.

MOST OF US who observe from home face the same dilemma: Do we take apart the telescope every time we move it inside or out, or do we try to transport it in one piece? Small scopes are fairly easy to move as a unit, but it doesn't take much size before the scope and mount combination becomes too cumbersome to handle. Even the mount alone can be a chore when it's a big, beefy equatorial head on a tripod.

Wheeled telescope buggies have long been a solution to that problem, but there's one serious shortcoming: They don't go up and down stairs very easily.

Or do they?

Pittsburgh amateur Dennis Fisher has figured out how to make a telescope buggy climb stairs. The inspiration came from a six-wheeled dolly he saw in a movie that seemed to glide effortlessly up and down steps, but Dennis was never able to come up with a decent method for building the multi-wheel assembly. "Then one day on Amazon while looking for something else, I saw a picture of a shopping cart with the three-wheel assembly on it and thought . . . hmm." That particular unit was too expensive ("I would have had to buy $100 worth of carts to butcher them for the wheel assemblies"), but at the bottom of the screen was a list of spare parts, and the wheel sets were perfectly reasonable at $19 per pair. So Dennis ordered two pair and set to work modifying his transporter.

▲ The three-wheel assembly goes over stairs like they weren't even there.

He had already built a T-shaped buggy similar to JMI's well-known design, though as he says, "Not wanting to copy the Wheeley Bar bit for bit, I just kept the basic design in mind and went to work. A hollow aluminum square tube for the front, an aluminum angle for the back, some angle brackets to hold the wheels, shoulder bolts for axles, lawnmower wheels, and there it was." A very simple, very light solution to the problem that's also strong enough to carry 40 pounds or more. The front wheel support was probably the most complicated part, with bent-steel bars providing a gap that allows the front wheel to steer, and a turnbuckle tensioner to provide strength. Everything came from a hardware store, and the most sophisticated tool necessary was a drill press.

The PVC pipe caps that hold the tripod leg tips look undersized in the photo, but Dennis says they're just the right size to hold the legs without slipping. Bungee cords snug them tightly in place so they don't go anywhere even when the buggy is tilted for climbing stairs.

Dennis reports, "The addition of the tri-wheel assemblies took a little modification of the buggy, but not much. Now when I go over the step, I can just pull it along and the triple wheels will roll and maintain contact with the ground and the riser of the stair to make for smooth transport over the stairs."

Problem solved! But transporting the scope is only part of the buggy's

Dennis Fisher displays his stair-climbing telescope buggy.

▲ Stabilizing legs swing down to lock the platform in place when observing.

job. It has to provide a stable platform to observe from, especially for Dennis, who does astrophotography with his 6-inch Newtonian. He tried long screws that extended down through the frame to the ground, but they proved to be far too wobbly. So he built better stabilizers out of aluminum U-channel with 2-inch PVC pipe endcaps for feet. "When all three are extended, the wheels are off the ground and the cart provides a stable platform for the mount and scope," he says. Simple friction from the metal-on-metal contact keeps them from slipping sideways when the clamp screws are tightened firmly.

Dennis removes the telescope and counterweight from the mount before wheeling it inside or out, but that's mostly to prevent banging it on door frames and the like. The buggy and wheels would easily handle the weight of the entire system, though Dennis admits "the entire assembly with the scope and counterweight may just be too heavy for me to move around reliably."

The wheels are soft plastic. Dennis worried that they might not hold up over time, but so far after about a year of use they're still good as new. And Dennis is quite pleased with how much easier it has made the job of transporting his mount outside for observing.

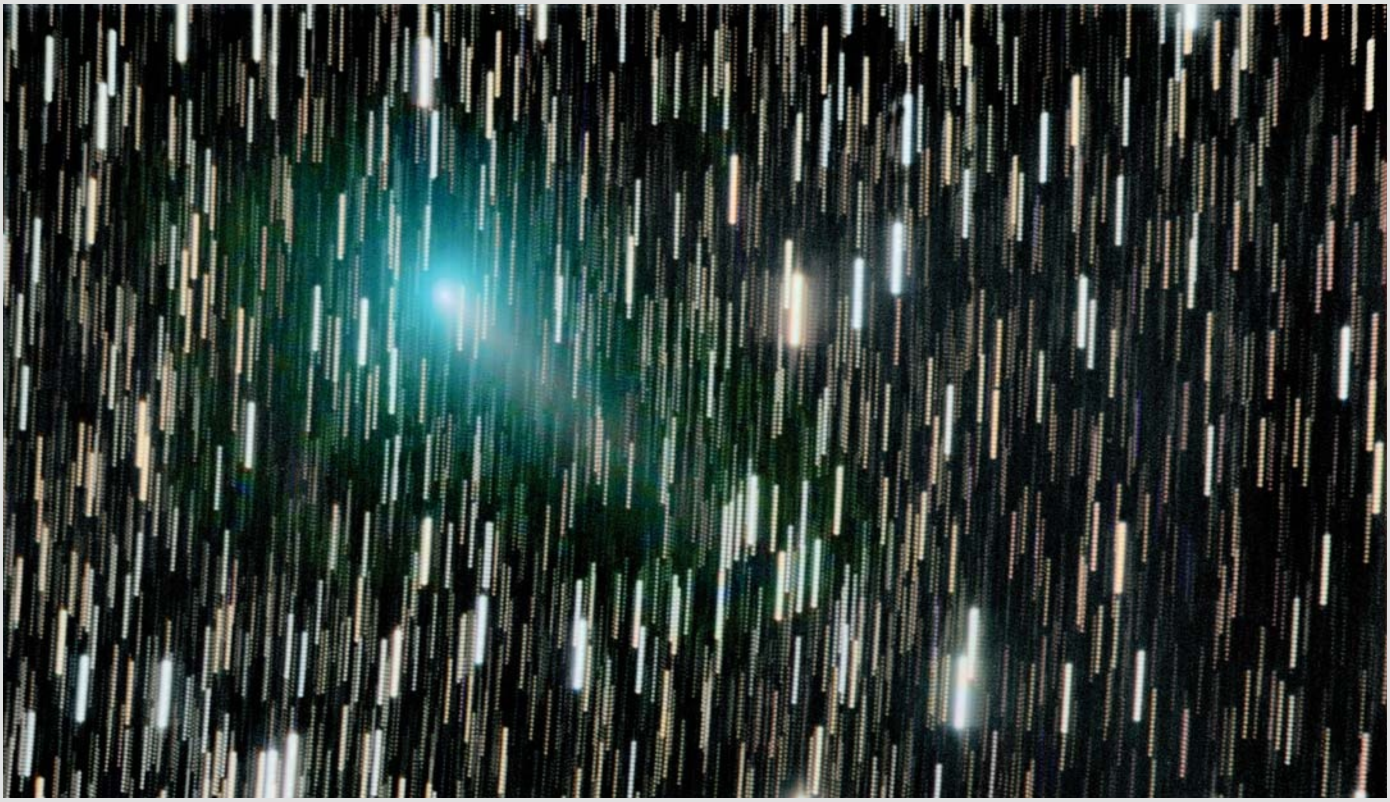
For more information, contact Dennis at **fisher2314@hotmail.com**.

■ Contributing Editor **JERRY OLTION** helped build a ramp onto his astronomy club's elevated observing site. Dennis's is a more elegant and individual solution to the problem.

◁ **CAROLINE'S ROSE**
Jaspal Chadha
The rich open cluster NGC 7789 in Cassiopeia, about 8,000 light-years away, has a total magnitude of 6.7. Caroline Herschel discovered it in 1783.
DETAILS: *Takahashi TOA-130 apochromatic refractor and QSI 690 CCD camera used with LRGB filters. Total exposure: 2.3 hours.*

▷ **TORTURED CLOUDS**
Frank Sackenheim
Searing radiation from hot, young stars lights up and sculpts the clouds of NGC 6188 in the southern constellation Ara. At right is jewel-like NGC 6164.
DETAILS: *Takahashi FSQ-106ED astrograph, Moravian G3-16200 CCD camera, and Baader Hα and LRGB filters. Total exposure: 16 hours.*

▽ **ICY RECEPTION**
Chris Schur
Last October 14th, Comet ASASSN1 (C/2017 O1) was about 8th magnitude as it crossed Perseus. Its coma glowed blue-green in a view about 1° wide.
DETAILS: *Orion 10-inch Newtonian astrograph reflector, SBIG ST-10XME CCD camera, and Astrodon LRGB filters. Total exposure: 2 hours.*



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△ ROSETTE NEBULA (CLOSE-UP)

Robert Gillette

Also known as Caldwell 49 and NGC 2237/8, this spherical cloud of ionized hydrogen in Monoceros is a favorite among astro-imagers. This close-up accentuates the star cluster NGC 2244 at its center.

DETAILS: *Takahashi FSQ-85ED apochromatic refractor, QSI 583wsg CCD camera, and Astrodon Hα and RGB filters. Total exposure: 10 hours.*

▷ ROSETTE NEBULA (WIDE FIELD)

Ron Brecher

Binoculars reveal the stars of NGC 2244 — but the nebula itself, despite being more than 1° across, requires a telescope at a dark site.

DETAILS: *Takahashi FSQ-106ED astrograph, Moravian G3-16200 CCD camera, and Optolong RGB filters. Total exposure: 2½ hours.*

◁ ROSETTE NEBULA (HUBBLE PALETTE)

Dustin Gibson

Pristine skies aren't essential when imaging with narrowband filters. For example, this view was taken from an RV park just a few feet from a street. Compare its details with the other two Rosette images here.

DETAILS: *Stellarvue SVA130 apo refractor, SBIG STT-8300M CCD camera, and Astrodon Hα, S II, and O III filters. Total exposure: 15 hours.*

▷ DISTANT FACE-ON SPIRAL

Warren Keller, Steve Mazlin & Jack Harvey

About 39 million light-years away and 11th magnitude, IC 5332 is a seldom-seen spiral galaxy in Sculptor. But it's beautiful and delicate nonetheless. Note the numerous distant galaxies scattered around it.

DETAILS: *RC Optical Systems 16-inch Ritchey-Chrétien astrograph, Apogee Alta U9 CCD camera, and Astrodon Hα and RGB filters. Total exposure: 55.5 hours.*

△ COLORFUL COMPETITION

Giuseppe Petricca

On the night of November 7, 2017, just after a wee bit of rain in Scotland's Outer Hebrides, green curtains of auroral light vied for attention with a double "moonbow" arcing across the sky.

DETAILS: *Canon EOS 700D DSLR camera set to ISO 1600 and 14-mm lens. Exposure: 10 seconds.*

◁ KNIFE-EDGE SPIRAL

Ian Gorenstein

NGC 5907, called the Knife Edge (or Splinter) Galaxy, lies about 40 million light-years distant in Draco. Seen nearly edge on, its disk is slightly warped due to past interactions with other systems.

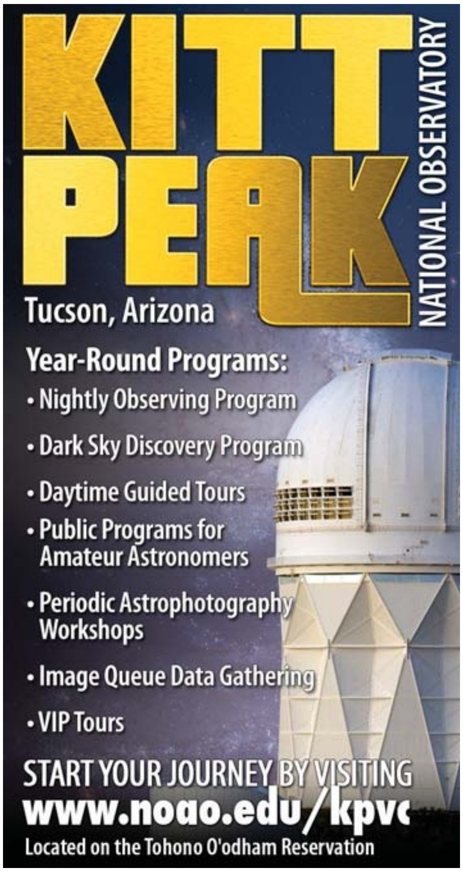
DETAILS: *Celestron EdgeHD 14 aplanatic Schmidt-Cassegrain telescope and Atik 460EX monochrome CCD camera used with LRGB filters. Total exposure: 18 hours (taken over 2 years).*

▷ STARBIRTH IN CEPHEUS

César Blanco González

Intense radiation from hot stars, having recently formed amid the clouds of NGC 7822 in eastern Cepheus, has begun to clear away the residual gas and dust in their portion of the nebula.

DETAILS: *Takahashi FSQ-106ED astrograph, QSI 583ws CCD camera, and Astronomik Hα, S II, and O III filters. Total exposure: 15 hours.*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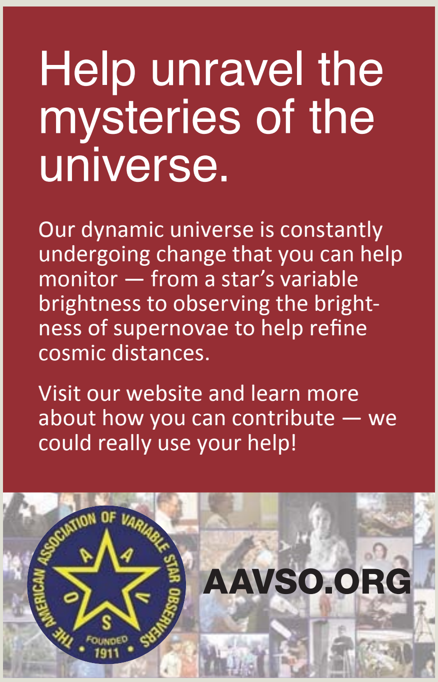

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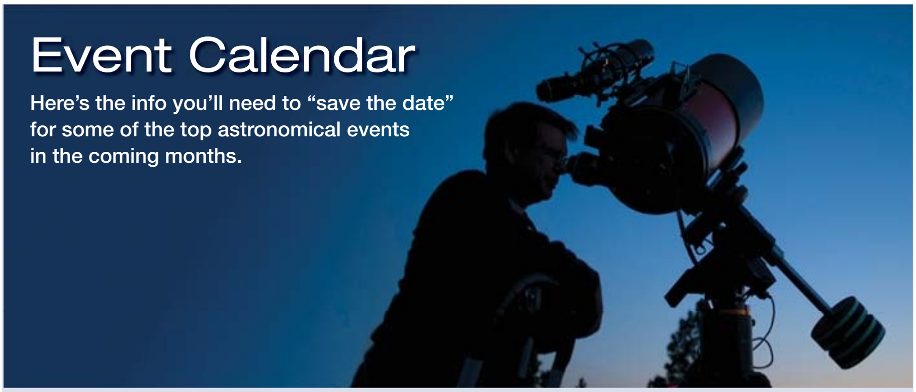


Event Calendar

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

February 9–10
EUROPEAN ASTROFEST
London, England
facebook.com/AstroFest

February 12–18
WINTER STAR PARTY
Chiefland, FL
scas.org/home/winterstarparty

March 3
TRIAD STARFEST
Jamestown, NC
observatory.gtcc.edu/tristar

April
GLOBAL ASTRONOMY MONTH
Everywhere!
astronomerswithoutborders.org/global-astronomy-month-2018.html

April 5–8
SOUTHERN STAR
Little Switzerland, NC
charlotteastronomers.org/southernstar

April 11–14
MID-SOUTH STAR GAZE
French Camp, MS
rainwaterobservatory.org/rainwater

April 15–21
INTERNATIONAL DARK SKY WEEK
Everywhere!
darksky.org/dark-sky-week-2018

April 21 (also October 13)
ASTRONOMY DAY
Everywhere!
astroleague.org/astronomyday/facts

April 21–22
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

May 6–13
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 10–13
STARGAZE STAR PARTY
Trap Pond State Park, DE
delmarvastargazers.org

May 18–20
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org/index.php/msp10

May 24–28
RTMC ASTRONOMY EXPO
Big Bear City, CA
rtmcastronomyexpo.org

June 9–16
GRAND CANYON STAR PARTY
Grand Canyon, AZ
tucsonastronomy.org/upcoming-events/grand-canyon-star-party

June 13–17
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 14–17
CHERRY SPRINGS STAR PARTY
Coudersport, PA
astrohbg.org/CSSP

July 11–15
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

July 12–15
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
new-star.org/index.php?Itemid=82

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

NATIONAL PARK SERVICE / MICHAEL QUINN

A Brief Eternity

It seems ages since we launched the Voyagers. But in the grand scheme, it's but a moment ago.

INSPIRED BY THE VOYAGER mission's 40th anniversary last summer, I recently watched a 1999 BBC series, *The Planets*. In particular I savored Episode Three, which focused on the giant planets and the Voyager spacecraft. The episode recalled those heady days in the mid-1960s when NASA's deep thinkers envisioned dispatching probes on a "Grand Tour" of all the outer planets.

I was quickly reminded how space exploration then remained in its infancy. In those days, unmanned craft had ventured no farther than to Venus and Mars. For the Grand Tour to be successful, scientists would have to overcome many mission "impossibles."

But I was even more struck by how the series had captured *brevity*. Henry Thoreau's maxim, "Time is but the stream I go a-fishing in," came to mind. Despite being our longest-lived spacecraft, Voyagers 1 and 2 constitute but a ripple in the endless current of Time.

In the decade-plus that saw the canceling of the Grand Tour program and the launching of its replacement, the Voyagers, in 1977, scientists shared their fears: Constrained by limited electronics and navigational knowledge, could they build machines that could last in space for at least 10 years? Would planet-aided gravity assists really reduce travel time? Could the spacecraft survive crossing the asteroid belt and Jupiter's intense radiation field? Could we receive the data transmitted by these spacecraft across billions of kilometers of space?

> Where in that flow of Time and Space will humankind's continuum lie?

To their everlasting credit, the scientists and engineers figured it out. In the early 1970s they dispatched two less-elaborate probes, Pioneers 10 and 11, as scouts to reconnoiter the way. Learning vital lessons from them, NASA personnel hurriedly redesigned both Voyagers and fortified the Deep Space Network to enable the all-important transfer of data.

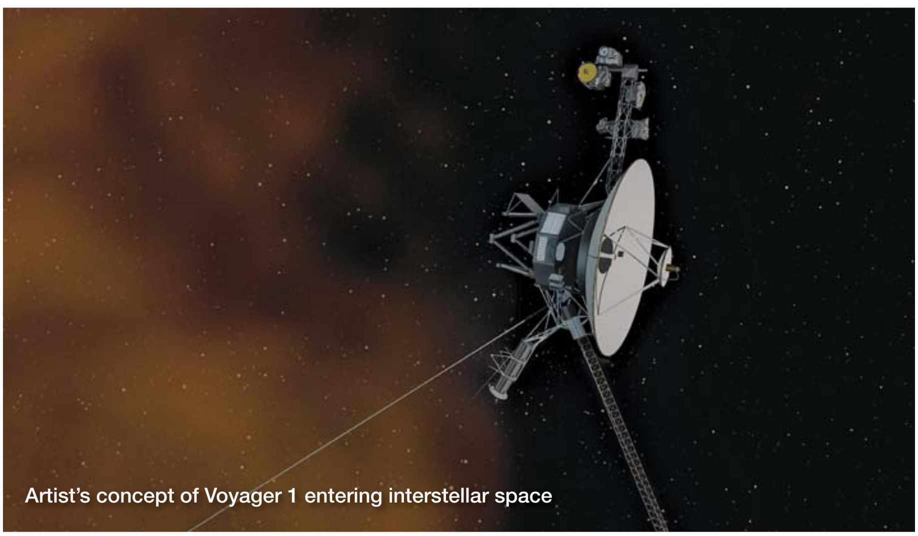
The Voyagers pushed the very limits of our science and engineering. But we prevailed, and in a comparative tick of cosmic time. In the coming decades, that tick generated wide-spreading reverberations across the solar system: roving on Mars, orbiting Jupiter and Saturn, landing on Titan, flying by Pluto, and landing on a comet, to share but a few.

Now, as Voyager 2 punches the heliosheath to join Voyager 1 in interstellar space, these hoary spacecraft are nearing the end of their scientific lifetimes. And so, alas, are their creators, who were at the height of their careers when the Voyagers launched.

Aerospace engineer Gary Flandro, who calculated the rare planetary alignment underlying the entire adventure, is now reaching his mature years. Voyager chief scientist Ed Stone and imaging-team head Brad Smith — the same. James Van Allen, Carl Sagan, and former Jet Propulsion Laboratory director Bruce Murray are sadly no longer with us, their energies extinguished even as their contributions continue to influence the scientific continuum.

We humans wish we could anchor ourselves for a longer stay, but each of us is merely a drop in Thoreau's ceaseless stream, as ephemeral as a drop of dew on a sunny morning. What will the next drop or ripple produce? Who will contribute and for how long? What will we learn about the cosmos? Where in that flow of Time and Space will humankind's continuum lie?

Watching *The Planets*, I realized more poignantly than ever before how everything we have ever known, or ever will know, is but a single breath in the life of the grandest continuum of all: the universe itself.



Artist's concept of Voyager 1 entering interstellar space

NASA / JPL-CALTECH

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