COMET 67P: Rosetta's Trove of Discoveries
PAGE 14

TEST REPORT: Celestron's App-Controlled Scopes
PAGE 60

DIY TELESCOPES: How It All Began
PAGE 22

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

BIG SCOPE CHALLENGE

Colliding Galaxies

PAGE 28

Universe 2.0

New Simulations Solve Cosmic Problems

PAGE 34

Astro Gear:
Star Trackers Galore

PAGE 66

Napoleon's Comets

PAGE 52

MAY 2017

SKY & TELESCOPE

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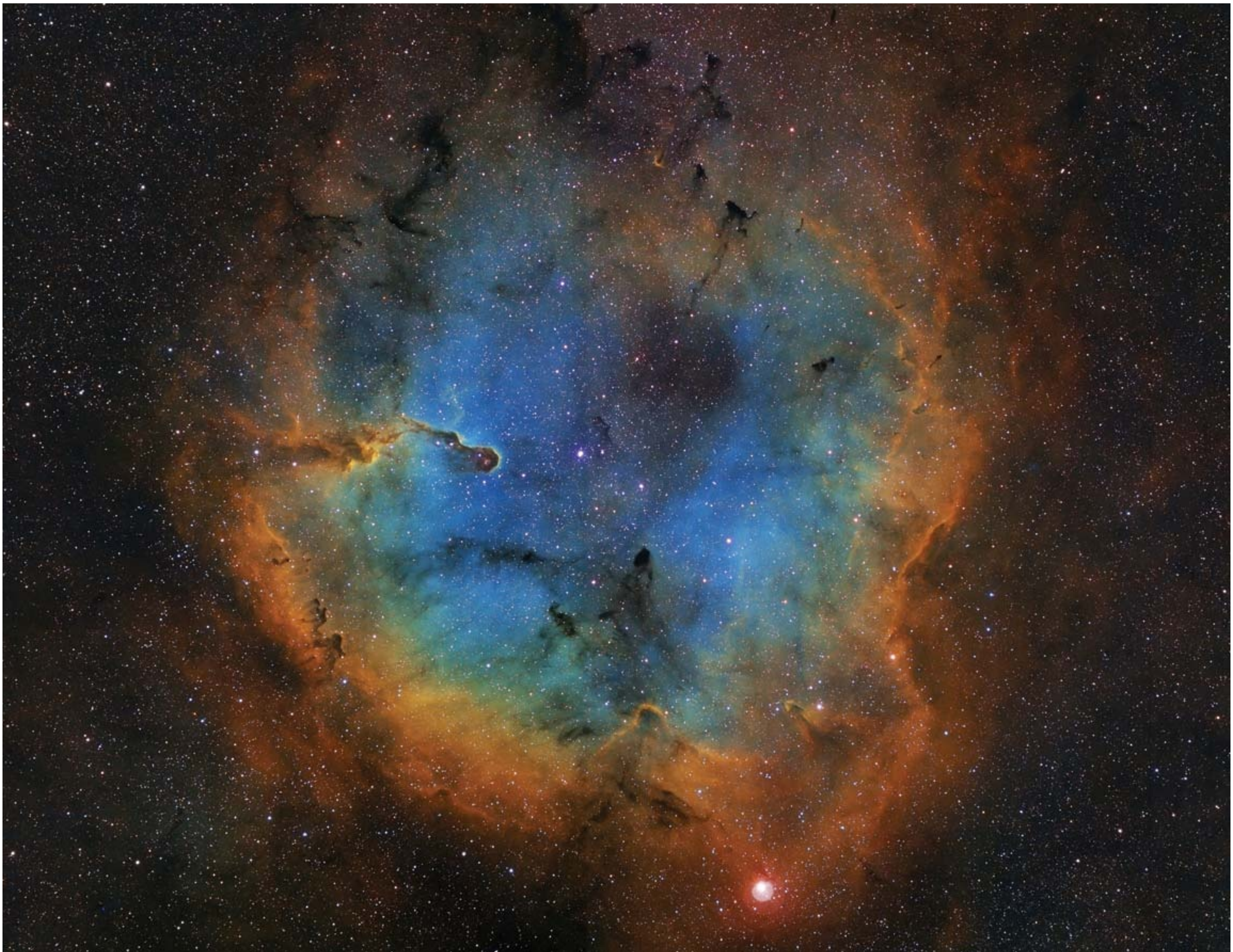
Deep-Sky Wonders:
Elliptical Galaxy in Virgo

PAGE 54



IC 1396. FLI camera with 50 megapixel KAF-50100 sensor. Image Courtesy Wolfgang Promper.

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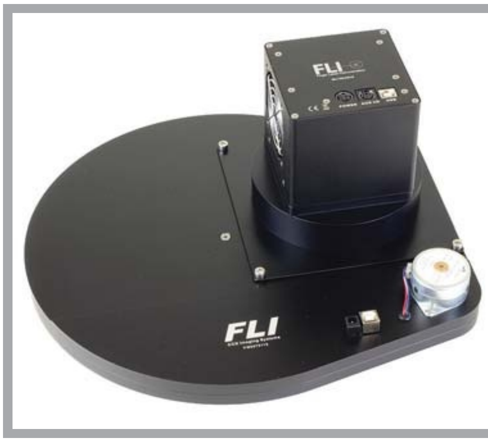

MicroLine ML50100 Camera on CFW10-7 Filter Wheel

CONTENTS

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Comet 67P/Churyumov-Gerasimenko 14

ESA / ROSETTA / MPS FOR OSIRIS TEAM

May 2017 VOL. 133, NO. 5

ON THE COVER

The Antennae Galaxies in Corvus, the Crow, are an iconic colliding pair of stellar metropolises.
ESA / HUBBLE & NASA

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This Is, and No Mistake

ALTERNATIVE FACTS. FAKE NEWS. A post-truth world. These newfangled locutions are unsettling, if not insulting, to astronomers and all scientists. After all, the scientific method, which undergirds and validates all their efforts, secures the opposite: actual facts, truly newsworthy discoveries, and, eventually, incontrovertible truth.

In the face of recent cases of Orwellian doublespeak and even reckless prevarication on America's national stage, shall we now dispense with the scientific method? Stop insisting that hypotheses be falsifiable and experiments repeatable? Choose the subjective over the objective? The unreal over the real?

Of course not. The scientific method is the most effective tool humankind has invented for winnowing what *is* from what *isn't*. How it works bears repeating: 1. Observe something. 2. Craft a hypothesis that is consistent with what you've observed. 3. Make predictions based on your hypothesis. 4. Test those predictions by well-designed experiments or further observations, and modify your hypothesis as needed based on what you find. 5. Repeat until no mismatches exist between your premise and your experimental results or observations.

Conclusions reached through a strict adherence to the scientific method will hold fast irrespective of aspirations, prejudices, or ulterior motives, like barnacles no matter how strong the current. By the same token, any hypothesis that clearly fails such rigorous vetting must be dropped.

At *Sky & Telescope*, we pride ourselves on accuracy. What could be more critical when reporting on science? We're manic about fact-checking, and it pains us when an error creeps into our pages. But when one does, we correct it for the record in our print and online errata sections.

Together with other democratic institutions whose existence is predicated on respect for the truth — the judiciary, universities, and scientific organizations — the free press today must redouble its efforts to expose misinformation. Journalists, and perhaps none so much as we science writers, need to tirelessly dig down in our stories and in our culture until we reach the bedrock of authenticity.

Henry David Thoreau, one of history's greatest insisters on veracity, might have said it best in *Walden*:

> *Let us settle ourselves, and work and wedge our feet downward through the mud and slush of opinion, and prejudice, and tradition, and delusion, and appearance, that alluvion which covers the globe, through Paris and London, through New York and Boston and Concord, through Church and State, through poetry and philosophy and religion, till we come to a hard bottom and rocks in place, which we can call* reality, *and say, This is, and no mistake . . .*

The truth, the whole truth, and nothing but the truth — it's the foundation of any advanced society.

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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H. P. Lovecraft's Take on Totality

I enjoyed reading Eli Maor's article about how New Yorkers viewed the 1925 total solar eclipse (*S&T:* Jan. 2017, p. 66). This eclipse occurred when horror and science-fiction author H. P. Lovecraft lived in New York City. Lovecraft, also an amateur astronomer, observed the eclipse under "marrow-congealing" conditions and was able to see the corona. Visit **https://is.gd/Lovecraft** to read his letters concerning this eclipse and the one seen from New England in August 1932.

Aaron McNeely
New Carlisle, Indiana

The Rocky Road to Mars

I was inspired by David Grinspoon's history of our preconceptions and realizations concerning the study of Mars (*S&T:* Jan. 2017, p. 20). Yes, we've read or seen the perspectives of H. G. Wells, Percival Lowell, Carl Sagan, Bruce Murray, and many others — and what Grinspoon calls their "brilliant mistakes." But let's continue with both science and imagination. There are so many of us with portions of both.

Earl Finkler
Medford, Wisconsin

Grinspoon makes telling points about the difficulty of predicting what we will discover about Mars or anything in the cosmos. I was present, as a 14-year-old, in the audience at the 1971 gathering he describes. My father, an engineering professor at Caltech, knew of my interest in planetary exploration and got us tickets. At the time I had only a general idea who Sagan and Murray were and was not yet familiar with the science journalism of moderator Walter Sullivan.

My strongest memory of that evening was the moment Ray Bradbury, who was no myth to me, stood up and read a poem. Even today, I tell the undergraduates in my astronomy classes that science cannot describe to us the true meaning of nature's huge numbers, immense distances, and eons of time. We need the artists, musicians, writers, and poets to do that.

Ken Coles
Indiana, Pennsylvania

Kudos for Deep-Sky Wonders

Although I've mostly given up visual for imaging, I get a lot of target ideas from Sue French's observing column in **@SkyandTelescope**.

Richard S. Wright Jr.
@AccidentalAstro

FOR THE RECORD

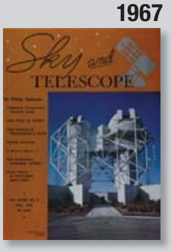
✸ The amount of dirt and stone removed for the FAST radio telescope was 900,000 cubic meters, not nearly 1 cubic km as the caption states (*S&T:* Feb. 2017, p. 29).

✸ The reference star used as an aid to spotting NGC 1954 (*S&T:* Feb. 2017, p. 56) is 8 Lep, not 8 Lac.

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

1942

1967



1992

◖ May 1942

How Old Are We? "More accurate measurements, recently made . . . on sample meteorites, indicate a considerable range in the helium content of iron meteorites and a remarkable constancy of uranium and thorium, the elements important in age-determinations. The highest ages derived from the helium content amount to 6,000 and 7,000 million years. [But an] extrapolation from data regarding the 'expanding universe' would allow only 2,000 million years as the age of the universe. Evidently mother nature is skillful in concealing her true age."

Better methods have adjusted estimates of the ages of meteorites and our solar system to about 4,600 million (4.6 billion) years. But since 1942 cosmologists have often revised the intergalactic distance scale and expansion rate, leading to a sevenfold "aging" of the universe as a whole.

◖ May 1967

What Are Tektites? "For two centuries scientists have been puzzled by certain small glassy objects, usually rounded, that are found in great numbers in some geographical areas, but are virtually absent elsewhere. These *tektites* are ordinarily in the size range of gravel. . . . The term *strewnfield* is used for a major area of the earth's surface in which tektites are found. [There are] four known strewnfields, each of which has a different estimated age. . . .

"In color, tektites range from black through dark brown to bottle green. . . .

"[Most scientists] agree that tektites are in some way or another the result of large meteorite impacts. Some theories maintain that tektites are lunar material, dislodged by impacts from the moon's surface; others state that they are terrestrial material affected by impact."

Author Darryl Futrell went on to describe and illustrate the known varieties in detail. The actual lunar samples returned a few years later by Apollo astronauts did not match tektites in composition. Most experts now regard tektites as impact-shocked terrestrial material.

◖ May 1992

Missing Clusters "A few years ago R. Sagar and A. K. Pandey collected all the available age determinations for star clusters in the Magellanic Clouds, the Milky Way's two largest satellite galaxies. Surprisingly, they found no cluster in the Large Magellanic Cloud (LMC) with an age between 5 and 15 billion years. . . .

"Is this apparent 10-billion-year age gap real, or is it due to systematic errors in determining cluster ages? . . . The strongest argument actually comes from the Small Magellanic Cloud (SMC), which does harbor clusters between 5 and 15 billion years old. . . . The reason for the long quiescent period in the LMC remains a complete mystery."

The age gap described here by Sydney van den Bergh (Dominion Astrophysical Observatory) remains an enigma.

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COSMOLOGY

Void "Repels" Milky Way's Galaxy Group

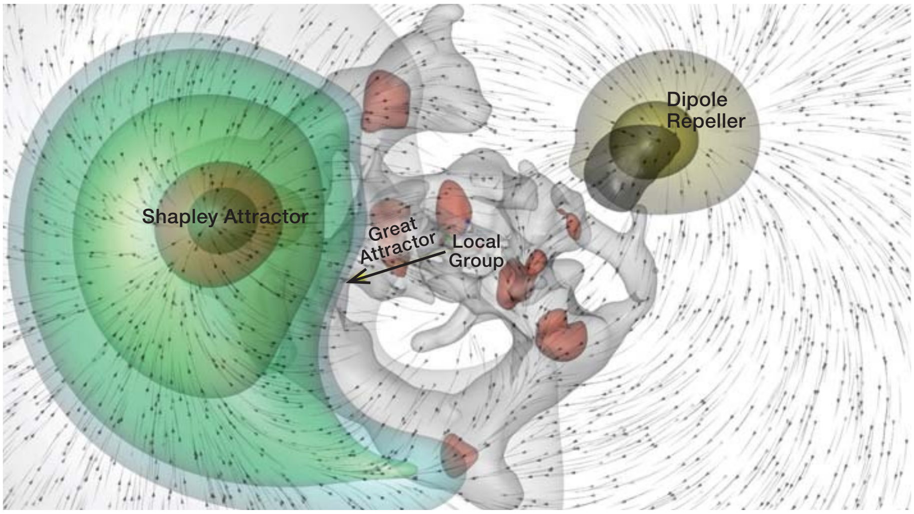
ASTRONOMERS HAVE DISCOVERED a giant cosmic void that explains why our Local Group of galaxies is moving through the universe as fast as it is.

The Local Group lies in a filament of a much larger cosmic structure. The galaxy clusters in this cosmic web don't stay still but rather gravitate (literally) toward the largest members. Our Local Group is moving toward what's called the Great Attractor, a dense collection in the vicinity of the Centaurus, Norma, and Hydra clusters about 160 million light-years away. Beyond that and about four times farther away lies another, equally influential attractor called the Shapley Supercluster.

But it turns out that there's another player. Using the Cosmicflows-2 catalog of galaxies, Yehuda Hoffman (Hebrew University, Israel) and colleagues have mapped the motion of more than 8,000 galaxies and confirmed that two titan structures determine how local galaxies flow through the cosmic web: Shapley on one side and a single, as-yet uncharted *void* in the opposite direction.

Think of the local cosmic structure as a gravitational water park: the twisty slides start high (where the void is) and end up low (where the supercluster is), with the natural motion always being down — that is, with gravity. Galaxies toboggan along the gravitational slides.

How fast the galaxies go depends on how tall the slides are. In the same



◀ Local cosmic structure (spans 1.7 billion light-years). The arrow is the cosmic dipole's direction.

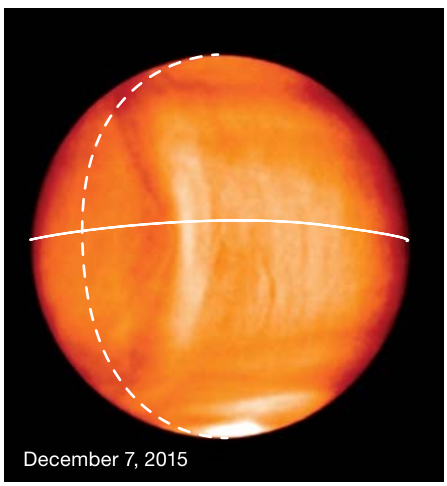
SOLAR SYSTEM

Akatsuki Spies Massive Wave on Venus

A MONSTER WAVE recently roiled Venus's atmosphere, forming a planet-spanning, bow-shaped feature. Japan's Akatsuki orbiter noted this disturbance in late December 2015 and early January 2016, shortly after the craft's arrival, Tetsuya Fukuhara (Rikkyo University, Japan) and colleagues report in the February *Nature Geoscience*.

When Akatsuki looked back at the region later in 2016, the wave had, for the most part, vanished.

The feature spanned the Venusian cloudtops from the northern to southern hemisphere, extending more than 10,000 km (6,200 miles). It appeared near the evening terminator on the dayside and was embedded in the interface between the upper troposphere and lower stratosphere. Although the cloudtops whip along at 100 meters per second (200 mph) — much faster than the slow-moving surface of the planet below — the curious structure seemed to stay in lockstep with the planet's rotation, suggesting a complex interplay between the surface and the atmosphere.



▶ Infrared image of Venus's gravity wave. The dashed line marks the day-night terminator.

The team's computer models suggest that air flowing over mountainous terrain produced a *gravity wave* that then propagated upward to the cloudtops, where the large bow wave was seen. (A gravity wave is an undulation triggered in a fluid — such as the atmosphere — by the interaction of gravity and other forces.) The wave's longitude corresponded with the western slope of Aphrodite Terra, the largest of Venus's three continent-size highlands, whose surface area is comparable to Africa's.

We see similar gravity-wave phenomena here on Earth, and NASA's New Horizons spacecraft chronicled evidence for gravity waves in the atmosphere of Pluto during its historic 2015 flyby.

■ **DAVID DICKINSON**

sense, the fact that there's a big void in one part of the gravitational landscape makes the Local Group flow faster toward the dense concentrations in the other direction than it would otherwise.

This discovery might solve a cosmic conundrum. Astronomers knew that the Local Group moves with respect to the cosmic microwave background (CMB). This motion is called the *CMB dipole*. But the velocity (630 km/s, or 1.4 million mph) is about double what it should be, if Shapley and the other clusters were solely responsible. The void's effect essentially doubles Shapley's pull, explaining why the Local Group moves as fast as it does. The team thus labels the region "the dipole repeller" in their January 30th *Nature Astronomy* paper.

■ CAMILLE M. CARLISLE

• Watch a video explaining the result at https://is.gd/cosmicrepeller.

STELLAR

Origin of Our Galaxy's Most Distant Stars

THE MOST DISTANT STARS discovered in the Milky Way's outer reaches might have been ripped away from a companion galaxy. Over the last decade, multiple groups of astronomers, including the author, have identified stars more than 300,000 light-years from Earth. (Our galaxy's disk is roughly 100,000 light-years across.) Possible explanations for how the stars got so far away have included that they were ejected from the Milky Way's disk, that they are the brightest members of a nearly invisible dwarf galaxy, or that they are the remnants of a galaxy shredded by the Milky Way's gravity.

Now, in an upcoming *Astrophysical Journal* issue, Marion Dierickx and Abraham Loeb (Harvard University) argue that some of these stars are probably members of what was once the Sagittarius dwarf galaxy.

Sagittarius is the best-studied dwarf remnant. This object passes close by the Milky Way in its eccentric orbit and every time it sweeps by, it sheds stars. The streams loop around our galaxy in majestic curves that crisscross the sky.

Starting with maps of these streams, Dierickx and Loeb created simulations that wound the clock backward more than 8 billion years, when the Sagittarius dwarf would first have started interacting with the Milky Way. Then they varied the initial velocity and direction of the dwarf and let time run. Five of the 11 most distant stars astronomers have discovered matched the positions, velocities, and distances expected for Sagittarius members at very large distances. The other six might be members of another former dwarf galaxy, but this is less certain.

■ JOHN BOCHANSKI

MISSIONS

Juno Swoops Past Jupiter's South Pole

DAMIAN PEACH

▲ NASA's Juno spacecraft took this image of Jupiter's south pole on February 2nd from a range of 76,600 km (47,600 mi). The flyby was the spacecraft's fourth perijove pass, which brought it just 4,300 km (2,670 mi) above the Jovian cloudtops. Despite previous problems (*S&T:* Feb. 2017, p. 10), all eight science instruments operated during this close pass. Juno's preliminary data suggest that Jupiter's extensive magnetic field is larger and more powerful than thought. Also, the zones and belts seen along the Jovian cloudtops could extend deep into the planet's interior, though how deep they go is still unclear.

■ DAVID DICKINSON

Milky Way Mass Still Contentious

Gwendolyn Eadie and William Harris (McMaster University, Canada) have observed the motion of distant globular clusters to measure our galaxy's mass. The new estimate, including both normal and dark matter within a radius of 600,000 light-years, lies between 600 and 750 billion Suns' worth of material. This value is significantly below previous measures, which have put the Milky Way's mass at roughly a trillion Suns, the team reported at the winter American Astronomical Society meeting and in the October 1, 2016, *Astrophysical Journal*. However, Dennis Zaritsky (University of Arizona) and Helene Courtois (Lyon University, France) claim in the March 2017 *Monthly Notices of the Royal Astronomical Society* that mass estimates well below a trillion Suns imply too low a fraction of dark matter. Since astronomers know dark matter's contribution via other methods, that ought to rule out lower mass estimates such as the one obtained by Eadie and Harris.

■ MONICA YOUNG

• Learn more about the study and lingering questions at https://is.gd/mwgmass.

EXOPLANETS

Proxima Centauri b Likely a Desert World


Artist's concept of a young, flaring *M* dwarf.

THE CLOSEST STAR to the Sun likely desiccated its exoplanet and destroyed that world's chances for habitability, astronomers reported at the winter American Astronomical Society meeting.

With a minimum mass of 1.3 Earths, Proxima Centauri b might be either a terrestrial or a Neptune-like world. It orbits its small, red *M* dwarf in the star's putative habitable zone.

But being in this sweet spot might have instead spelled Proxima Centauri b's biological doom. Young *M* stars are significantly brighter and more active than older ones, shooting out potentially atmosphere-stripping eruptions and gads of X-ray and ultraviolet radiation — roughly 100 times as much in X-ray and 10 to 20 times as much in UV as dwarfs as old as the Sun do, said Edward Guinan (Villanova University) on January 4th.

All these factors put together mean that, in Proxima Centauri's earliest days, its habitable zone was farther out than it is now. If the planet formed where it currently resides (in the modern habitable zone), then the world "underwent a living hell in its early 300 to 400 million years," Guinan said.

Victoria Meadows (University of Washington), who presented in the same session, has come to the same conclusion. Her team's simulations of different types of atmospheres and their evolution over the planet's 5-billion-year history suggest that, if the planet once had surface water, then the incoming radiation likely would have evaporated most or all of it. The result would be a substantial atmosphere rich in either oxygen or carbon dioxide.

Nevertheless, Proxima Centauri b might be habitable if it started out with a protective, hydrogen-rich envelope, or if it formed farther from the star — and thus farther from the deadly radiation — and then migrated to its current, close-in position. Forming farther out would also enhance its chances for retaining water, because ices are more prevalent in the outer reaches of planet-forming disks.

Guinan's team looked at two other potentially habitable exoplanets: Kapteyn b (13 light-years away) and Wolf 1061 c (14 light-years). Both have masses of at least 4 to 5 Earths.

Given their stars' ages and their X-ray and ultraviolet outputs, the team determined that Wolf 1061 c also offers poor chances for habitability. But Kapteyn b looks favorable. It currently receives 8 times more X-ray energy from its star than Earth does from the Sun, and less than twice Earth's ultraviolet level. Kapteyn b is also 3½ times farther from its *M* dwarf than Proxima Cen b is from its host. So the former might potentially have been far enough out to weather the star's violent youth. Notably, Kapteyn's star is about 11 billion years old and probably stolen from a dwarf galaxy.

■ CAMILLE M. CARLISLE

METEORITES

Micrometeorites Found on City Rooftops

A RECENT EUROPEAN STUDY has confirmed that a silent cosmic rain of micrometeorites is falling on us.

Matthew Genge (Imperial College London) and colleagues discovered the small particles in sediment collected from the gutters of urban European rooftops by Project Stardust. The team sifted through 300 kilograms (660 pounds) of material from a total collection area covering some 30,000 m^2 (300,000 ft^2). The scientists used magnets to pick out pieces with high iron content, then washed and sorted those candidates by size and shape. The final suspects were examined under a binocular microscope for signs of atmospheric entry. Only 500 particles passed stringent scrutiny. Forty-eight were chosen for detailed study.


Potential micrometeorite

The micrometeorites collected are tiny, most 300 to 400 microns in size. The largest of them are just under a half millimeter across, barely visible to the eye. Their compositions are consistent with meteoritic origin.

The existence of "rain-gutter micrometeorites" has been a matter of minor controversy in meteorite-collecting circles for several decades. The study, which appears in the February *Geology*, demonstrates that they do in fact occur.

Scientists estimate that 100 billion micrometeorites fall to Earth each year, about one per square meter.

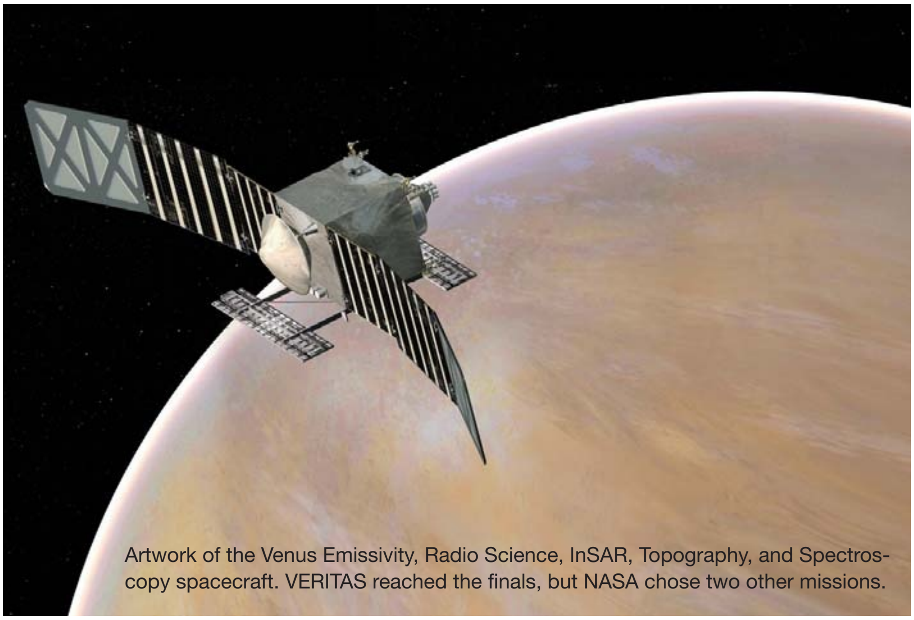
■ DAVID DICKINSON

• **Learn more about the micrometeorite study and how to go on the hunt at https://is.gd/gutterites.**

ILLUSTRATION: NASA GODDARD SPACE FLIGHT CENTER / S. WIESSINGER; PHOTO: RYAN THOMPSON

Not Venus Again

Once more, NASA leaves our sister planet out of the mix of new missions. Ouch.



Artwork of the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy spacecraft. VERITAS reached the finals, but NASA chose two other missions.

NASA / JPL-CALTECH

HELLO, MY NAME IS DAVID, and I have a Venus problem. For decades I've had an unhealthy compulsion. I've been doing the same thing over and over again and expecting a different result. And there's a whole community of us who share this questionable obsession.

The title of this column is the perennial answer to where NASA will send its next interplanetary spacecraft. The U.S. hasn't launched to Venus since 1989. That mission, Magellan, revealed our sister planet to be an incredibly beautiful and geologically interesting place, and it raised many new questions: What's in that thick atmosphere? Was there an ocean, and for how long? Could life have gotten started? In the wake of Magellan, we thought these and other burning questions would logically lead to new NASA spacecraft that would address them.

Since then we Venus researchers have proposed orbiters, entry probes, balloons, and landers. Every one has been shot down. Part of the problem is that the risk of Venus missions is perceived as too high. The observing conditions are so challenging that, judged against a mission to a more well-explored planet, we will always get less data with more risk, for the same money.

The Europeans and Japanese have helped fill the gap with small missions that have kept some vital data flowing. But without data from ambitious new NASA missions there's less funding for new studies, fewer resources to train students, and fewer people coming into the field. Yet every time NASA has called for proposals, we've gone back for more. It's the fix we can't resist.

Recently we made the finals. In NASA's Discovery Program competition, for missions costing up to $450 million, the agency selected two Venus contenders for the final round, out of five total. We'd been through many competitions in which no Venus missions had been selected. We'd been assured by many NASA officials that this doesn't reflect policy or official bias, and encouraged to keep trying. Now we had 40% of the finalists. It felt like it could be our time at last.

So a lot of us took it very hard when we learned in January that NASA had chosen two missions, neither going to Venus. Both are worthwhile and exciting, flying to new kinds of asteroids never before visited. But how are we supposed to respond, emotionally and strategically, to our repeated defeat? We are like Cubs fans if the Cubs had made it to the World Series but hadn't won. Do we buy tickets for another season? At what point are we no longer admirably committed, but merely pitiful?

Alas, we will get up, dust ourselves off, and try again. NASA is soliciting proposals for the next iteration of the New Frontiers Program, which has a higher budget than a Discovery mission. Several teams are organizing to propose new Venus sorties.

I could make up excuses for this behavior pattern. I could tell you why sooner or later the U.S. *must* return to Venus, because without doing so there will be limits to our ability to understand Earth, or climate, or what exoplanets are really like. I could tell you that we keep trying because sooner or later the gaps in our knowledge — compared to other places in the solar system — will become so glaring that it would be as if we'd explored the entire Earth carefully but ignored one whole continent.

But really we just can't help ourselves. Someday, someday . . .

We are like Cubs fans if the Cubs had made it to the World Series but hadn't won. Do we buy tickets for another season?

■ **DAVID GRINSPOON** is an astrobiologist at the Planetary Science Institute. **Follow him on Twitter at @DrFunkySpoon**.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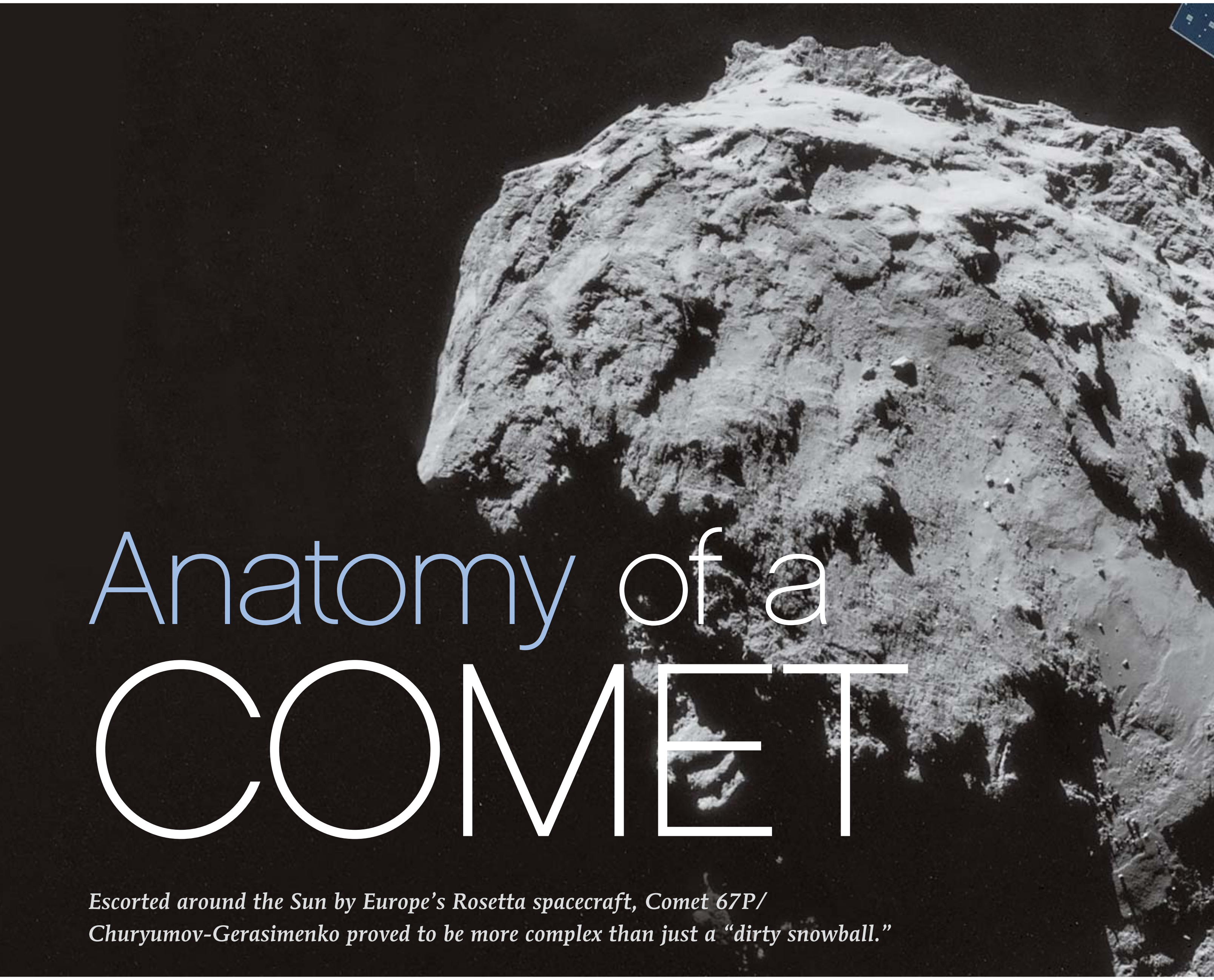


Anatomy of a COMET

Escorted around the Sun by Europe's Rosetta spacecraft, Comet 67P/ Churyumov-Gerasimenko proved to be more complex than just a "dirty snowball."

ESA / AIG MEDIALAB / ROSETTA / NAVCAM TEAM

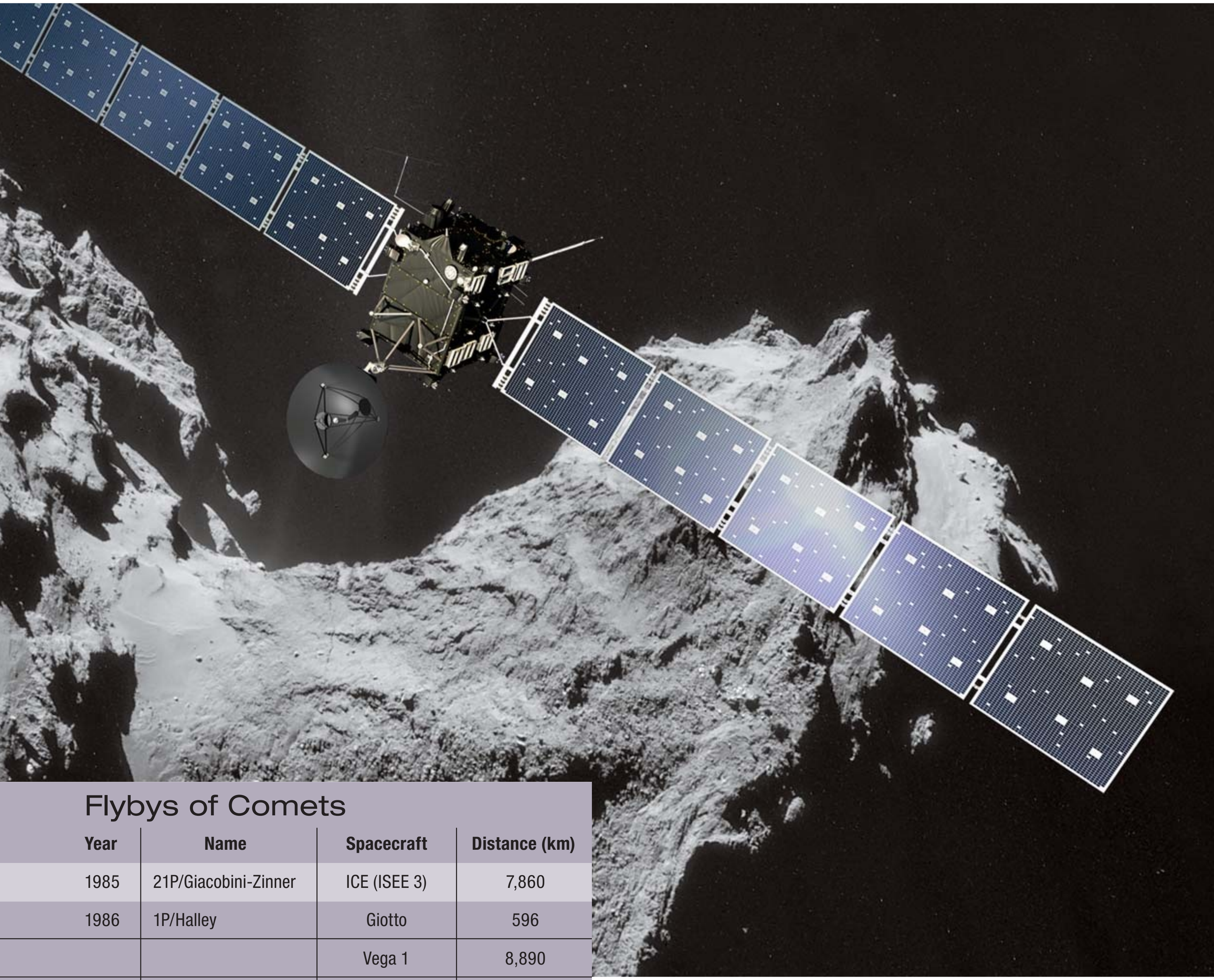
"Farewell, Rosetta. You've done the job. That was space science at its best. Thank you."

With those simple words from mission manager Patrick Martin, the Rosetta effort was over. Mission Complete. The audacious European Space Agency project that had been in flight for 12½ years ended on September 30, 2016, with a controlled thump onto the surface of the comet it had studied in exquisite detail. It was a poignant moment for those of us who'd been involved for two decades or more.

But there was also a sense of relief. After countless hours spent planning and executing how to put a spacecraft in orbit around an irregularly shaped and unpredictably temperamental nucleus, we found ourselves with time to dig deeply into the treasure trove of data that Rosetta and its lander, Philae, had returned to us.

Rosetta wasn't the first spacecraft to visit a comet (see table at right), but those were all flyby missions. Rosetta was the first comet rendezvous, escort, and landing operation. Think of those flybys as snapshots, while Rosetta was an HD movie.

The mission's "big picture" science goals were to understand the origin of comets, the relationship between cometary and interstellar material, and the implications of those results to the origin of the solar system. To do that, the team needed to measure the large-scale properties of a comet's nucleus, study its surface, determine the chemical and



Flybys of Comets

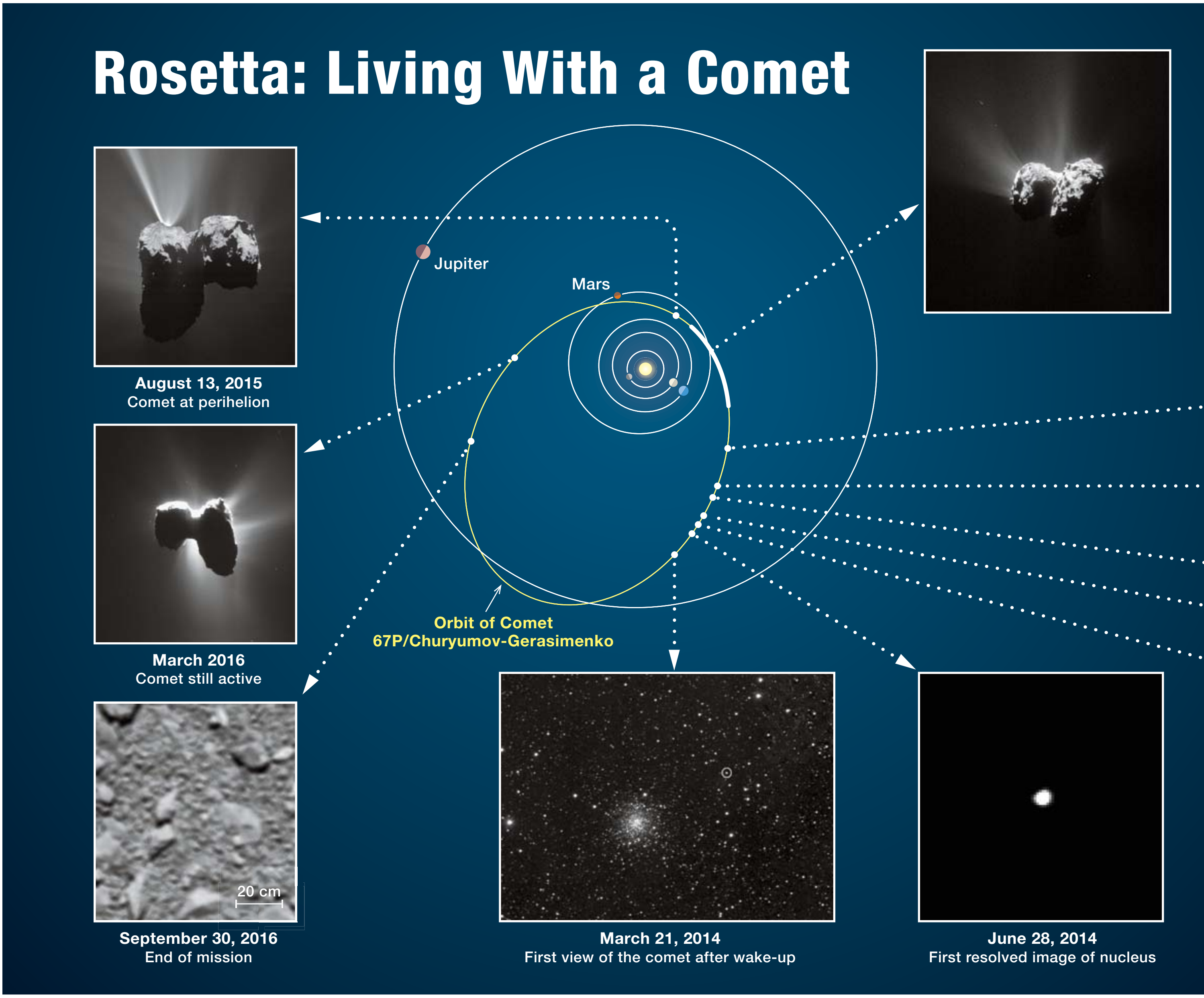
Year	Name	Spacecraft	Distance (km)
1985	21P/Giacobini-Zinner	ICE (ISEE 3)	7,860
1986	1P/Halley	Giotto	596
		Vega 1	8,890
		Vega 2	8,030
		Suisei	151,000
		Sakigake	7×10^6
1992	26P/Grigg-Skjellerup	Giotto	200
2001	19P/Borrelly	Deep Space 1	2,171
2004	81P/Wild 2	Stardust	237
2005	9P/Tempel 1	Deep Impact	500
2010	103P/Hartley 2	EPOXI (DS1)	700
2011	9P/Tempel 1	Stardust	180

dynamical properties of its coma, and study the "life" of the comet as it became more and more active as it approached the Sun, including the interactions of its gas and dust with the solar wind.

And to do some of that science directly on the nucleus, Rosetta would have to successfully deliver the Philae lander to the surface. (For a thorough description of Rosetta and Philae, including the 21 instruments they collectively carried, see my "preview" article in the August 2014 issue, p. 20.)

A Conjoined Comet

Rosetta launched in March 2004, and after a long cruise that included flybys of Earth, Mars, and two asteroids — plus an



August 13, 2015
Comet at perihelion

March 2016
Comet still active

September 30, 2016
End of mission

March 21, 2014
First view of the comet after wake-up

June 28, 2014
First resolved image of nucleus

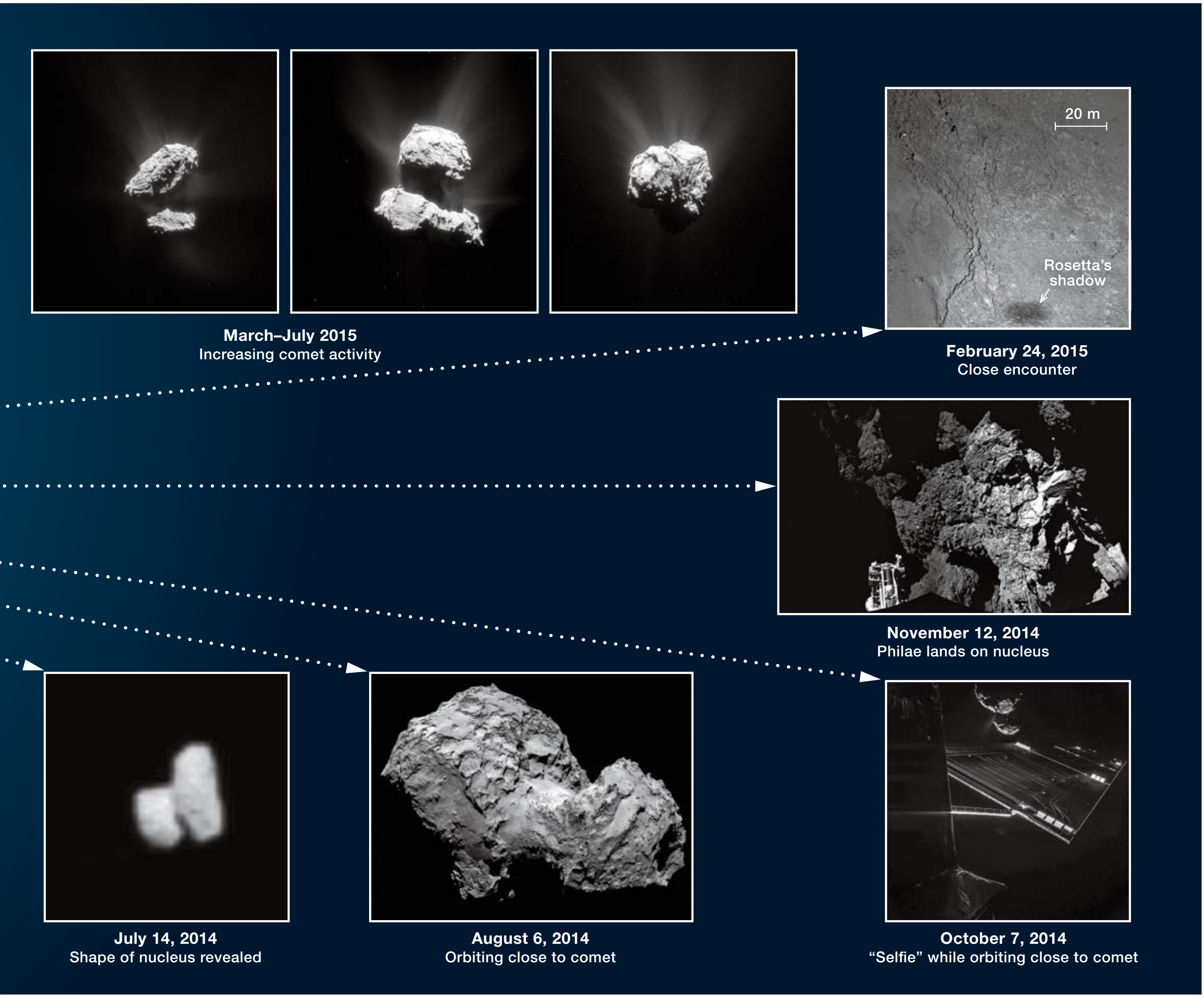
unnervingly long hibernation period — the spacecraft arrived at its primary target, a periodic comet called 67P/Churyumov-Gerasimenko, in August 2014.

And what an arrival it was! As Rosetta approached its target, images first showed an unresolved dot of light, then a roundish blur, then a larger and distinctly *not* roundish blur. Soon it became obvious that the nucleus looks nothing like a lumpy potato, as Hubble Space Telescope light curves had hinted. Instead, this comet has two distinct lobes, earning it a descriptive nickname of the Rubber Ducky — with a "head" (the small lobe) and "body" (the large lobe) connected by a narrow "neck."

Somehow we needed to find a place to land Philae on this duck in a very short time. We feverishly mapped and analyzed the nucleus before it became too active as it neared the Sun. Following some scientific arm-wrestling, the team deployed the lander on November 12, 2014.

But Philae failed to "stick the landing" — a faulty valve prevented its hold-down thruster from working, and harpoons meant to secure it to the surface didn't fire. Instead the lander bounced a few times over the course of a couple of hours and drifted more than a kilometer to an unknown location that unfortunately proved too shadowed to let its batteries recharge (*S&T:* Feb. 2015, p. 12).

However, Philae was able to run many of its primary science activities and transmit results to the mother ship during the 57-hour lifetime of its onboard battery. What was frustrating was that the lander's true location was unknown and remained that way until the last few weeks of the mission, when Philae was located during a close flyover



SOURCE: ESA / ROSETTA / NAVCAM & OSIRIS TEAMS

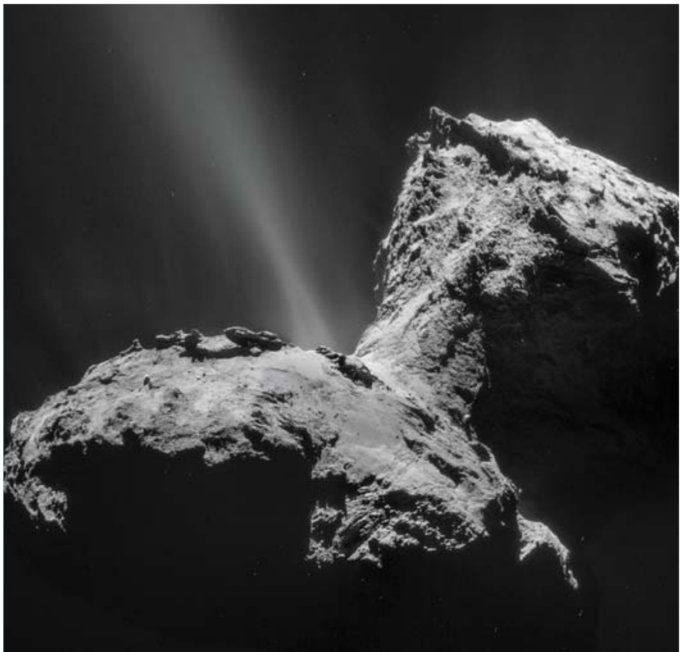
by Rosetta (*S&T:* Jan. 2017, p. 12). Getting the exact location was important for determining the accuracy of Philae's radio-wavelength probing of the comet's interior and also to know the context for other Philae measurements.

Rosetta itself continued to orbit and study the comet with its full instrument suite for more than two years, sometimes getting as close to the surface as about 7 km (4 miles) early in the mission — and down to 2 km during its end-of-mission orbits. Yet at times the spacecraft had to stand off at distances of 300 to 400 km or more because the comet became so active that the resulting blizzard of dust blinded Rosetta's star trackers. Two distant excursions, 1,000 to 1,500 km away, enabled studies of the comet's tail and its interaction with the solar wind.

Why go to all this trouble and expense? Because we were seeking some fundamental understanding about comets, which are made from the primitive materials present during the formation of the solar system. So by studying one up close, we stood to learn about the conditions and constituents that formed the Sun's planets.

Since comets spend most of their time in the distant Kuiper Belt or Oort Cloud — very difficult or impossible to study with spacecraft — we observe the ones that venture inward as escaped examples of those regions of the solar system. And because comets sometimes also *hit* the inner planets (including Earth) and deliver water, other volatiles, and organics, studying them up close can tell us how they might have influenced conditions here, including those important to the origin of life.

First and foremost, how do we explain the dramatic shape of Rosetta's target? Two-lobed objects *do* exist among small



▲ **THE LAST WORD** Paolo Fermi, ESA's head of mission operations, sends the final command to Rosetta on September 30, 2016, as mission manager Patrick Martin (white shirt) and others look on.

◀ **COMET ENCOUNTER** Rosetta's view of Comet 67P/Churyumov-Gerasimenko, taken on January 31, 2015, shows a misshapen nucleus packed with features and a strong jet of gas and dust.

Comet 67P/Churyumov-Gerasimenko at a Glance

Discovery	September 11, 1969 (photograph)
Discoverers	Klim Churyumov, Svetlana Gerasimenko
Orbital period	6.45 years
Perihelion	186×10^6 km (1.24 a.u.)
Aphelion	851×10^6 km (5.69 a.u.)
Orbital eccentricity	0.64
Orbital inclination	7.04°
Obliquity (to orbit)	52°
Overall size Large lobe Small lobe	4.3 × 2.6 × 2.1 km 4.1 × 3.5 × 1.6 km 2.5 × 2.1 × 1.6 km
Volume	18.7 km^3
Mass	9.982×10^{12} kg
Density	0.53 g/cm^3
Rotation period	12.40 hours (June 2014) 12.06 hours (September 2016)
Surface temperature	–93° to 53°C (–135° to 127°F)
Water vapor output	300 g/s (June 2014, August 2016) 300 kg/s (August 2015)
Dust-to-gas ratio	4 ± 2 (by mass)

bodies like asteroids and comets, and in fact three of the five other comets imaged by flyby missions have this general shape. But Comet 67P is a wonderfully extreme example.

There are two main possibilities: Either two objects slowly collided and stuck together, or the neck region preferentially eroded due to an abundance of volatile ices there that escaped quickly. Crucially, Rosetta's images show that the two lobes are layered — and that the layers in one lobe do not align with those in the other. The densities of the two lobes might be different as well. These differences suggest that the lobes formed independently and then became stuck together.

Comet 67P's density is so low, about half that of water ice or about the density of flour, that it would float in water. The porosity is very high, about 70%, but only on relatively small scales. The portion of the interior probed by the CONSERT experiment, which sent radio signals back and forth between Philae and Rosetta *through* the nucleus, is uniform on scales larger than 10 meters. So there don't seem to be any large cavities inside the part of the nucleus probed by radio waves.

Watching the Comet Change

By measuring the gravitational field's effect on Rosetta as it orbited, we could measure the comet's mass very precisely. It's 9.982 trillion kilograms. And we were able to determine that the nucleus lost about 0.2% of that (18 billion kilograms) over just two years. This mass was lost as heat from the months-long close exposure to the Sun penetrated the nucleus to *sublimate* (evaporate) buried ices. The escaping gases also dragged out dust, creating the classic gas and dust tails well known to comet watchers.

We also found that 67P's rotation period decreased by about 21 minutes during Rosetta's extended visit. A day on the comet lasted about 12.4 hours before perihelion (August 13, 2015) and was around 12 hours afterward. Apparently

COMET: ESA / ROSETTA / MPS FOR OSIRIS TEAM; CREW: ESA / J. MAI

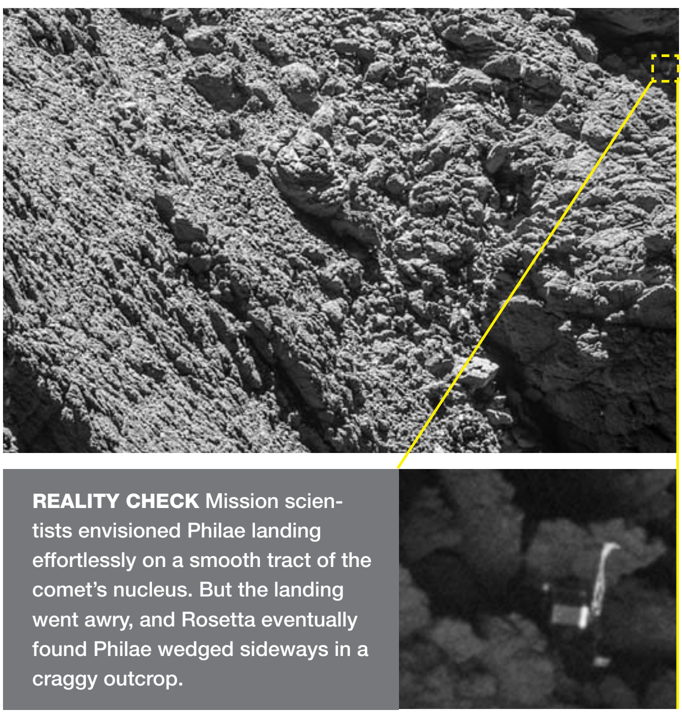
the nucleus spins faster with every 6½-year-long loop around the Sun. Most likely, escaping gas exerted asymmetric forces due to the comet's unique shape and the strikingly different "seasons" that each lobe experiences.

The axis of rotation is oriented as if the comet were spinning sideways. That is, one side of the "duck" is the northern hemisphere (we sometimes call it the "hemiduck") and the other side is the southern one. The 52° *obliquity* (tilt) of 67P's rotation axis relative to its orbit keeps the north hemisphere in sunlight during the long, distant part of the orbit, and the southern hemisphere is illuminated during the fast, close part of the orbit. The upshot is that northern summer lasts 5.5 years and is relatively cold, whereas the southern summer is much shorter, less than a year — but it's much more intense because it occurs when the comet is closest to the Sun.

Because of this seasonal asymmetry, we see distinct differences between the two hemispheres. The mass loss in the south during its short, hot summer is significantly stronger, potentially eroding many meters in some regions during each pass around the Sun. This material mostly escapes, but what falls back preferentially settles on the cold northern hemisphere. Many regions in the north end up thickly mantled with dust, leaving the southern regions mostly dust-free and exposing the more solid surface.

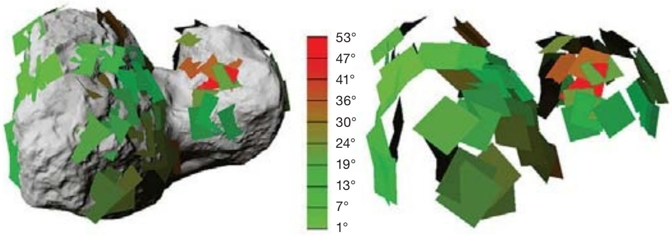
We also see chemical differences in the gas coming from the two hemispheres — the ratio of carbon dioxide to water escaping from the south is higher. This perhaps has less to do with the lobes having different compositions than with the fact that they experience different heating, erosion, and chemical evolution histories.

Rosetta also recorded daily effects due to the comet's rotation — a kind of cometary "water cycle" — in which two

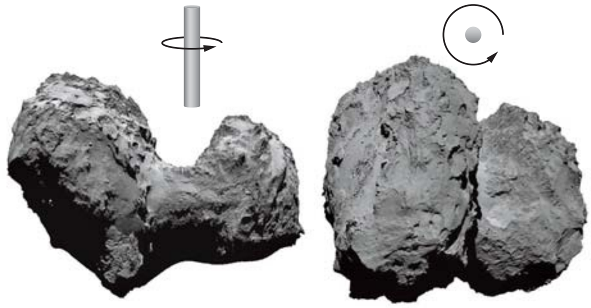


REALITY CHECK Mission scientists envisioned Philae landing effortlessly on a smooth tract of the comet's nucleus. But the landing went awry, and Rosetta eventually found Philae wedged sideways in a craggy outcrop.

COMET AND SPIN DIAGRAM: ESA / ROSETTA / MPS FOR OSIRIS TEAM; LAYER DIAGRAM: M. MASSARONI ET AL. / *NATURE*



▲ **TELLTALE SHAPES** Careful analysis shows that each of the comet's lobes is draped with a unique set of layered deposits — indicating that the two lobes formed apart and then became joined. Colors show how well each layer's plane matches the local gravity vector, with angular deviations ranging from 1° (green) to 53° (red).



▲ **WHIRLING "DUCK"** Comet 67P/Churyumov-Gerasimenko spins every 12 hours around an axis through the narrow neck that connects its two lobes. *Left:* The upper (northern) portion of each lobe spends more time in sunlight, on average, but at times when the comet is farthest from the Sun. The lower (southern) portions experience a shorter but more intense exposure to sunlight when the comet is near perihelion.

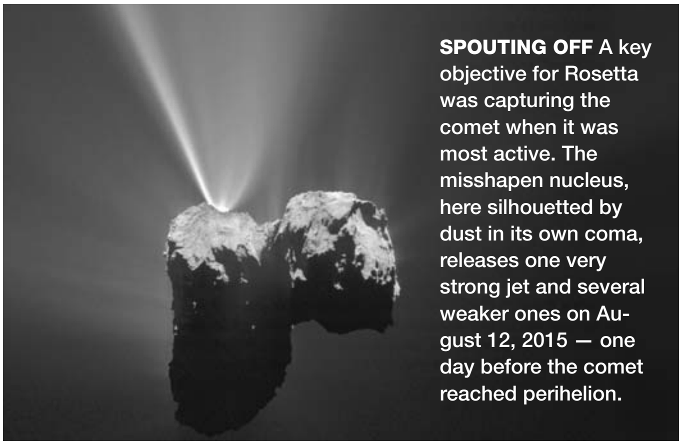
processes might be at work. In one, ice sublimates from the dayside, and that gas subsequently freezes as a frost on the colder, nightside surface. This frost then sublimates again as the Sun rotates into view, and the process repeats. Another possibility is that, after local sunset, residual heat inside the nucleus liberates some buried water, which then freezes out again on the surface experiencing night.

Either way, these constant flows are punctuated by sudden events, jets of gas and dust, which are likely due to the Sun hitting freshly exposed ice on part of the surface that collapsed from a cliff or from the walls of a pit. Other speculation is that jets also form when the thermal pulse reaches subsurface pockets of ice that then quickly sublimate, building up pressure and explosively escaping.

In physics, we often refer to a simplified version of a problem as a "spherical cow" because, as the old joke goes, to a first approximation a cow is roughly spherical. The nucleus of comet 67P definitely is not behaving like a spherical duck, and once we got close and saw all the details, we no longer could use many of our simplifying assumptions about comets. That's not a bad thing — it means the analysis and complex modeling of Rosetta's results likely will continue for decades to come.

Clues to 67P's Origin

One of the foremost questions in planetary science concerns the origin of Earth's water. Did it mostly come from comets, and if so were they like 67P? Key to figuring out the answer is



SPOUTING OFF A key objective for Rosetta was capturing the comet when it was most active. The misshapen nucleus, here silhouetted by dust in its own coma, releases one very strong jet and several weaker ones on August 12, 2015 — one day before the comet reached perihelion.

the ratio of deuterium ("heavy hydrogen") to normal hydrogen in water molecules. This D:H ratio varies based on where it's measured in the solar system. Meteorites and asteroids have D:H values similar to Earth's. Although we think of these objects as very dry, some types of *carbonaceous chondrite* meteorites can have a water fraction as high as 20%. But whether these could have delivered enough water to Earth is still debated.

Meanwhile, the most distant, longest-period comets — those coming from the Oort Cloud — all have D:H ratios that are too high, compared with our planet. However, the value measured in a short-period comet, 103P/Hartley 2, has a very Earth-like value. This object is a *Jupiter-family comet* (JFC), an object with a relatively short-period orbit that is dynamically controlled by Jupiter. So we were eager to know if 67P, which is also a JFC, likewise has an Earth-like D:H ratio.

The first and strongest result regarding this question came from Rosetta's ROSINA mass spectrometer, which found a D:H ratio 3½ times higher than Earth's — a value even higher than those of Oort Cloud comets! This confirms what many planetary scientists had already come to suspect: Perhaps comets of *any* type are not the primary source of Earth's water. Instead, maybe most of it really did come from asteroids — or was here from the outset in the materials from which Earth formed.

Still, comets have and will continue to hit Earth and deliver some water. So every glass of water you drink has comet water in it, just not as much as once thought.

An exciting implication of the different D:H values in comets Churyumov-Gerasimenko and Hartley 2 is that JFCs might have originated from widely different regions of the solar system. Moreover, apparently the water ice in 67P is original to the comet — it was never "reprocessed" and mixed with water from other sources in the primordial solar nebula.

So do we have any clue where Comet 67P/Churyumov-Gerasimenko formed? One hint comes from the ROSINA and Alice instruments, which detected molecular oxygen (O_2). This is surprising because O_2 is very reactive — it's hard to understand how it could have been retained in a 4.5-billion-year-old comet.

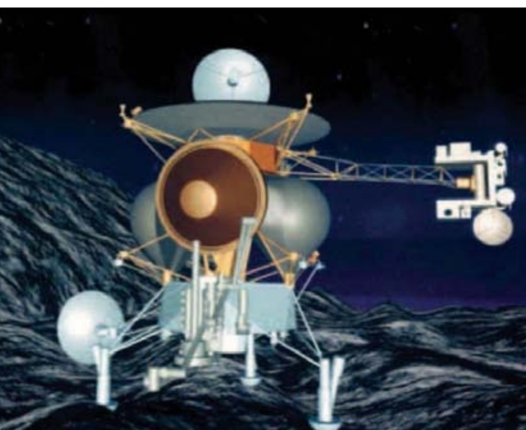
One idea that's become a lively topic of discussion among Rosetta's scientists is that the O_2 became trapped in "cages" of ice (called *clathrates*). This would keep the oxygen from escaping or reacting until the ice sublimates whenever the comet comes close to the Sun.

ROSINA also discovered molecular nitrogen (N_2). This finding, the detection of O_2, and the high D:H ratio all indicate that 67P formed at very cold temperatures (25 to 30 K). This would place its origin in the outer fringe of our planetary system, likely in the Kuiper Belt. That's also dynamically consistent with current models of solar system formation.

So let's recap: Measurements from Rosetta and dynamical models imply that 67P formed in the Kuiper Belt, and that its two lobes were separate bodies that gently collided and stuck together. But how did those 2-km-wide bodies come to exist so far from the Sun in the first place?

One clue comes from the "goose bumps" observed on the nucleus — perhaps an appropriate term considering how cold it is out there. On the walls of pits and cliffs we identified textures that look like they are built of many small boulders just

COMET: ESA / ROSETTA / MPS FOR OSIRIS TEAM; ROSETTA CONCEPT: ESA



PLAN A ESA's original concept for Rosetta. Note the sample-return capsule (brown).

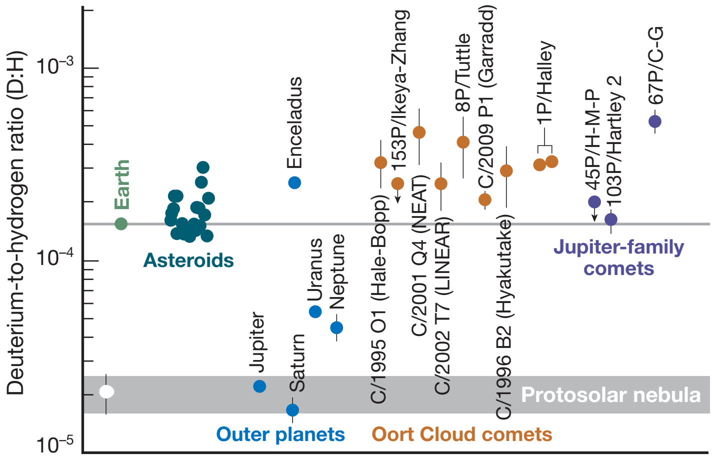
Rosetta, circa 1992

This mission didn't end up the way the European Space Agency conceived it in the early 1990s. The original plan called for a spacecraft able to return a sample of comet nucleus. Then it became a mission with two landers (NASA's Champollion and ESA's RoLand) before morphing to the orbiter-lander configuration finally built by ESA.

Even the original target, a comet named 46P/Wirtanen, had to be changed. The failure of an Ariane V rocket just one month prior to Rosetta's planned January 2003 launch caused a year-long postponement. That delay put a rendezvous with Comet Wirtanen out of reach. So the Rosetta team scrambled to find another target that was scientifically interesting, similarly sized (Philae had been designed specifically for the mass of Comet Wirtanen), and in an orbit that could be reached.

The decision to go to 67P/Churyumov-Gerasimenko was a compromise. This body, like Wirtanen, is also a Jupiter-family comet — but one that's at least three times larger and up to 30 times more massive. So the lander did have to be modified a bit. And while 67P could be reached with decent fuel reserves, it also took the longest time to reach— which made it a more risky choice.

Comet 67P was amazing, so imagine what that "other" mission would have been like.



▲ **WATER'S ORIGINS** The proportions of hydrogen and its heavier isotope deuterium vary widely across the solar system. The ratio is unexpectedly high in Rosetta's comet, 67P/Churyumov-Gerasimenko, implying that most of Earth's water must have come from water-rich asteroids or was already here when our planet formed.

PLOT: KATHRIN ALTWEGG ET AL. / *SCIENCE*; IMAGES: ESA / ROSETTA / MPS FOR OSIRIS TEAM (3)

a few meters wide. Could these be our first peek at the basic building blocks that created comets and eventually planets?

Results From Philae

In addition to the CONSERT measurements of the interior of the nucleus, Philae provided valuable measurements about the properties of the comet's surface. Even the unplanned "bounces" helped us gauge the hardness of the surface. Thanks to MUPUS, which tried to hammer an instrumented penetrator into the nucleus, we know that there's a surface layer of dust covering a very hard, compacted dust-ice crust. The lander also confirmed that the nucleus has no intrinsic magnetic field.

COSAC, which paired a gas chromatograph and mass spectrometer, identified 16 organic compounds, four of which — including acetone and acetamide — had never been detected in a comet. Gases measured by Ptolemy, another mass spectrometer, contained not only the expected water, carbon monoxide, and carbon dioxide, but also organic compounds including formaldehyde. Many of these compounds are important in creating amino acids, sugars, and nucleobases. In addition, ROSINA detected the amino acid glycine. Even if comets didn't supply the majority of water on Earth, they could have provided essential raw materials for life.

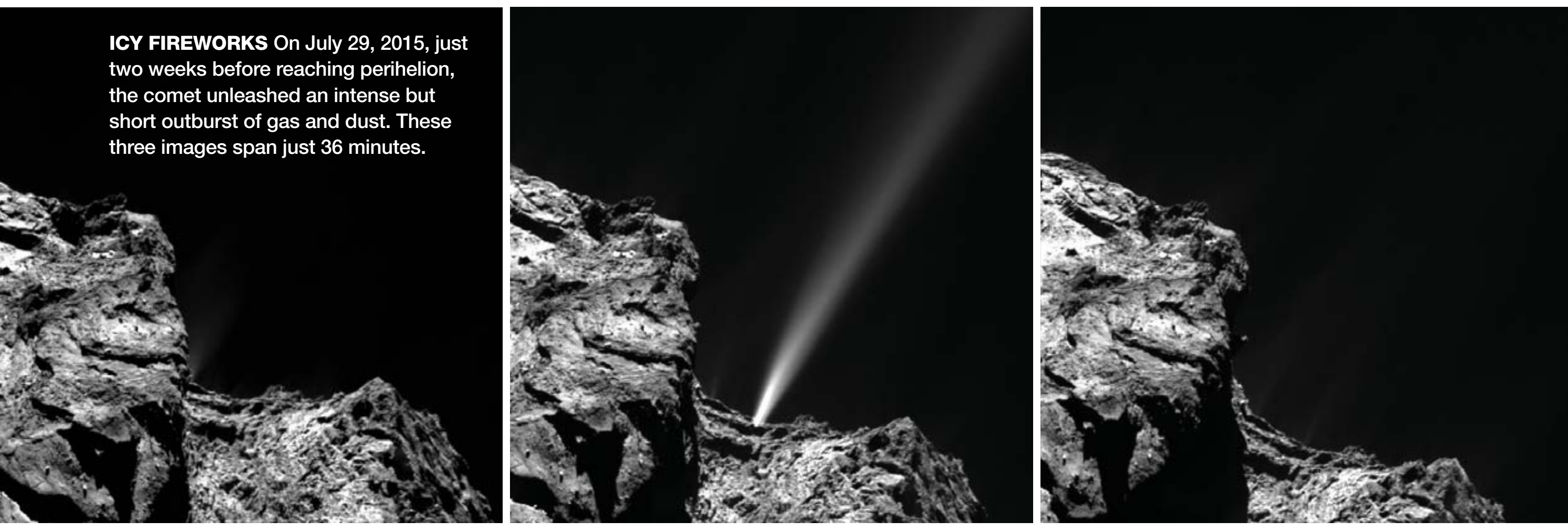
We'll never hear from Rosetta again, but this is not the last that we'll hear from its host. The comet will have a fairly close encounter with Jupiter, only about 56 million kilometers, at its next aphelion in November 2018. Jupiter's gravitational tweak will decrease 67P's perihelion. So when the comet next comes its closest to the Sun, on November 2, 2021, chances are good that we'll see more vigorous activity. That coming apparition also offers quite good observing geometry from Earth, with the comet just 0.42 astronomical unit (63 million km) away and well positioned high in the northern night sky (declination +26°).

But it will be a long time, if ever, that we'll see Comet 67P/Churyumov-Gerasimenko as well as we have these past three years. And as I watched Rosetta take its final plunge to the surface, streaming to us in real time images of new vistas seen in more detail than ever before, I couldn't help but think of this quote from the movie *Blade Runner:*

> *"I've seen things you people wouldn't believe. Attack ships on fire off the shoulder of Orion. I watched C-beams glitter in the dark near the Tannhauser Gate. All those moments will be lost in time, like tears in rain. Time to die."*

Rest in peace, Rosetta and Philae. I'm sure those moments will not be lost as we continue to use this mission's vast stockpile of data to further our knowledge about comets, the origin of our solar system, and perhaps ourselves.

■ **JOEL PARKER** (Southwest Research Institute) is on the science teams of Rosetta and several other space missions. He produces and hosts the radio science show "How on Earth."



ICY FIREWORKS On July 29, 2015, just two weeks before reaching perihelion, the comet unleashed an intense but short outburst of gas and dust. These three images span just 36 minutes.

The Real Origins of Amateur Telescope Making

FIRST STELLAFANE By 1926, the Springfield Telescope Makers had built a clubhouse atop Breezy Hill on the outskirts of Springfield, Vermont, where they held the first official Stellafane Convention. But contrary to legend, the amateur telescope making movement began much earlier and far away.

SPRINGFIELD TELESCOPE MAKERS

Amateur astronomy is what it is today because of mirror-grinding enthusiasts more than a century ago.

Many things make history fascinating. One is that so much of today's world stemmed from little flukes of fate that might easily never have happened.

The fact that you became an amateur astronomer and are holding this magazine, for instance, and the fact that a magazine like this exists for you to hold, likely trace back to a shipwrecked Arctic explorer surviving two years of starvation and disease on a frozen island north of Russia from 1903 to 1905. Russell W. Porter was among the rescued crew. Beaten down by failure, he gave up his polar dreams and eventually settled down to be a machinist in Springfield, Vermont. There, pursuing a new enthusiasm he'd picked up leafing through some old magazines, he recruited fellow workers to do something few had heard of: build their own astronomical telescopes. An editor of *Scientific American* got wind of the group, wrote it up — and a movement was off and running.

Earlier, amateur telescopes had been the province of a few wealthy people who could afford to buy expensive small refractors. The new movement's step-by-step guides to grinding and figuring a large, high-quality parabolic mirror — and where to find clubs of other people doing the same — democratized astronomy for the 20th century.

Modern manufacturing later made telescopes as cheap to buy as to build. Today, amateur telescope making — ATMing — has shrunk to a niche for dedicated do-it-yourselfers and perfectionists who are unsatisfied with the adequate-to-okay mirrors churned out by machine in factories. But, goes the popular narrative, amateur astronomy would never have become the widespread thing it is today (why not amateur seismology? amateur chemical engineering?) were it not for those Vermont telescope makers, the movement they spawned, and the serious-telescope companies that some of the movement's members went on to found.

It's an inspiring story, often told. And like most such narratives, it's too tidy, too pat, and only partly right.

Russell Porter didn't spring from nothing. The movement wasn't founded in America, and it didn't begin as late as the 1920s with the Springfield Telescope Makers. Here is a deeper look at how it, and thus we, came to be.

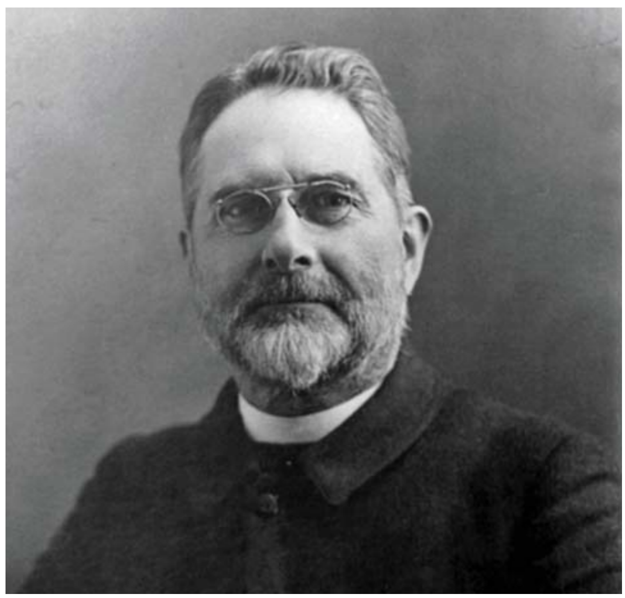
Origins

Until the late 19th century there was little to distinguish amateur from professional astronomy (*S&T:* June 2016, p. 36). This was also true for telescope making; scientists of many sorts generally had to craft their own instruments. But with the rise of specialist instrument makers in Europe and then the United States, well-to-do "gentleman astronomers" could satisfy their curiosity and show off their wealth by buying small refractors at prices equivalent to several thousand dollars today. As people less well off began to gain more education and a modicum of free time, some of them might have thought about making a telescope, but the optics were dauntingly hard to handcraft even by the most resourceful and motivated.

Then came two breakthroughs. The first was the chemical process to deposit silver on glass, perfected by C. A. Steinheil and Léon Foucault in 1857. No longer did telescope makers have to choose between small achromatic lenses or brittle, expensive mirrors made of speculum metal that needed frequent repolishing and refiguring.

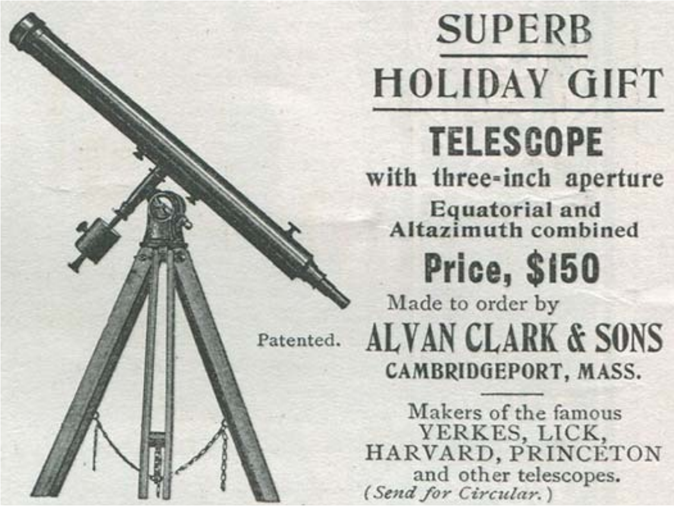
The second was the Foucault knife-edge test, described by Léon Foucault the following year. It provided a simple but extremely sensitive way for a mirror maker to shape a glass

◀**FLUKE OF FATE** On the failed Ziegler-Fiala polar expedition, the crew of the icebound ship *America* photographed it by moonlight on January 2, 1904, before it broke up and sank.

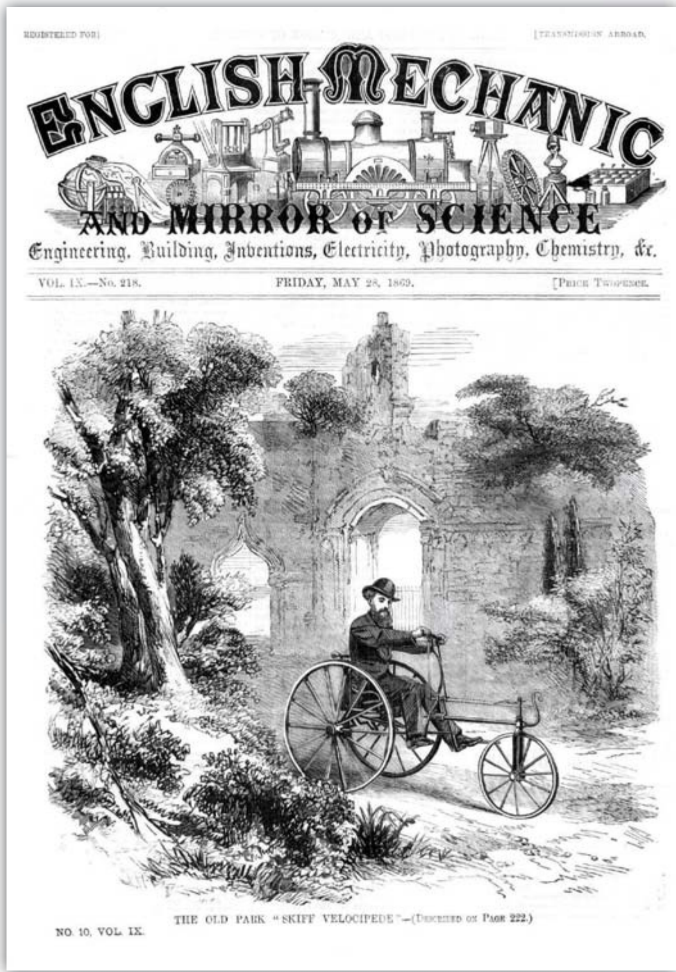


▲**TRUE FOUNDER** Rev. William F. A. Ellison (1864–1936), rector of a small-town church in Northern Ireland, was the prime mover enabling amateur hobbyists to build serious astronomical telescopes.

SHIP: FRESHWATER AND MARINE IMAGE BANK / UNIV. OF WASHINGTON
ELLISON: ARMAGH OBSERVATORY



▲ **OUT OF REACH?** In 1900, the famed Alvan Clark & Sons offered an equatorially mounted 3-inch refractor for the equivalent of $4,000 today. Now you can get a similar 3-inch — but including a finder, star diagonal, and slow-motion controls — for about $150. Real telescope prices have declined since 1900 at the same average rate as inflation has grown: about 3% annually.



▲ **THE VEHICLE** The *English Mechanic,* 24 pages long and issued weekly, became the breeding ground for the telescope-making hobby.

disk to diffraction-limited quality in the workshop, without having to test it on a star outdoors at every step of the way as it neared completion.

Today you can start learning how to make a telescope with a quick web search. Books have always been central to learning a subject, but when the subject is evolving quickly, they're less useful. For early amateur telescope makers, the media that played the pivotal role were bulletins and magazines.

In 1865 a periodical appeared in England that would become just the right vehicle. Fascination with science and technology was spreading, and so were, for some, shorter working hours and more disposable income. The *English Mechanic* initially covered a wide range of subjects, but certain new developments in technology came to predominate (such as a deep interest in engines and motor cars around the turn of the 20th century). Each issue of the *English Mechanic* was about half articles and, importantly, half letters from mechanically inclined readers. These letters were the equivalent of internet users' groups today, and like today, many contributors used pen names to protect their privacy. The paper came out weekly, allowing threads of dialogue to build up quickly, often quite heated and impolite!

Astronomy and ATMing became a substantial part of the *English Mechanic.* Between 1900 and 1920, at times half of its content was astronomy related. Many of the contributors who can be identified were prominent and respected, and many were in the United States. Unfortunately some who used pen names have never been identified, such as "Southern Cross," a particularly prolific and forceful contributor.

One frequent contributor was the Rev. William F. A. Ellison, the well-educated rector of a small-town church in Ireland. His duties must have been mild, for they left him the time to write about 500 articles and letters for the *English Mechanic* over the years. Ellison also became adept at producing high-quality lenses and mirrors. His personal logbooks show that he worked on more than 170 mirrors and was employed by the George Calver optical firm to achieve the final figure on some of its own mirrors.

In 1918 the *English Mechanic* published a series of articles by Ellison describing how to make reflecting telescopes and, in particular, how to shape their parabolic mirrors. In 1920 Ellison collected the articles into a book: *The Amateur's Telescope.* They were remarkable in their level of detail, showing not just how to produce a basic telescope mirror, but how to determine and correct its aberrations and bring it to perfection.

Ellison's articles and book were a watershed. In 1918, as a result of his demonstrated expertise, he was appointed director of the Armagh Observatory in Northern Ireland, a post he held until his death in 1936.

The Americans

Winding back the clock a little, the pages of the *English Mechanic* show that other early pioneers were building their own telescopes in the United States. A major American contributor to its pages was John Mellish, born in 1886 as

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▲ **STARS** Albert G. Ingalls (left) and Russell W. Porter pose in the early 1930s with a reflector on an equatorial "Springfield mount" of Porter's design. It kept the eyepiece at a fixed position, at the cost of three mirror reflections and a high counterweight.

the son of a farmer and living in Madison, Wisconsin. He was not only an accomplished telescope maker but also a very good observer, scrutinizing the planets and discovering a number of comets.

In 1907, when Mellish was about 21, the new American magazine *Popular Mechanics* published an article by him on building telescopes. By the time he was 26, Mellish had made increasingly large reflectors with apertures of 7½, 8½, 10, 11, 12, and 16 inches. A letter Mellish published in the *English Mechanic* in 1912 shows him proudly standing in a Wisconsin field by his massive, long-focus 16-inch.

Mellish also became secretary of the Society for Popular Astronomy (SPA) when it was formed in 1909 by Frederick C. Leonard — who was 13 years old. Perhaps because of his age, Leonard wasn't afraid to ruffle establishment feathers. The prevailing view at the time was that amateurs ought to work on behalf of professionals, and that to form a society of their own would interfere with the more learned bodies. Leonard's society lasted only until 1918, but by then it had set the mold for future amateur astronomical societies in America. Leonard was a prolific writer from an early age, and his articles and letters were a common feature of the *English Mechanic*.

Meanwhile, a 1910 article in *Popular Mechanics* had inspired Russell Porter, back from the Arctic, toward his new interest. Porter befriended the enthusiastic young Frederick, and in 1914 Porter hosted the first SPA Convention in his own home in Maine. It was a small affair, but a sign of greater things to come.

Flowering in Vermont

By that time Porter was 42 years old. Born in Springfield, Vermont, in 1871, he was educated as an engineer and architect but his dream was to reach the undiscovered North Pole. To this end he participated in six arctic expeditions, generally as a surveyor and artist. Most of these ventures ended in shipwreck or other calamity. The Ziegler-Fiala Expedition of 1903–05, whose crew was stranded for two years on the northernmost island of the Franz Josef Archipelago, finally ended Porter's polar ambitions. He tried to set up an artists' colony in Port Clyde, Maine, but it failed. He did, however, marry the local postmistress, Alice Marshall.

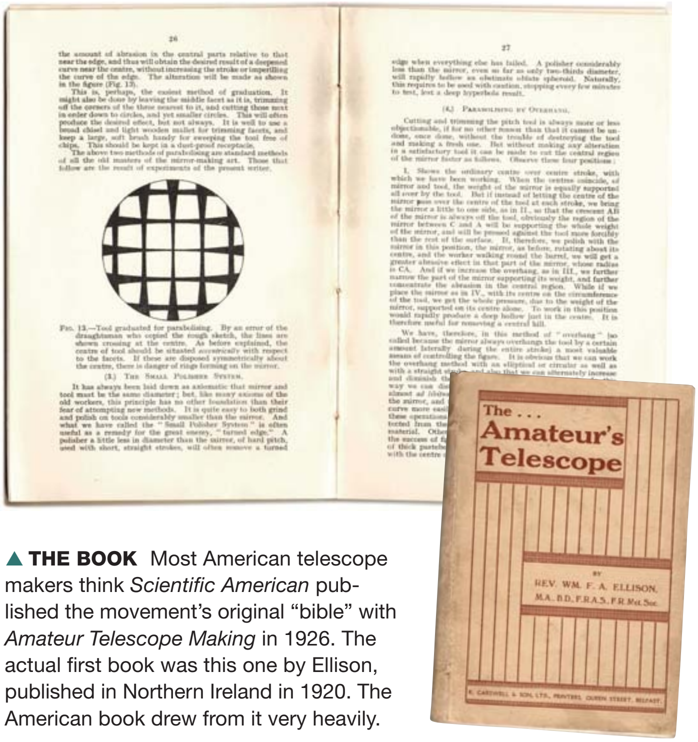
It seems that while recovering from an illness in the home of his friend James Hartness, an amateur astronomer and president of the Jones & Lamson Machine Company of Springfield, Porter passed time skimming through some back copies of magazines. Two articles from 1910 caught his attention: one by John Mellish on telescope making in *Scientific American,* and one on mirror making by Leo Holcomb in *Popular Astronomy.* In 1913 Hartness sent Porter two 16-inch glass blanks and some notes. Porter used these to make his "Polar Reflector," which he described in *Popular Astronomy* in 1916. It is thought that Porter used a book titled *Glass Working by Heat and Abrasion,* by Paul Hasluck, for very basic instruction on mirror making and testing. But it was published in 1899, and he would have had to make significant adjustments for newer grinding and polishing materials.

Porter moved back to Springfield in 1919 to work at Jones & Lamson. With his and Hartness' telescope-making experience, the company's facilities, and its technically skilled workforce, all the ingredients for something special were in place.

In 1920 Porter recruited 14 of the company's workers and a local schoolteacher into a series of evening classes on telescope making. Many of the group completed Newtonian reflectors and, in 1923, they formed the Springfield Telescope Makers. That year Porter wrote an article for *Popular Astronomy* describing the group and their work. He also provided some hilltop land, where the men built a clubhouse and named it Stellafane, "shrine to the stars." The club invited visitors and other groups to its site. In 1926 it hosted the first Stellafane Convention, which continues annually to this day.

Going National

We now turn to another key player in the story. In the photo of that first Stellafane Convention on page 22, Albert G. Ingalls stands at far right next to Porter. Ingalls had become an editor at *Scientific American* in 1923 and apparently saw Porter's many articles in *Popular Astronomy.* The two met in 1925 and started the long association and friendship that



▲ **THE BOOK** Most American telescope makers think *Scientific American* published the movement's original "bible" with *Amateur Telescope Making* in 1926. The actual first book was this one by Ellison, published in Northern Ireland in 1920. The American book drew from it very heavily.

truly set ATMing in America onto its historic course. In 1925 Ingalls wrote an article about the Springfield Telescope Makers and asked readers if they were interested in more information. Nearly 1,000 readers sent letters saying they were! So in 1926 he published two articles by Porter: the first on mirror making, and the second on mounts for reflecting telescopes.

Porter referred readers to material from Ellison's book for the necessary mirror-making details, but not for the mounts. Here he was full of ideas from his own training and experience as an engineer, and the article describes mounts that we would be familiar with today.

In 1926 Ingalls had *Scientific American* publish a groundbreaking book: *Amateur Telescope Making.* He pulled together contributions from many sources, including Ellison for the mirror-making section. Revised, expanded editions were later issued, and two additional volumes came out in 1937 and 1953 based on the abundance of ATM columns *Scientific American* had published by then. These books are still in print, in reorganized form (available from Willmann-Bell).

Thus was spread the material for a full-scale amateur movement. Telescope-making clubs sprang up around the country, some of the largest in the basements of big-city museums and planetariums that provided institutional support and publicity.

KEITH VENABLES

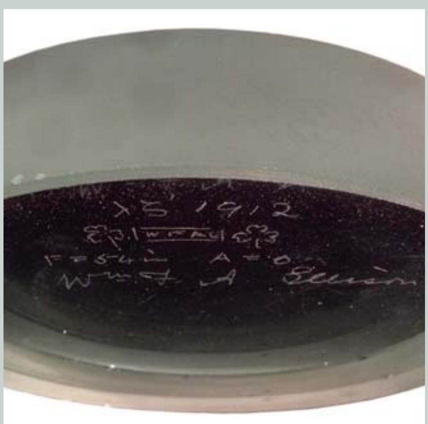
Restoring an Ellison Reflector

How I got interested in the history of amateur telescope making.

At a party in historic East London in 2009, my son-in-law mentioned that an old telescope had been found in the backyard of the premises. Would I give it a look? I was presented with a badly painted metal tube that looked like it had been driven over. The focuser and some fittings were of brass, all damaged to varying degrees. There was no mount. It didn't seem promising, but I took it home for further inspection.

The next day I dismantled the telescope to find the optics intact and some intriguing signs of quality and old age. The 6¼-inch primary mirror was wedged into a solid oak mirror cell that had shrunk and warped. Carefully prising out the mirror, I was surprised to see handwriting scratched into its back side. I have to admit not knowing the significance of the signature "Wm. F. A. Ellison," but an internet search quickly revealed who he was and produced his 1920 book *The Amateur's Telescope.* I was immediately struck by a photograph in the book of one of the author's telescopes. It looked like the very same one I had rescued!

I set about restoring it. As I peeled off layers of paint applied over many years, it quickly became clear that I did indeed have Rev. Ellison's 6¼-inch. I was able to make contact with his grandson, great-grandson, and Armagh Observatory, all of which were extremely interested and helpful in my research. An astronomy friend of mine, Brian Johnson, a professional metalworker, kindly helped me restore the damaged tube and focuser to excellent condition.



As for the mount, the photo in the book enabled me to reconstruct the altitude support and its adjustment mechanism quite faithfully. Unfortunately, the azimuth adjustment isn't really visible in the photo. I shall therefore do what Ellison probably did: make a mount based on contemporary telescopes of the time.

A number of interesting issues arose during restoration. The secondary mirror was not very good at all — its surface had a peak-to-valley deviation from flatness of 0.85 wave. But a contemporary Steinheil monocentric eyepiece was still in the focuser, and it has an estimated entrance pupil of about 2 mm, so only about the middle 25% of the secondary mirror would have been used, reducing the effect of such a poor surface. Ellison didn't attempt to work the surfaces of secondary mirrors; he cut them out of pieces of plate glass that he deemed most flat.

The primary was in a different league. It measured up with a peak-to-valley of $1/6$ wave and an rms of $1/30$ wave. This quality adds weight to Ellisons' own logbooks

KEITH VENABLES

S&T ARCHIVES

IMPORTER In America, *English Mechanic* contributor John Mellish built telescopes and told Americans how it was done in a seminal *Popular Mechanics* article in 1907. Here he looks into Yerkes Observatory's 12-inch refractor in 1915.

A number of these mirror grinders went on to form companies to make and sell serious astronomical telescopes in quantity, at reasonable prices. All these efforts enabled amateur astronomy to expand and become an important fount of science enthusiasm in America by the beginning of the Space Age.

To feed the interest, magazines continued to publish ATM articles, letters, and advertisements for supplies. New magazines appeared too — *Amateur Astronomy* in 1929, *The Telescope* in 1931, and *The Sky* in 1935. An indicator of the strength of reader interest was the addition of regular ATM columns to existing publications: "The Backyard Astronomer" section in *Scientific American* started in 1928, followed by "Gleanings for ATMs" in *The Telescope* in 1933.

The Great Depression forced some consolidation. *Amateur Astronomy* was absorbed into *The Sky,* and in 1941 *The Sky* and *The Telescope* merged to form the magazine you're holding. That tale is told in last November's 75th-anniversary cover story.

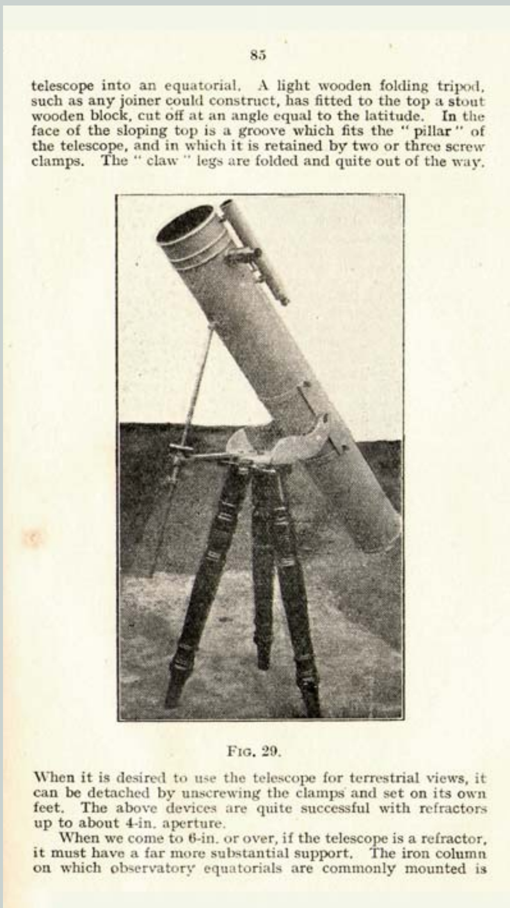
Although the birth of ATMing in America was clearly a second-generation birth, I would suggest that 1918 to 1926 was indeed the most crucial time, with perhaps 1920 as the key moment — with the publication of Ellison's book and Porter's evening class in telescope making. What is also evident, in my view, is the difference between the quite reserved English ATM scene where it all began, and the enthusiastic take-up of ATMing in the United States, which set the pace forever after.

■ **KEITH VENABLES**, FRAS, lives in the U.K. near London. He uses his skills as an engineer to make ultra-portable telescopes and is looking forward to his 18th trip to the Texas Star Party.

that suggest he was regularly figuring and refiguring mirrors for Calver telescopes.

Ellison's skill as a mirror maker is undoubted, but his mirror cells and tubes were less advanced. His reflectors usually had not a solid tube like my example, but a partially open arrangement of parallel wooden battens for ventilation. He thought that solid tubes could never produce satisfactory results due to thermal air currents. He may well have based that opinion on his use of this very scope. My own use of the telescope has led me to conclude that it isn't the solid tube but the thick, solid mirror cell in the back that was the problem.

How one of Ellison's telescopes ended up as junk in a backyard in East London we will probably never know. Fortunately, it led to a fascinating insight into a key period in the development of amateur telescope making.



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telescope into an equatorial. A light wooden folding tripod, such as any joiner could construct, has fitted to the top a stout wooden block, cut off at an angle equal to the latitude. In the face of the sloping top is a groove which fits the " pillar " of the telescope, and in which it is retained by two or three screw clamps. The " claw " legs are folded and quite out of the way.

FIG. 29.

When it is desired to use the telescope for terrestrial views, it can be detached by unscrewing the clamps and set on its own feet. The above devices are quite successful with refractors up to about 4-in. aperture.

When we come to 6-in. or over, if the telescope is a refractor, it must have a far more substantial support. The iron column on which observatory equatorials are commonly mounted is

KEITH VENABLES (2)

▶ **RESCUE** The author discovered a 6¼-inch reflector made by William Ellison, and pictured in Ellison's 1920 book, as an apparent piece of beat-up trash in a London yard. He restored it to working order. *Left:* Scratched on the back of its mirror are William F. A. Ellison's signature, "1912," and Irish shamrocks.

Galaxies in Collision

A dark night & a big scope produced fantastic views of these seven interacting pairs.

Halton Arp's *Atlas of Peculiar Galaxies* (1966) and Boris Vorontsov-Velyaminov's *Atlas and Catalogue of Interacting Galaxies* (1959) offer a sample of several hundred interacting and merging galaxies. Unlike symmetrical spiral and elliptical galaxies, or known irregular galaxies such as the Magellanic Clouds, many of these merging pairs display strange structures such as loops, narrow streamers, and rings.

When the Arp and Vorontsov-Velyaminov catalogs were published, the physical processes involved in shaping these galactic deformities were poorly understood. But the carnage clearly resulted from the interaction, and the atlases provided intriguing targets for future investigations. During the past two decades, space and ground-based telescopes have studied the dynamics of interacting galaxies across X-ray, ultraviolet, visual, infrared, and radio wavelengths, and the high-resolution of the Hubble Space Telescope (HST) cameras have captured the galactic mayhem in exquisite detail.

A 12- to 18-inch telescope will display subtle structure in many colliding galaxies. But through Jimi Lowrey's 48-inch f/4 telescope in West Texas, the views can rival a high-quality image. Under good observing conditions we routinely pick out jaw-dropping interaction features such as tidal tails, bridges, and starbursts.

The Penguin & Egg

Arp 142 (VV 316) shows the violent merger of NGC 2936, a highly disrupted spiral resembling a celestial penguin on the HST image at right, and an egg-like elliptical companion, NGC 2937. The "eye" of the penguin is marked by the nucleus of NGC 2936, and a remnant arm, ablaze with knots of massive blue stars, serves as the "beak." Gravitational forces pulled gas and dust out of the plane of NGC 2936, warped the disc, and triggered torrents of blue star-streams in the shredded "neck." NGC 2936 took the brunt of this cosmic train wreck, while the elliptical NGC 2937 survived the encounter relatively unscathed.

This small pair resides in Hydra, just southwest of its border with Sextans and Leo, at a distance of 320 million light-years. Viewed through the 48-inch, the surface brightness of NGC 2936 is highly irregular, showing a slightly curving body and sharply bending tail. The central region extends

The Vorontsov-Velyaminov Catalogs

Although Halton Arp's 1966 *Atlas of Peculiar Galaxies* is better known, Boris Vorontsov-Velyaminov (Sternberg Astronomical Institute, Moscow University) published a list of interacting galaxies some seven years earlier in *Soviet Astronomy*. The list consisted of the preliminary results of his study of the photographic plates taken during the first Palomar Observatory Sky Survey (POSS) in 1958. He followed this up with his 1959 *Atlas and Catalogue of Interacting Galaxies*, now known as VV Part I, which included 355 interacting galaxies, the majority of which he discovered on the POSS plates.

Vorontsov-Velyaminov issued a second catalog (known as VV Part II) in 1977, expanding the list of interacting galaxies by 497. Astrophysicist V. P. Arkhipova (Lomonosov Moscow State University) added an additional 1,162 galaxies originally cataloged by Vorontsov-Velyaminov to the *Morphological Catalogue of Galaxies* in 2001, expanding the numbered VV list to a total of 2,014.

• **FURTHER READING:** Both the Arp and Vorontsov-Velyaminov catalogs can be accessed via the NASA/IPAC Extragalactic Database (NED). See **https://is.gd/VVCatalog** for the VV catalog and **https://is.gd/ArpCatalog** for the Arp catalog.

VIOLENT MERGER The distorted form of spiral galaxy NGC 2936 *(top)* suggests that it bore the brunt of the damage during its close encounter with the elliptical galaxy NGC 2937 *(bottom)*. This image combines visible and infrared data gathered by the Hubble Space Telescope Wide Field Planetary Camera 3.

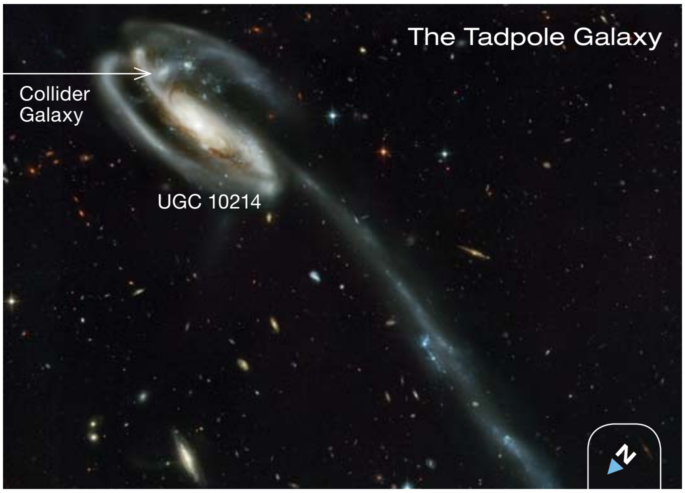
NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

30″ × 20″, tapering on the east end and punctuated by a conspicuous nucleus. A broad, low surface brightness tidal tail is attached on the west side. It curls south-southwest, gradually fading out due west of the intensely luminous but diminutive NGC 2937.

A 13th-magnitude star shines 1′ northwest of NGC 2937 and a ghostly 16.5-magnitude sliver (PGC 1237172) points northwest from the star. Arp called this object a “shred” ejected from NGC 2936, but its radial velocity implies the companion is in the foreground at only 70% the distance, so it isn’t physcially related to the Penguin.

The Tadpole Galaxy

Arp 188 (VV 29, also cataloged as UGC 10214) is a severely deformed 13.7-magnitude spiral in Draco, a little over ½° southwest of 6.4-magnitude Theta (θ) Draconis. Fritz Zwicky photographed its huge tidal ribbon in the mid-1950s using the 200-inch at Palomar Observatory and remarked, “The system obviously has suffered some encounter with other galaxies which, however, cannot be located with certainty at the present time.” The spectacular HST image on page 30 caught the small collider (a compact blue galaxy) partially hidden by a spiral arm. The close encounter, which occurred 100 to 200



▲ **THE INTERLOPER** The long plume of stars and dust trailing behind the spiral galaxy UGC 10214, the residue of its collision with a smaller galaxy, gives it the appearance of a tadpole racing across a pond. Close examination of UGC 10214's remaining structure reveals the guilty party, a compact, blue galaxy still entangled in the larger galaxy's spiral arms.

NASA / HOLLAND FORD (JHU) / ACS SCIENCE TEAM / ESA

million years ago, separated a major spiral arm from the galaxy and stretched it into a dramatic plume, rich in dust and gas. The galaxy's distance of 420 million light-years implies the Tadpole's tail unfurls across some 280,000 light-years!

In the 48-inch the main section of the galaxy extended 1.2′ × 0.6′ and encompassed an elongated central bar. The debris tail extending east was easily seen as a delicate, low surface brightness plume, nearly tripling the length of the galaxy. A couple of miniscule condensations sparkled, including one right at the tip. A 2003 HST study using the newly installed wide-field Advanced Camera for Surveys (ACS) concluded these clumps are super-massive clusters only 4 to 5 million years old. With time, they may evolve into dwarf companions in the Tadpole's halo.

The Heron Galaxy

Arp 84 (VV 48), the interacting pair NGC 5394 and NGC 5395 in Canes Venatici, is another stunner through the 48-inch at 610×. The flattened halo of 11.4-magnitude NGC 5395, which forms the Heron's "body" and "wings," spans 2.5′ × 1.0′ and envelops a blazing 30″ core. The most exciting feature is a well-defined, somewhat splotchy arm that wraps nearly 360° around the galaxy, forming a partial ring.

The arm emerges at the core's north edge, shoots directly south on the east side, and twists tightly backwards to the north along the west edge of the halo. A dark absorption lane clearly separates the luminous central region from this arm. An irregular offshoot on the north side includes a brighter patch.

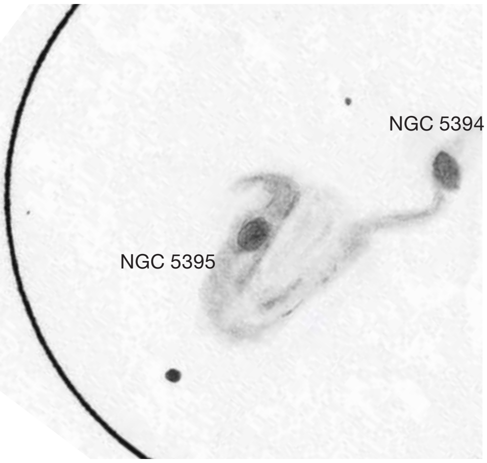
NGC 5394, centered 2′ to the north-northwest, is a compact 13th-magnitude disc only 30″ in diameter with a strongly concentrated center and brilliant stellar nucleus. The Heron's neck, a long, thin tidal arm, was easily visible, hooking southeast and nearly touching the northwest arm of

Colliding Galaxies & Where to Find Them

Arp / VV Number	Object	Type	Mag(v)	Size	RA	Dec.	Nickname
Arp 142 / VV 316	NGC 2936	Irr	13.1	1.6′ × 0.9′	09^h 37.7^m	+02° 45′	The Penguin and Egg
	NGC 2937		13.7	0.8′ × 0.4′	09^h 37.8^m	+02° 45′	
Arp 188 / VV 29	UGC 10214	SBc pec	13.7	3.6′ × 0.8′	16^h 06.1^m	+55° 26′	Tadpole Galaxy
Arp 84 / VV 48	NGC 5394	SBb pec	13.0	1.7′ × 1.0′	13^h 58.6^m	+37° 27′	The Heron Galaxy
	NGC 5395	SAb pec	11.4	2.9′ × 1.5′	13^h 58.6^m	+37° 26′	
Arp 242 / VV 224	NGC 4676A	S0 pec	13.7	2.3′ × 0.5′	12^h 46.2^m	+30° 44′	The Mice
	NGC 4676B	SBa pec	13.6	2.0′ × 0.8′	12^h 46.2^m	+30° 43″	
Arp 55 / VV 155	UGC 4881A	Double	14.5	0.9′ × 0.8′	09^h 15.9^m	+44° 20′	The Grasshopper
	UGC 4881B		15.1	—	00^h 15.9^m	+44° 20′	
Arp 244 / VV 245	NGC 4038	SBm pec	10.3	5.2′ × 3.1′	12^h 01.9^m	–18° 52′	The Antennae
	NGC 4039	SAm pec	10.6	3.1′ × 1.6′	12^h 01.9^m	–18° 53′	
Arp 81 / VV 247	NGC 6621	SBc pec	13.3	2.1′ × 0.9′	18^h 12.9^m	+68° 22′	Edward's Galaxy
	NGC 6622	E/S0 pec	11.9	0.6′ × 0.5′	18^h 13.0^m	+68° 21′	

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.

BRIGHT EYE Even under difficult skies, with the right scope you might be able to pull out the luminous cores of these interacting galaxies, particularly the bright “eye” of the Heron, NGC 5394. This sketch was drawn using a 20-inch (505-mm) reflecting scope and a deep-sky video camera.



BRIGHT-EYED BIRD The interacting pair NGC 5394 and NGC 5395 lie about 165 million light-years from us in the direction of Canes Venatici. This image was captured through the 20-inch f/8 Ritchey–Chrétien telescope at Kitt Peak Observatory during the Overnight Telescope Observing Program.

NGC 5395. The opposing arm (“head” and “bill”) was spied as a tenuous smoke trail to the northwest.

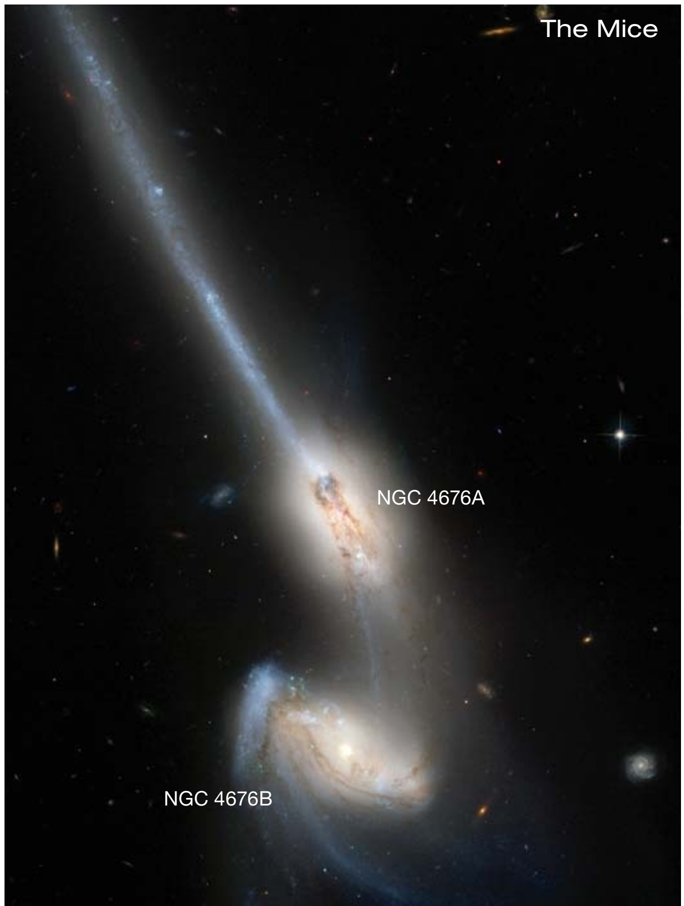
A near-infrared study published in the *Astronomical Journal* in October 2005 concluded, “This tightly wound structure [in NGC 5395], resembling a broken ring, supports the scenario of a strong interaction in the system, probably a collision with NGC 5394 crossing through the disk of NGC 5395.” A spectroscopic investigation published in the *Monthly Notices of the Royal Astronomical Society* in 2015 by astronomers working with Calar Alto Legacy Integral Field Area (CALIFA) survey data reported key evidence of the earlier collision, with a flurry of star-forming activity a few hundred million years ago, as well as detailing an ongoing nuclear starburst in NGC 5394.

The Mice

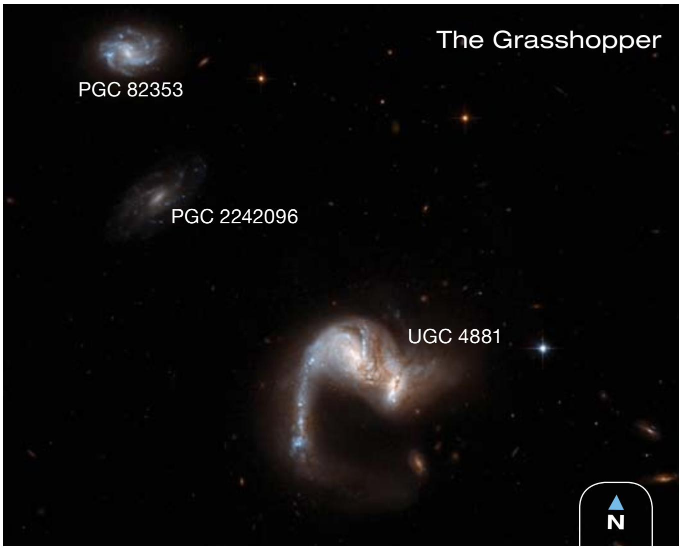
Vorontsov-Velyaminov dubbed the two interacting members of NGC 4676 that form **Arp 242** (VV 224) the “Playing Mice” based on their two oval bodies and long tails. This duo lies in northern Coma Berenices, just 1.5° south-southeast of the “Hockey Stick” galaxy NGC 4656, a well-known, highly distorted edge-on. But NGC 4676 lies far in the background at a distance of 300 million light-years in the outskirts of the rich Coma Galaxy Cluster (Abell 1656).

Astronomers consider the Mice the archetypal prograde merger of equal-mass disc galaxies — colliding with the same sense of rotation and orbital motion. In a seminal 1972 paper “Galactic Bridges and Tails,” Alar Toomre (MIT) and Juri Toomre (University of Colorado) used computer simulations to trace the evolution at various time intervals and successfully reproduced the tidal features of the Mice. Joshua Barnes (University of Hawai‘i) used a more sophisticated dynamical simulation in 2004 and concluded the collision occurred 170 million years ago with a final head-on encounter and coalescence destined in 540 million years.

NGC 4676A is a small, high surface brightness oval. Through the 48-inch, it extended 24″ × 16″. Its singular visual feature is a thin tidal tail shooting 80″ due north and dimming out just east of a 17.3-magnitude star. The surface brightness of this spike is the highest for any long tidal tail and is a good target for 12-inch or larger scopes under pristine skies.



PLAYMATES Interacting pair NGC 4676, commonly known as “The Mice” because of the long tidal tails streaming from the galaxies, lies 300 million light-years away. This image, taken with the Hubble Space Telescope’s Advanced Camera for Surveys, shows the charming yet catastrophic merger.



MID-WAY POINT The curled body of the Grasshopper, UGC 4881, shows two spiral galaxies halfway through a merger. The Orthoptera's body and head are particularly luminous, lit up by the process of star formation triggered by the galactic collision.

NGC 4676B is just 40″ southeast, connected to its neighbor by a diffuse tidal bridge. The luminous 30″ × 20″ halo, with a visual magnitude of 13.6, tilts northeast to southwest and increases to a vivid nucleus, but we saw only the initial extension of the southern tail.

The Grasshopper

Arp 55 (VV 155, UGC 4881) is a 14th-magnitude mid-stage merger of two gas-rich spirals, unusually luminous in the infrared (500 billion times the Sun's luminosity) because of intensive star formation in the nuclei and the tail. This tangled pair dwells 540 million light-years away in Lynx.

Vorontsov-Velyaminov assigned the nickname "Grasshopper" to this interacting pair because of the suggestive shape on the Palomar Observatory Sky Survey plates. In the eyepiece, the "head" and "body" appeared as a mottled, 30″ × 15″ glow. A nearly stellar knot on the southwest end marked the nucleus of the smaller galaxy, while the fused northeast member has a larger core but no discernible nucleus. The Grasshopper's "leg" is partially formed by a straight tail that extends 20″ due south from the northeast end. It brightened slightly at a star-forming site at the south tip.

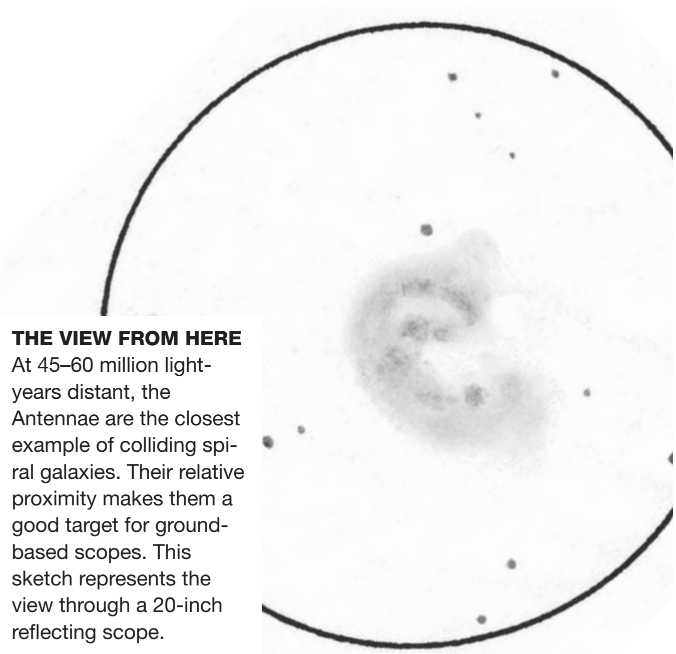
Three faint galaxies within 2.3′ of Arp 55 share the same redshift and form a small group. The closest is PGC 2242096. With a visual magnitude of 17.1, it appears as an amorphous 15″ patch just under 1′ northeast of the Grasshopper. Arp conjectured this object was another ejected "filament"; in a controversial 1967 paper he argued for a physical association between nearby disturbed galaxies and high redshift radio sources.

The Antennae

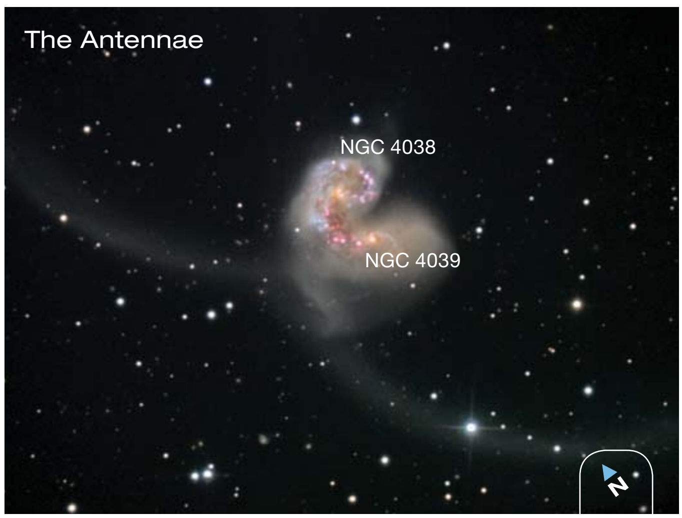
Arp 244 (VV 245) is made up of NGC 4038 and NGC 4039, galaxies found 3½° southwest of Gamma (γ) Corvi, the 2.6-magnitude star marking the northwest corner of Corvus's distinctive sail asterism. It's the closest example of an extreme mashup of two gas-rich spirals and really looks like colliding galaxies through an 8-inch telescope.

The Antennae galaxies provide an ideal astrophysical laboratory to investigate an ongoing interaction across all available wavelengths. At the galaxies' closest approach some 250 million years ago, gravitational tides pulled out two graceful narrow tails of gas, stars, and dust. Giant molecular clouds were compressed during the collision, triggering the formation of numerous super star clusters.

A few years ago I had an astonishing view of the Antennae using a 24-inch f/3.7 scope with the pair high overhead



THE VIEW FROM HERE At 45–60 million light-years distant, the Antennae are the closest example of colliding spiral galaxies. Their relative proximity makes them a good target for ground-based scopes. This sketch represents the view through a 20-inch reflecting scope.



EXTREME MASHUP The Antennae highlight the effects of galactic mergers. The collision triggered bursts of star production and the formation of numerous super star clusters. Graceful tidal tails, composed of stars, dust, and gas, arc away from the aftermath.

GRASSHOPPER GALAXY: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) / A. EVANS (UNIV. OF VIRGINIA / NRAO / STONY BROOK UNIV.); ANTENNAE GALAXY: NOAO / AURA / NSF / B. TWARDY / ADAM BLOCK; SKETCH: DALE HOLT from Australia. NGC 4038 has a bizarre annular shape due to a distorted spiral arm that forms a bright circular rim. The off-center nucleus seems misplaced along the east portion of the rim, and sparkling clumps are embedded on the west and north border.

A shrimp-like tail emanates from the eastern end of NGC 4038 as a large curdled patch. The appendage hooks counterclockwise around the south side to NGC 4039's core, a prominent irregular nodule. A large, fainter envelope spreads further southwest and widens to a bulbous end.

I shared a memorable view through Lowrey's 48-inch last May, with *S&T* Contributing Editor Howard Banich. The two "antennae" were subtle and only the initial portions of the tails were easy, but the northern streamer included a mildly enhanced section. Tip-to-tip, the two ethereal wings spanned 10′. The "Wow!" moment came when Jimi added a narrowband filter and numerous H II knots lit up along the rim. Howard compared the view to "looking at city lights from above on a foggy night."

Edward's Galaxy

NGC 6621 and NGC 6622 form **Arp 81** (VV 247), a unique interacting system with a single tidal tail that wraps along the east side of both galaxies. The merged duo is located in Draco, just 2.2° northeast of NGC 6543, the Cat's Eye planetary nebula.

So, who's Edward? He's the son of prolific comet hunter Lewis Swift. At the age of 14, Edward discovered NGC 6621 while assisting his father with observations. He's credited with the discovery of 48 NGC/IC objects between 1883 and 1891, but NGC 6621 is our favorite from that list.

In 2003 astronomers William Keel (University of Alabama) and Kirk Bork (Institute for Science and Technology, Raytheon/NASA-Goddard) used observations from the HST Wide-Field Planetary Camera 2 and a computer *N*-body simulation to model Arp 81's one-sided tidal tail, the star-forming complexes bridging the region between the galaxy nuclei, and a twisting system of dust lanes. They found a near-grazing encounter of two equal-mass galaxies about 100 million years ago matched the current morphology.

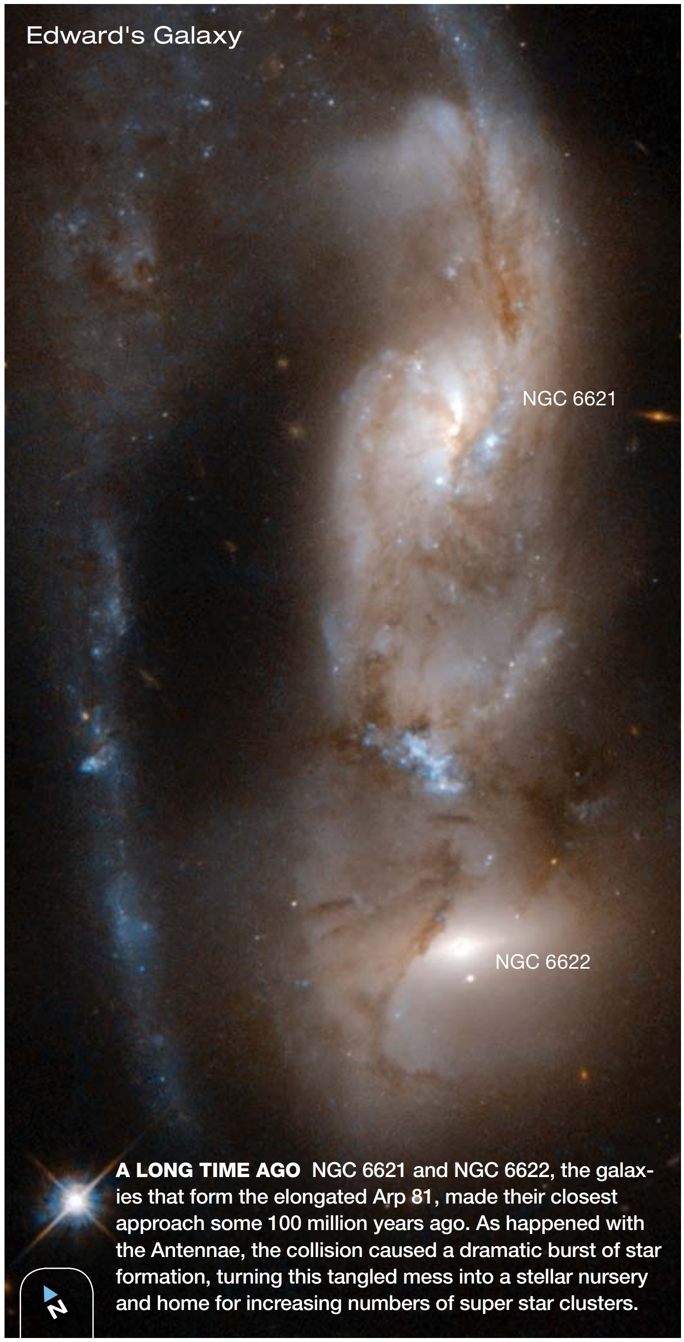
With excellent seeing and transparency (Sky Quality Meter reading of 21.8), NGC 6621 appeared sharply concentrated at 697× with a brilliant 15″ core intensifying to the center. The main halo extended 1′ long and ⅓ as wide with slightly brighter "handles" marking the ends of the main spiral arms. The southeast end appeared fused with the halo of NGC 6622, creating a contiguous glow with the two cores separated by 40″. We glimpsed a brighter 10″ patch at the midpoint, which corresponds with a blue splash of starburst activity in the overlap region on the HST image.

The most startling feature we saw in the eyepiece, however, was the broad tidal arm that emerged to the north of NGC 6621 and folded back on itself nearly 180° to the south-southeast. The tail gradually faded while hugging the entire length of NGC 6621 and terminated in a small knot.

A 15th-magnitude star sits 0.6′ east of NGC 6622, just beyond the end of the tail.

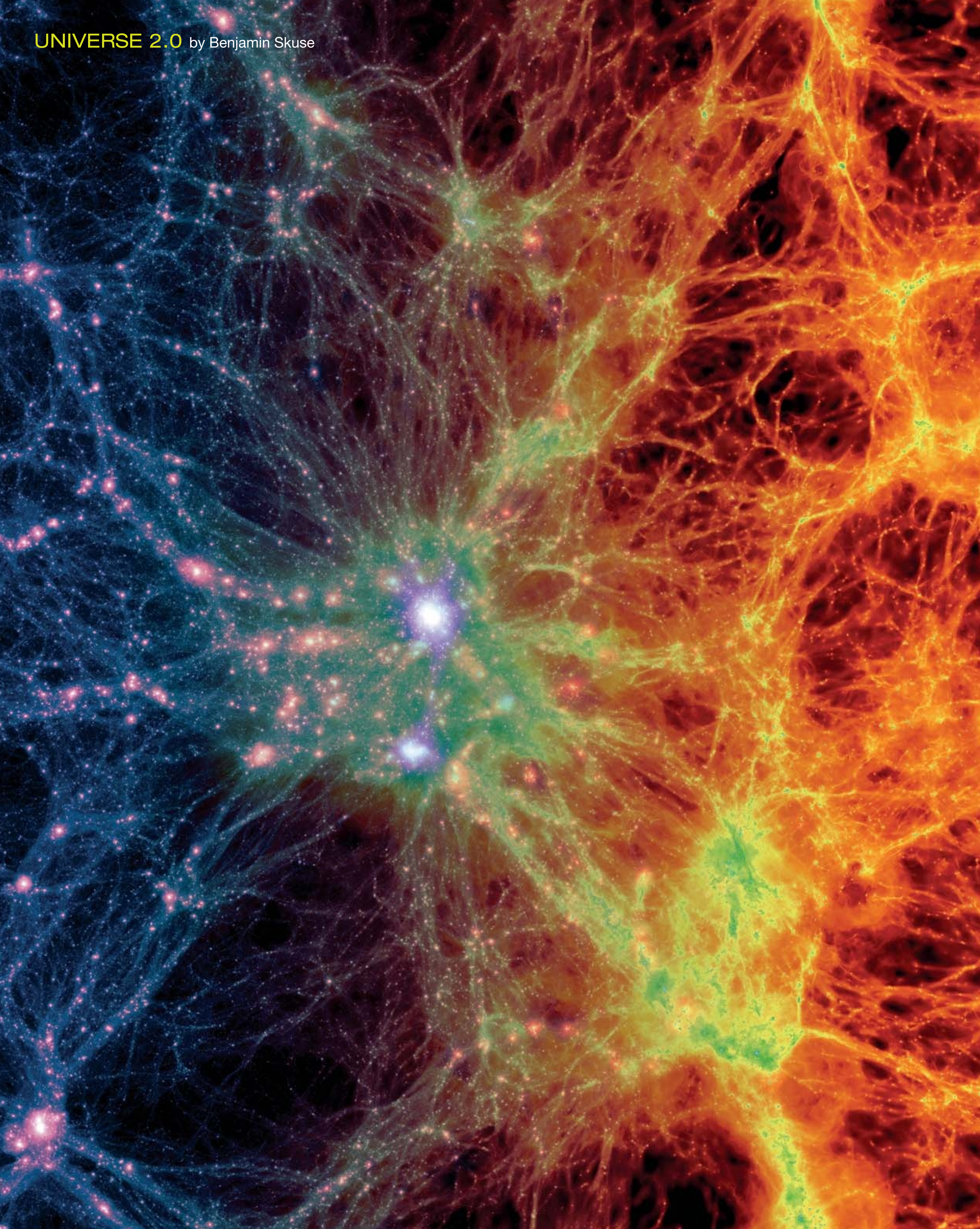
This view of Edward's Galaxy was a perfect ending to a thrilling night. Interacting galaxies offer an intriguing target, no matter the catalog, no matter the instrument. But in good seeing with a master-class scope, they become something truly spectacular to behold.

■ A dedicated observer, Contributing Editor **STEVE GOTTLIEB** usually keeps an eye on the sky for us from California. He welcomes your questions and comments at **steve_gottlieb@comcast.net**.



A LONG TIME AGO NGC 6621 and NGC 6622, the galaxies that form the elongated Arp 81, made their closest approach some 100 million years ago. As happened with the Antennae, the collision caused a dramatic burst of star formation, turning this tangled mess into a stellar nursery and home for increasing numbers of super star clusters.

UNIVERSE 2.0 by Benjamin Skuse



Baking a Universe

Some of our best cosmological simulations don't even include what we're made of — ordinary matter — but maybe this is just what's needed to shine a light on the universe's mysteries.

When you go to bake a cake, the first ingredients you grab are the eggs and flour. But it's the muscovado sugar, the vanilla pod, or maybe the orange zest that really determines what kind of cake you end up with.

Similarly, until recently, most cosmological simulations of the evolution of galaxies and the universe were basic bakes, including only the big main ingredients — dark matter and gravity. Dark matter is computationally "simple," immune to everything but gravity. So, limited by how many calculations their supercomputers could run simultaneously, researchers have long chosen to use just dark matter and gravity and assume that "normal" matter follows along.

At first glance this makes sense: Dark matter is five times more abundant than normal matter, meaning it should have a much larger impact on what the universe looks like. And these vast, dark-matter-only simulations have managed to mimic in stunning detail the intricacy and scale of the cosmic web, the large-scale invisible structure of galaxy clusters that fills the universe. Most importantly, they also very successfully match the abundance, sizes, and distances between galaxies with those of real observations — allowing insights and predictions to be made of how the universe fits together at the largest of scales.

But on smaller, galactic scales, these simulations have had their problems. For example, they predict hundreds of dwarf galaxies should swarm around larger systems like the Milky Way, yet observers have found only dozens (*S&T:* Mar. 2017, p. 16). They also predict that dark matter is denser in a galaxy's core than observations suggest.

Now, astronomers are discovering that the solution to understanding what's really going on in the universe lies with the very thing they were leaving out: ordinary matter.

In the Dark

Bolshoi, for instance, is one of the most accurate cosmological simulations of the evolution of the large-scale structure of the universe (*S&T:* July 2012, p. 28). Within a box roughly 1 billion light-years across, the Bolshoi team followed the development of 8.6 billion lumps of dark matter, all gravitationally interacting with one another, from 20 million years after the Big Bang to the present day. As time passed, these lumps combined to create galaxies and the larger cosmic web.

The simulation has had many successes. For instance, it reproduces the number of massive satellite galaxies (like the Large and Small Magellanic Clouds) around Milky Way–like galaxies, which in turn constrains the properties and mass of the Milky Way's dark matter halo, the big cloud of dark matter that our galaxy sits in (*S&T:* Apr. 2017, p. 22).

Yet, there is one gaping omission — the complete lack of what humans, stars, gas, and galaxies are made of: ordinary matter (or in astronomers' slang, "baryons").

"Baryonic physics can affect the properties of the galaxies that form and even the distribution of dark matter around a galaxy, even though baryons do not dominate the mass budget of the universe," says Andrew Wetzel (Caltech). "So any real connection to observations must include baryons, full stop."

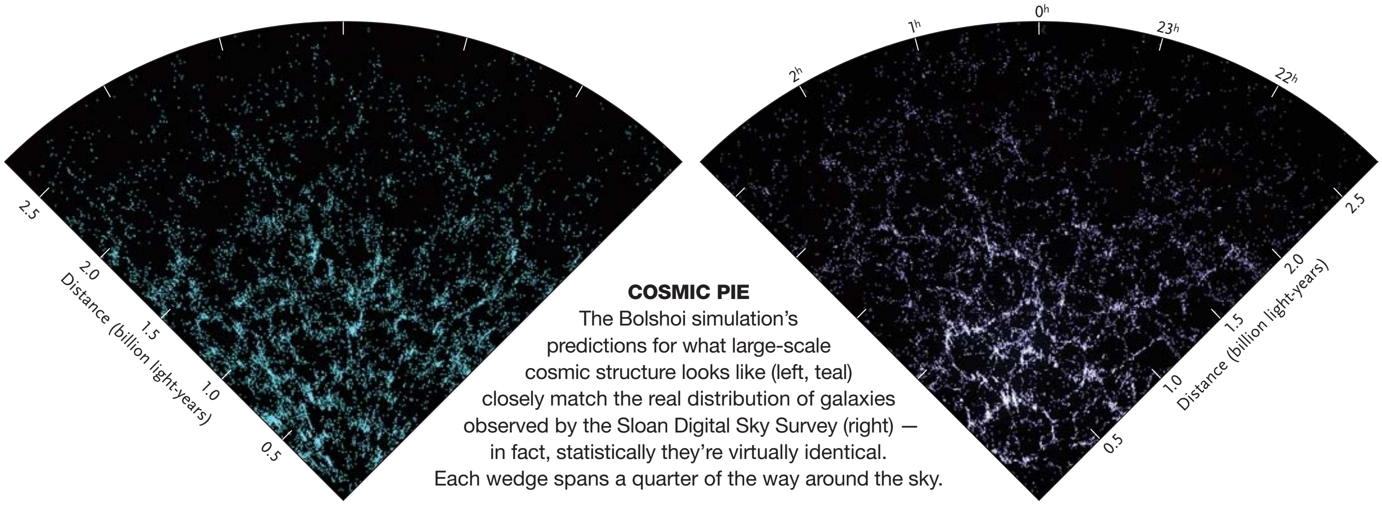
Unfortunately, adding ordinary matter is no easy task. Normal matter adds a huge amount of complexity and, according to Wetzel, "always makes simulations much more expensive

BARYONS

Technically, *baryons* are a class of subatomic particle that includes protons and neutrons but not all non-dark matter (such as electrons). But astronomers use the term as a catch-all for "normal" matter in simulations.

ILLUSTRIS COLLABORATION

UNIVERSE AGLOW This snapshot from the Illustris simulation shows structure in a modern-day universe, revealing both dark matter density (left, blue) and gas density (right). The clump in the middle is a massive galaxy cluster.



COSMIC PIE The Bolshoi simulation's predictions for what large-scale cosmic structure looks like (left, teal) closely match the real distribution of galaxies observed by the Sloan Digital Sky Survey (right) — in fact, statistically they're virtually identical. Each wedge spans a quarter of the way around the sky.

[i.e., time-consuming] than dark-matter-only simulations."

"It's easier to simulate dark matter than to simulate baryons," confirms Claude-André Faucher-Giguère (Northwestern University). "This is because dark matter is postulated to interact only via gravity, whereas baryons experience many other forces, like electricity and magnetism. So we have to solve many more equations, including those of hydrodynamics, to simulate the baryons."

As a result, the cosmological simulations community has long been waiting for a time when computers and algorithms would be powerful enough to handle the complexity of baryonic physics. That time is now.

Small Beginnings

While the dark-matter-only simulation experts offer insights into how the universe evolves as a whole — albeit without directly including anything in the simulations that is observable — those running cosmological simulations that include ordinary matter have faced a dilemma akin to trying to make a big cake with a delicate, complex taste: how to simultaneously bind together large-scale dark matter structure growth with smaller-scale baryonic objects and processes — things like black hole feedback, gas dynamics, and star formation. It all boils down to computational cost: the effort, complexity, and time required to complete a realistic simulation.

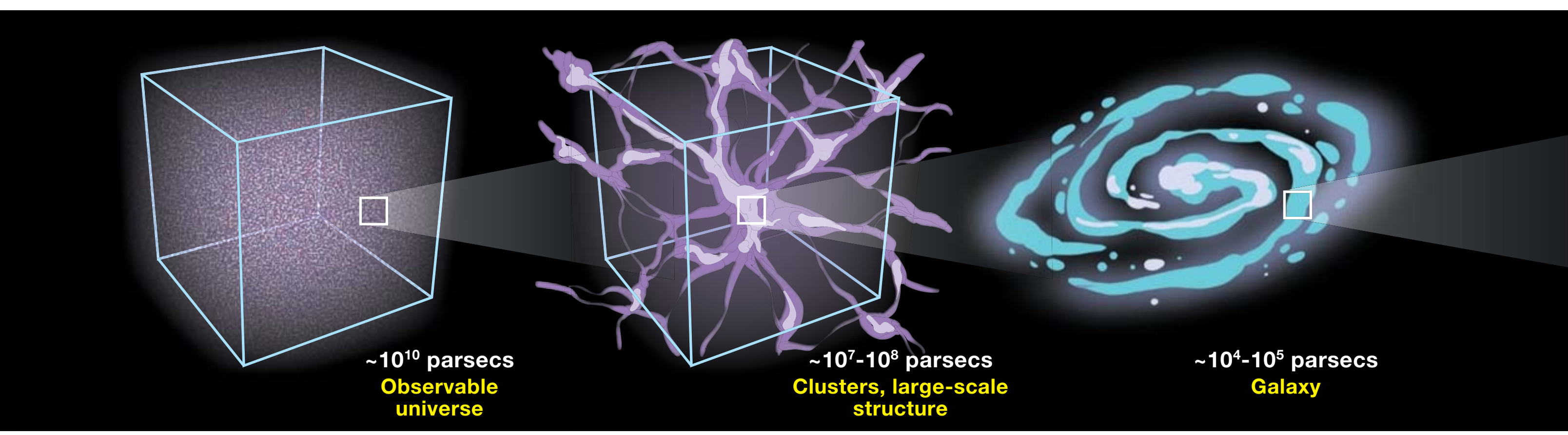
"The community has bifurcated a bit now," says Wetzel. "Groups doing large-volume simulations that encompass thousands of galaxies at a time gain excellent statistics to compare against observational surveys. But the trade-off is that these simulations are not able to resolve the relevant physical processes within a galaxy."

In contrast, groups conducting "zoom-in" simulations start with a large-volume box but only have high resolution in the region immediately around a single galaxy. "This means that such simulations only model one galaxy at a time, but they resolve it exquisitely well," he says.

Zoom-in simulations that focus on a smaller cosmic box can be likened to home baking. Bakers can pick as many ingredients as they want and take their time over the bake, because the simulation is covering a smaller spatial area and thus can

BOLSHOI SLICES: N. MCCURDY (UC-HIPACC) / R. KAEHLER & R. WECHSLER (STANFORD) / M. BUSHA (UNIV. ZURICH) / SDSS

▼ **COSMIC SCALES** Cosmological simulations try to replicate the universe and its evolution, and early ones produced remarkable matches to large-scale structures (left-hand boxes in this illustration). But for many years astronomers were forced to fudge what was happening at the smallest scales (other illustrations) — processes that, it turns out, heavily influence the larger structures. (A parsec is 3.26 light-years.)



incorporate more physical processes at higher resolution.

FIRE (Feedback In Realistic Environments) and CLUES (Constrained Local Universe Simulations) are two projects running such simulations, with vastly different approaches.

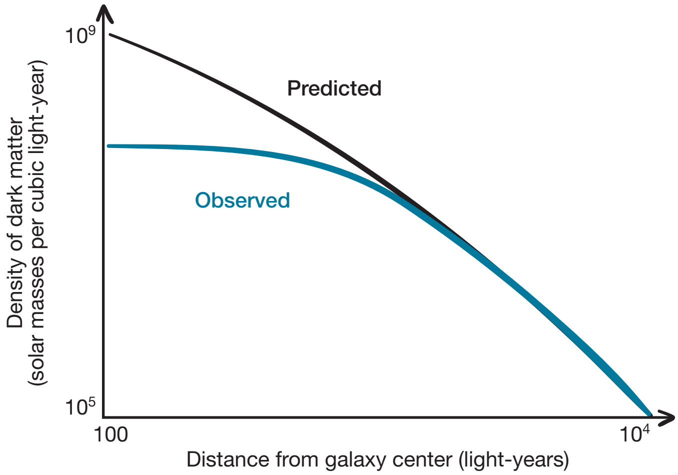
What sets FIRE — and its more recent higher-resolution offspring, "Latte" — apart is the researchers' attempt to build the simulations from the bottom up. "We start by asking ourselves, for example, how stars behave on small scales — how they form, how they die, and how they affect their environs," outlines Faucher-Giguère, joint principal investigator (PI) on FIRE. Working in concert, these small-scale processes from billions of stars affect the larger-scale properties of the galaxy as a whole.

"With the FIRE approach, we can directly test physics on the smallest resolved scales and see if additional processes are needed to explain galaxy formation," says Dušan Kereš (University of California, San Diego), another FIRE PI. This tack is highly novel, as simulations traditionally start from a large cosmic volume, resolve everything that is possible to resolve, and then approximate what happens on smaller, unresolved scales.

Meanwhile, CLUES focuses on the Milky Way's Local Group of galaxies — a galaxy cluster 10 million light-years across consisting of our own Milky Way, the neighboring Andromeda Galaxy, and the Triangulum Galaxy, as well as dozens of smaller galaxies — and "constrains" the large-scale structures around it. "What this means is that we ensure, through a kind of manipulation, that the galaxies we simulate are in the correct place," clarifies CLUES joint-PI Noam Libeskind (Leibniz Institute for Astrophysics Potsdam, Germany). "What we are constraining is the initial conditions of the problem. We are essentially artificially selecting initial conditions that we know, when run to conclusion, will result in simulations that mock the local cosmography."

This allows researchers to conduct various experiments more easily, because large galaxies will all be in the right places regardless of the assumptions on dark matter, gas physics, and star formation used, while the amounts and distributions of dark matter, gas, and stars will be different. They can then compare these alternatives with observations to see which matches reality best.

Although wildly different in approach, both FIRE and

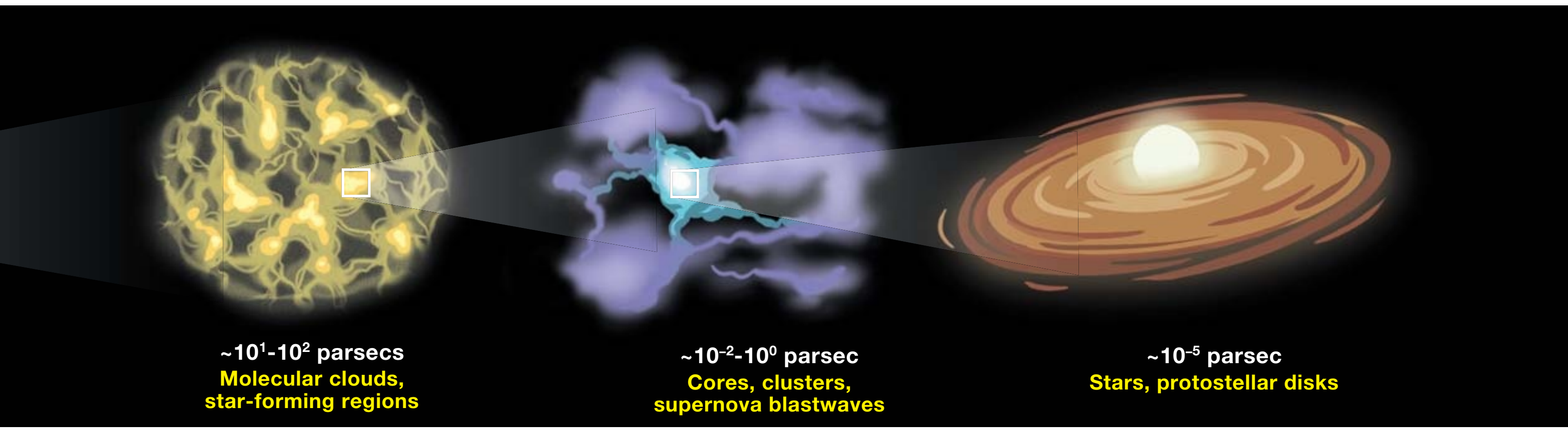


▲ **MISSING MATTER** Dark-matter-only simulations predicted that dark matter's density should be higher in a galaxy's core (black line) than observations show to be the case in the real universe (blue line). Results from the baryon-inclusive FIRE simulations match the observations.

CLUES have already offered new insights into a specific issue that has confounded astrophysicists for nearly two decades: the missing satellites problem. Dark-matter-only experiments have shown that a huge number of small satellite galaxies should have formed in our cosmic neighborhood, yet only a handful of these galaxies are seen orbiting the Milky Way.

However, in 2013 the CLUES collaboration analyzed its simulations and discovered that some of the dwarf galaxies in the Local Group move with such high velocities with respect to the cosmic web that most of their gas can be stripped as they pass through, essentially destroying their ability to make stars. Named "cosmic web stripping," the frictional mechanism can help explain the observed paucity of dwarf galaxies compared with that predicted (*S&T:* Feb. 2013, p. 14).

The bottom-up, FIRE-based Latte simulations also suggest normal matter solves the missing satellites problem. Wetzel, who leads the project, used Latte — the highest-resolution cosmological simulation of Milky Way–mass galaxies to date — to look at the dwarfs that form as the main galaxy coalesces and evolves. Compared to dark-matter-only simulations, only about a thousandth as many starry satellite galax-



LEAH TISCIONE / *S&T*, SOURCE PHIL HOPKINS (2)

▲ **REAL OR FAKE?** Shown here side-by-side are the real Hubble Extreme Deep Field observations and a "mock" observation of the Illustris simulation's results. Can you find the dividing line?

HUBBLE: NASA / ESA / STSCI / MAST / ILLINGWORTH ET AL. 2013, SIMULATION: ILLUSTRIS COLLABORATION

ies formed in Latte (*S&T:* Oct. 2016, p. 12). The team reasons this discrepancy is caused by two processes: The dwarf galaxies have their gas ripped away from them as they pass through the big galaxy's surrounding gas cloud, preventing star formation; and the main galaxy's central stellar disk gravitationally destroys the invisible dark-matter clumps in which the satellite galaxies would otherwise have been born.

FIRE also naturally reproduces the "low" density of dark matter in galactic cores, the highly inefficient rate of star formation in galaxies (roughly 30% of the Milky Way's baryons are in stars, instead of the nearly 100% predicted without feedback), and several other observations.

A Bigger Slice

If the zoom-in simulations — sacrificing scale for detail — equate to the serene pleasure of home baking, larger simulations that incorporate baryons, such as BlueTides, EAGLE, and Illustris, can be likened to wedding catering, constraining the number of ingredients and simplifying the recipe in order to feed the crowds in a reasonable amount of time. As a result, compromises have to be made.

Illustris and EAGLE (Evolution and Assembly of Galaxies and Their Environments), for example, run from early after the Big Bang until the present day and simulate a volume roughly 300 million light-years on a side. That's big enough to house tens of thousands of galaxies. However, it's at a lower resolution than zoom-in simulations, and it's still a fraction of the roughly 14 billion-light-year-wide box of Outer Rim (one of the biggest dark-matter-only simulations).

Even BlueTides' impressive 1.9 billion-light-year-wide box housing 697 billion particles comes with a caveat: Although taking the equivalent of one normal computer running for 300 million hours to complete, the simulation only looks at the first billion years of the universe. "Every simulation has to make some compromises, because we are fundamentally limited by computing resources," notes BlueTides team member Yu Feng (University of California, Berkeley). "BlueTides takes the unique approach of focusing on the earlier universe,

Some Examples of Cosmological Simulations

Simulation name	Type of particles	Number of particles	Particle mass (in solar masses)	Box side length (zoom length) (Mpc)
Bolshoi	DM-only	8.6 billion	190 million	350
MultiDark-Planck	DM-only	57 billion	2.2 billion	1,470
Q Continuum	DM-only	550 billion	150 million	1,300
Outer Rim	DM-only	1.1 trillion	2.6 billion	4,225
Latte	Baryon-inclusive	140 million	7,100 (baryons), 35,000 (dark)	85 (3)
CLUES	Baryon-inclusive	53 million	30,000 (baryons), 340,000 (dark)	91 (5.6)
BlueTides	Baryon-inclusive	697 billion	3.4 million (baryons), 17 million (dark)	570
EAGLE	Baryon-inclusive	6.8 billion	1.8 million (baryons), 9.7 million (dark)	100
Illustris	Baryon-inclusive	12 billion	1.3 million (baryons), 6.3 million (dark)	107

Note: Values for particle mass, box length, and spatial resolution take into account the expansion of the universe. Some teams report their numbers in terms of /*h*, where *h* is the Hubble parameter (the rate of cosmic expansion), so some entries may be different from what you see in a team's research paper.

▲ **EAGLE GALAXIES** The EAGLE simulation produces a population of galaxies similar to the one we see in the real universe, including elliptical (left) and bluer disk (right) galaxies.

when we have strong evidence the physics is cleaner," meaning primeval galaxies are mostly pure gas and unfettered by complex histories and mergers.

As a result, although BlueTides makes predictions — for example, that there should be a million galaxies detectable a billion years after the Big Bang with NASA's planned WFIRST survey — those forecasts remain unverified. Confirmations are held up by the fact that even the most advanced telescopes have struggled to see far enough back in time to the era in which the simulation evolves. Yet the promise of new telescopes, including the James Webb Space Telescope — scheduled for launch in 2018 — offers hope of observing the very first galaxies, and therefore potential proof of BlueTides' predictions.

In contrast, Illustris and EAGLE have been able to match many of the observed features of the present-day universe in remarkable detail, driving new insights and predictions. For instance, the EAGLE simulations uncovered the reason galaxies fall into two distinct types: 'blue-sequence' low-mass,

EAGLE GALAXIES: J. TRAYFORD AND THE EAGLE COLLABORATION (2); GRAPH: LEAH TISCIONE / S&T, SOURCE PHIL HOPKINS

The Dark Universe

Although there is huge diversity in the cosmological simulations mentioned here, they all share the same roots. In the 1980s, Bolshoi co-Principal Investigator Joel Primack (now at University of California, Santa Cruz) coauthored the theory dubbed *cold dark matter* (CDM). This theory described how the universe went from a smooth initial state at early times to the large-scale, intricate structure we see today, assuming that most matter is cold (i.e., moves slowly) and dark (i.e., does not emit electromagnetic radiation or scatter light). With the simple addition of an omnipresent anti-gravity force called Λ (lambda, or nowadays "dark energy"), the current ΛCDM paradigm also accounts for the accelerating expansion of the universe.

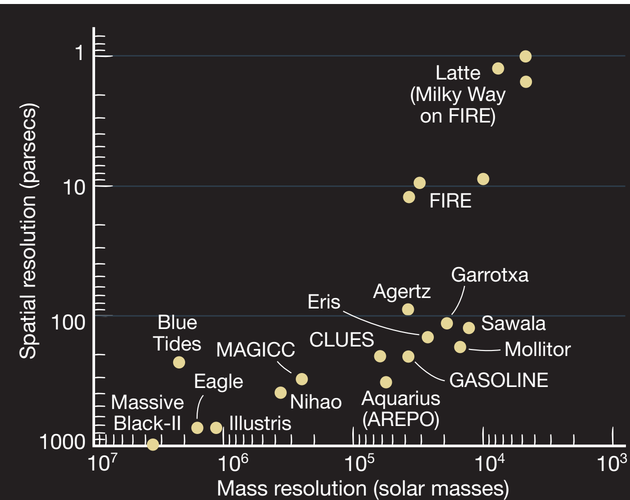
Simulations use ΛCDM for good reason, as it has done an exceptionally good job at explaining what telescopes have revealed of the universe's history and structure. Yet there is still an elephant in the room, as EAGLE team member Rob Crain (Liverpool John Moores University, UK) explains: "We still don't know the fundamental nature of the Λ or the CDM!"

Many believe there is still scope for a slightly more complicated theory, in which dark energy evolves, or where dark matter is not perfectly cold and collisionless. "But the impact on structure formation is very indirect and very difficult to distinguish from ΛCDM," says Illustris team member Volker Springel (Max Planck Institute for Astrophysics, Germany).

And there is still an even more extreme possibility. "One of the most uncomfortable aspects regarding ΛCDM is that most of the universe is composed of a particle we have yet to discover — dark matter — and a type of energy which we understand only phenomenologically: dark energy," remarks Libeskind. "It could very well be that neither of these proposed dark entities exists and that alternatives to the laws of gravity are more likely."

Spatial resolution (pc)	Temporal length (redshift range) in billions of years	CPU time (million hours)
1,400	13.7 (z = 80–0)	6
7,400	13.7 (z = 120–0)	not calculated
2,800	13.7 (z = 200–0)	not calculated
4,100	13.7 (z = 200–0)	not calculated
1	13.7 (z = 100–0)	0.7
150	13.7 (z = 99–0)	5
286	0.65 (z = 99–8)	300
700	13.7 (z = 127–0)	4.5
710	13.7 (z = 127–0)	19

We've also rounded the number and mass of particles to two significant figures.



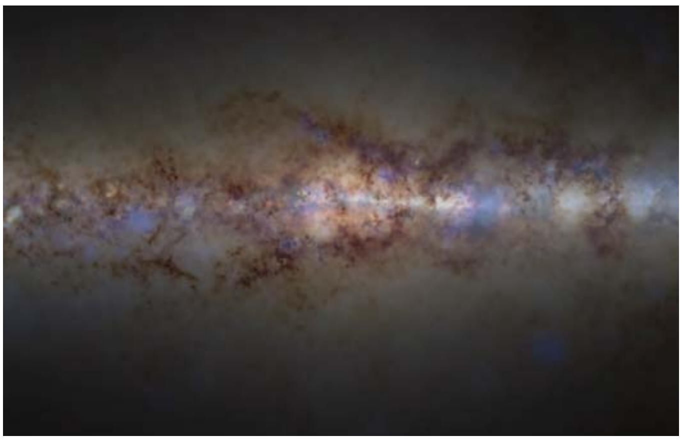
ALGORITHM BREAKTHROUGHS This graph shows the approximate parameters of various cosmological simulations. FIRE and its later iteration, Latte, have pushed to smaller scales than others.

usually disk galaxies (with less than 10 billion Suns' worth of stars, similar to the Milky Way) that continue to rapidly form young stars; and 'red-sequence' massive, usually elliptical galaxies in which star formation has almost completely ceased.

Essentially, they found that the central black hole of a galaxy competes with stars for gas. If the galaxy is above a critical mass, gas concentrates in the galactic center and the black hole rapidly grows, heating the galaxy's gas and preventing it from cooling and forming stars, leading to a red-sequence galaxy. If, however, the galaxy is below the critical mass, black hole growth is suppressed by stellar winds and supernovae, whose outflows prevent gas build-up near the black hole and keep it available for more star formation. That leads to a blue-sequence galaxy with a 'small' black hole — one maybe a tenth as big as astronomers would expect for a red galaxy of the same mass. Observations suggest that this prediction is in fact true (*S&T:* Feb. 2017, p. 18).

Meanwhile, Illustris's main achievement is its close agreement with reality, accurately mimicking observational data on small and large scales in our universe. "Illustris produces the correct mix of elliptical and spiral galaxies — none of the previous simulations was able to achieve this in detail," explains Illustris team member Mark Vogelsberger (MIT).

"This problem was so severe that some astronomers even questioned the underlying cosmological model," adds teammate Debora Sijacki (University of Cambridge, UK). "Illustris's success stems from its more sophisticated numerical code, more realistic physical processes, and high resolution." The result is a simulation that the team can use to look back in time and understand how different galaxies formed.



MOCK MILKY WAY The Latte simulation produces from scratch a Milky Way–like galaxy (top) that looks incredibly similar to our own galaxy (bottom), even down to the dust lanes. The simulation is positioned as seen from a star about as far from the galaxy's center as Earth is from the Milky Way's.

SIMULATED: FIRE TEAM, REAL MILKY WAY: ESO / S. BRUNIER

• **Fly through a simulated Latte galaxy as it merges with a dwarf satellite: https://is.gd/latteflythrough.**

Reuniting the Cooks in the Kitchen

Rapid progress in the zoom-in and large-scale communities is beginning to bring the two fields together, so that high-resolution, large-volume cosmological simulations that include baryons are almost in reach. "What will be exciting, over the next several years and as computational tools improve, is how we will gradually see a convergence of these two frontiers," says Faucher-Giguère. "On the one hand, we will increase our volumes, and conversely, large-volume simulations will improve their resolutions and physical realism."

But there is still a long way to go. In truth, most baryon-inclusive simulations use a lot of approximations. EAGLE PI Joop Shaye (Leiden University, The Netherlands) notes that although hydrodynamics is explicitly treated, radiation emission, star formation and evolution, and black hole processes are all approximated in their simulations.

This is essentially because current simulations are not granular enough to model the real physics of processes like star formation or the influence of black holes on galaxies, so they are put in by hand using a semi-analytic approach. Libeskind illuminates this best: "Take star formation. This happens on the scale of a star — or, let's be generous and say on the scale of a solar system. Most cosmological simulations don't resolve such small scales. Instead, our hard limit can be something like 100 parsecs (if you're lucky!) and that corresponds to something like 20 million times the distance to Pluto. Since we don't resolve the scales on which stars are born, we simply put them in 'by hand' when certain conditions are met. Needless to say, it would be better if we could actually resolve the formation of a protostar and follow its evolution in real detail."

Striving for an ever more complete description of the physics, researchers are also adding new ingredients to the mix, such as magnetic fields, cosmic rays, dust physics, and radiative transfer. Doing this efficiently on upcoming generations of supercomputers adds significantly to the challenge.

But it's a challenge worth rising to, because cosmological simulations are our one and only laboratory in which to test and expand upon theories of the origin and evolution of the cosmos. If these simulations capture enough of the physics of the universe, they might not only tell us why galaxies form — and therefore in essence how the conditions for life were first constructed — but they may also offer our first glimpse of what the dark universe is really made of.

■ **BENJAMIN SKUSE** is a science writer based in Bristol, UK.

3 **NIGHT:** Regulus, the brightest star in Leo, shines near the waxing gibbous Moon.

5 **PREDAWN:** The Eta Aquariid meteor shower, often the Southern Hemisphere's strongest of the year, should be at its best before dawn today and tomorrow. From mid-northern latitudes, few or no Aquariids are visible.

DUSK: Tiny Mars gleams 6° north (upper right) of Aldebaran, low in the west-northwest.

7 **NIGHT:** Look for Jupiter's yellow-white light about 3° right of the nearly full Moon. Blue-white Spica twinkles some 9° below or lower left of the pair.

11 **NIGHT:** A double shadow transit occurs on Jupiter from 9:59 p.m. to 10:06 p.m. Eastern Daylight Time.

18 **NIGHT:** A double shadow transit occurs on Jupiter from 11:53 p.m. to 12:43 a.m. EDT.

22 **DAWN:** The waning crescent Moon hangs about 3° or 4° lower right of Venus.

25 **NIGHT:** A double shadow transit occurs on Jupiter from 10:47 p.m. to 12:20 a.m. Pacific Daylight Time.

29 **EVENING:** Go out at dark to seek the waxing crescent Moon in the west. The Beehive Cluster (M44) sparkles about 3° to its upper right.

31 **EVENING:** The first-quarter Moon is high in the southwest at sunset. As twilight deepens, look for the bright spark of Regulus 5° or 6° right of the Moon.

UGC 8335 (Arp 238) consists of a pair of interacting galaxies, their spiral forms distorted and stretched by the proximity of their gravitational fields. See more on colliding galaxies on page 28.

NASA / ESA / HUBBLE HERITAGE TEAM (SCTSCI / AURA) / A. EVANS (UNIVERSITY OF VIRGINIA / NRAO / STONY BROOK UNIVERSITY)

MAY 2017 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
May 3
02:47 UT

FULL MOON
May 10
21:42 UT

LAST QUARTER
May 19
00:33 UT

NEW MOON
May 25
19:44 UT

DISTANCES

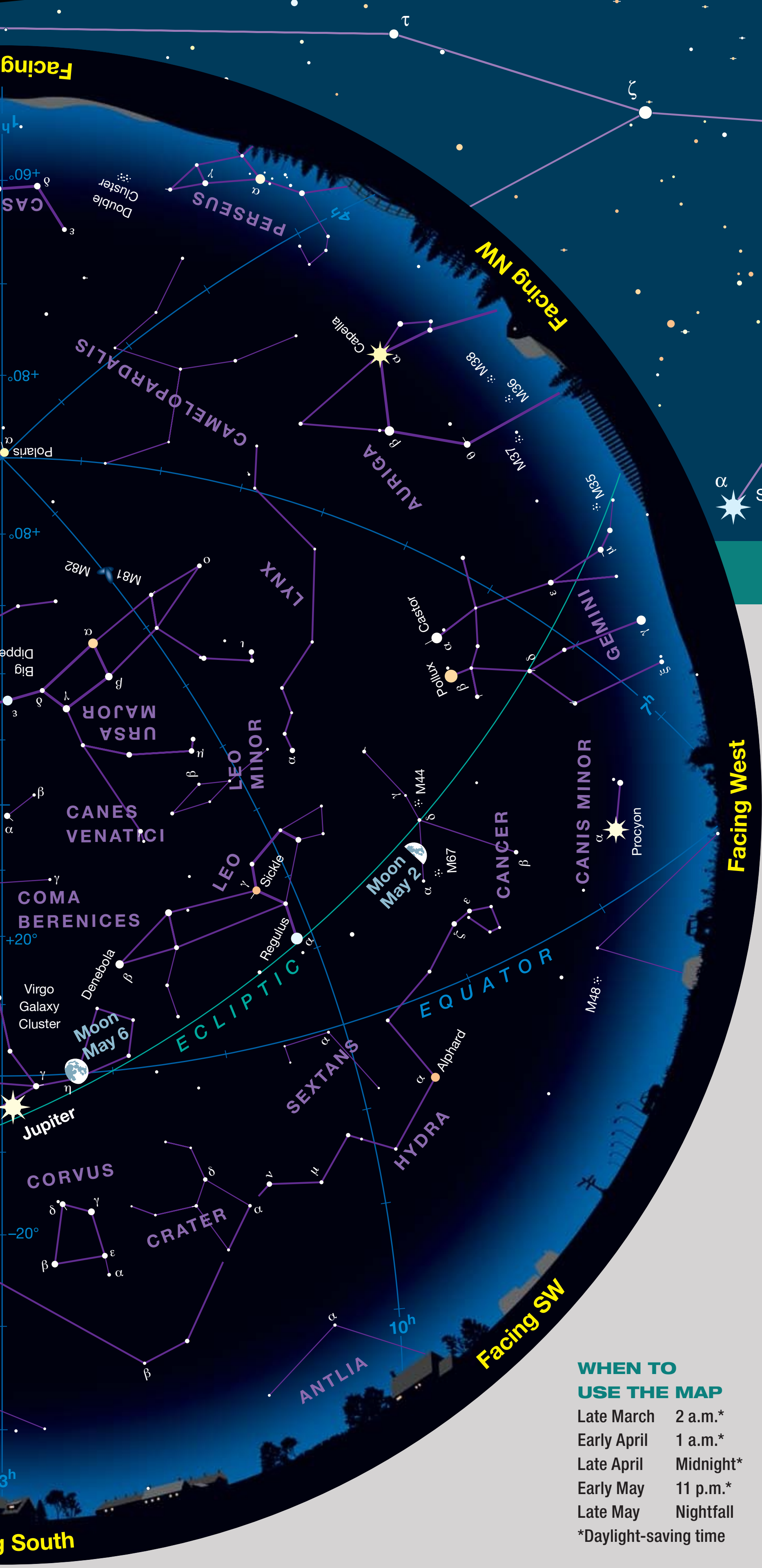
Apogee	May 12, 20^{h} UT
406,209 km	Diameter 29′ 25″
Perigee	May 26, 01^{h} UT
357,210 km	Diameter 33′ 27″

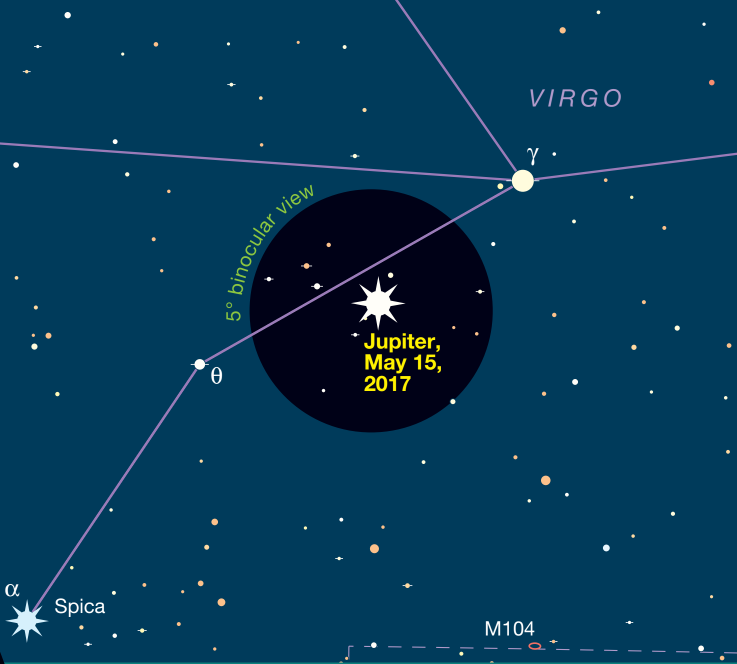
FAVORABLE LIBRATIONS

• Gauss Crater	May 1
• Mare Smythii	May 4
• Boussingault Crater	May 11
• Montes Cordillera	May 18

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 March	2 a.m.*
Early April	1 a.m.*
Late April	Midnight*
Early May	11 p.m.*
Late May	Nightfall

*Daylight-saving time

Binocular Highlight by Mathew Wedel

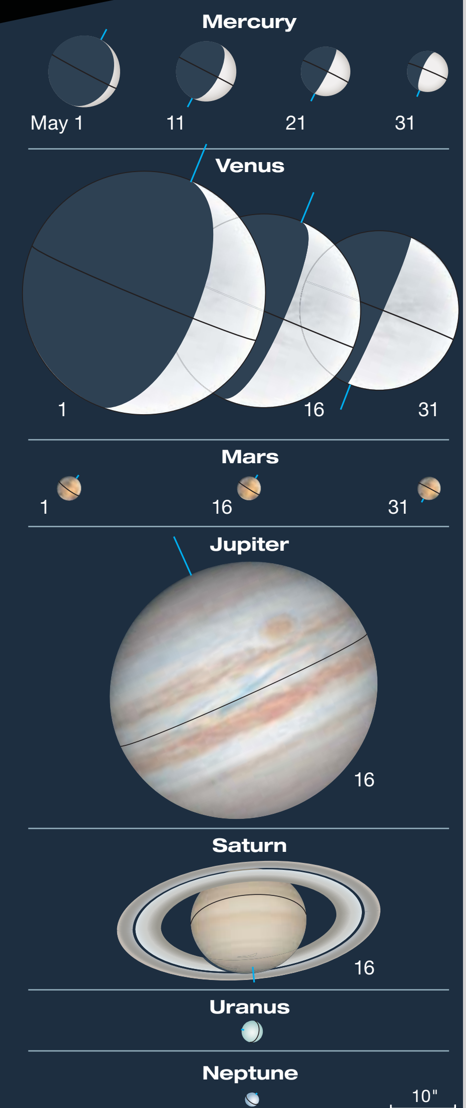
Hail to the King

Jupiter is this month's target, for three reasons. First, it's the most rewarding planet to observe with binoculars. Even at 7×, the King of Planets is a disk rather than a point of light. But the real show is the four Galilean moons — Io, Europa, Ganymede, and Callisto — visible to either side (assuming they're not hidden behind the planet). At 15×, the major cloud belts can be seen under good conditions. Once at a star party, I aimed my tripod-mounted 15×70s at Jupiter. After looking for a long time, a friend remarked, "With these, you hardly need a telescope!"

Second, it's no exaggeration to say that observing Jupiter with binoculars is the reason I'm a Contributing Editor. Back in 2007, I picked up a stargazing guide on a whim. The book made a remarkable claim: The moons of Jupiter were visible in binoculars. "No way!" But I was intrigued, so I dug my old 7×35s out of the closet. I went outside, focused on Jupiter, and behold: one bright light with little lights lined up beside it. That was it for me. A few days later I had my first telescope, and now I'm here.

Third, it's fate. I know that celestial objects don't control our lives, but sometimes they give us hints. When I went to pick out this month's subject, the sky was half-covered with patchy clouds. I needed to get my bearings, so I started with a bright star peeking out in the east. Was it Arcturus? Spica? No, it had a companion, had to be a double star. Wait, more companions? Oh, I get it — Jupiter! I was unreasonably happy, to have accidentally repeated my first-ever observation, a decade after the original.

■ MATT WEDEL likes to kick back with his binoculars on a driveway in Claremont, California.



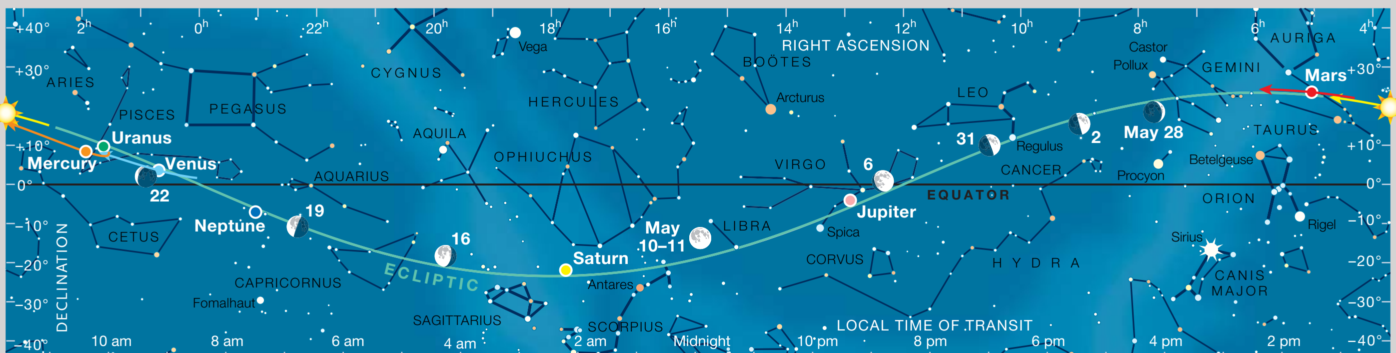
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury: Invisible all May • **Venus:** Visible all month, dawn, low east **Mars:** All month, dusk, low west-northwest • **Jupiter:** All month, dusk to pre-dawn, east to west **Saturn:** All month, late evening through dawn, SE to SW.

May Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$2^h\ 32.7^m$	+15° 00′	—	–26.8	31′ 45″	—	1.008
	31	$4^h\ 31.4^m$	+21° 52′	—	–26.8	31′ 33″	—	1.014
Mercury	1	$1^h\ 32.0^m$	+8° 14′	16° Mo	+2.5	11.2″	10%	0.601
	11	$1^h\ 41.2^m$	+7° 17′	24° Mo	+0.9	9.4″	28%	0.716
	21	$2^h\ 13.7^m$	+9° 55′	26° Mo	+0.2	7.7″	45%	0.873
	31	$3^h\ 05.0^m$	+14° 47′	22° Mo	–0.3	6.4″	64%	1.051
Venus	1	$0^h\ 01.4^m$	+1° 32′	40° Mo	–4.7	37.8″	27%	0.441
	11	$0^h\ 26.2^m$	+2° 35′	43° Mo	–4.7	32.4″	35%	0.515
	21	$0^h\ 56.6^m$	+4° 37′	45° Mo	–4.6	28.2″	42%	0.592
	31	$1^h\ 30.9^m$	+7° 17′	46° Mo	–4.5	24.8″	48%	0.672
Mars	1	$4^h\ 17.5^m$	+22° 01′	26° Ev	+1.6	3.9″	98%	2.396
	16	$5^h\ 01.3^m$	+23° 31′	21° Ev	+1.6	3.8″	99%	2.467
	31	$5^h\ 45.3^m$	+24° 15′	17° Ev	+1.7	3.7″	99%	2.528
Jupiter	1	$12^h\ 58.4^m$	–4° 34′	155° Ev	–2.4	43.5″	100%	4.528
	31	$12^h\ 50.5^m$	–3° 51′	124° Ev	–2.3	40.8″	99%	4.827
Saturn	1	$17^h\ 47.3^m$	–22° 02′	134° Mo	+0.3	17.8″	100%	9.336
	31	$17^h\ 40.1^m$	–21° 59′	164° Mo	+0.1	18.3″	100%	9.079
Uranus	16	$1^h\ 37.2^m$	+9° 31′	29° Mo	+5.9	3.4″	100%	20.804
Neptune	16	$23^h\ 01.5^m$	–7° 12′	71° Mo	+7.9	2.3″	100%	30.257

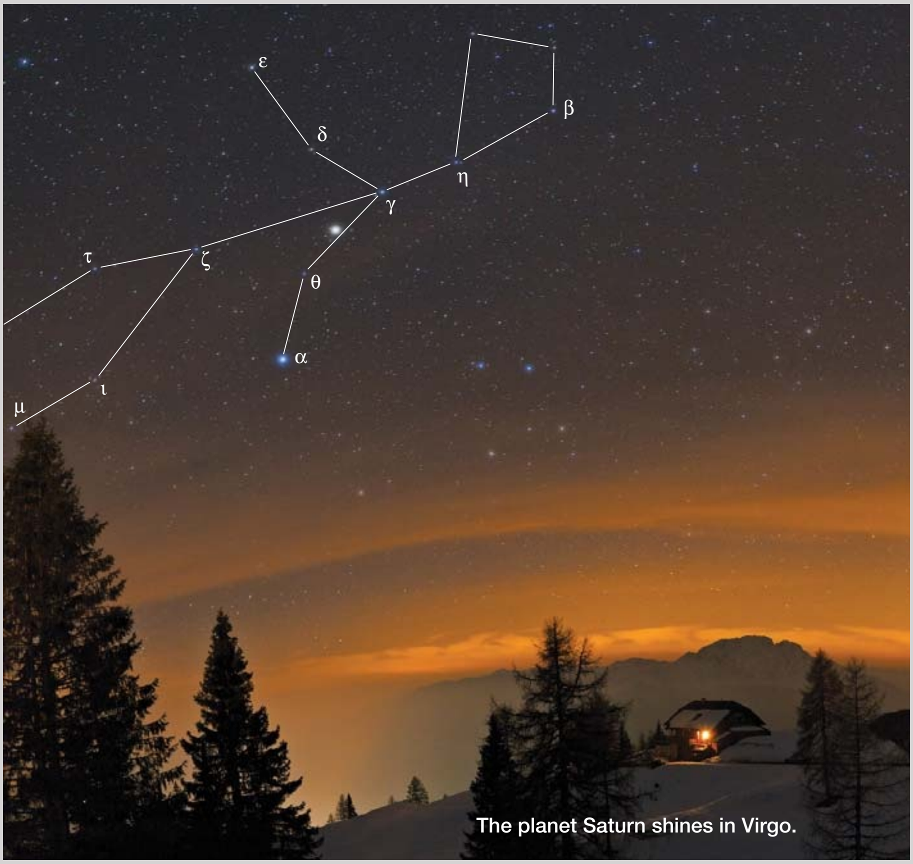
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial 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-May; 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.

Virgo's Flames

The stars of this outsize constellation burn brighter than expected.



The planet Saturn shines in Virgo.

BABAK TAFRESHI / GETTY IMAGES

WHICH IS BY FAR the longest constellation of the zodiac? As you may know, it's the lady of the zodiac, Virgo. The Sun travels 44° through Virgo, thus almost ⅛ rather than 1⁄12 of the zodiac falls in Virgo. The Sun is within the constellation's bounds in early autumn. In May, however, Virgo is well-placed for observation in the south, as shown in our all-sky map on pages 42–43.

Many deep-sky observers prize Virgo for just one thing: the vast Virgo Galaxy Cluster, composed of dozens of galaxies visible in small amateur telescopes and hundreds to thousands visible in larger ones. I want to make a suggestion about observing the galaxies of Virgo and of its neighboring constellations on spring evenings. But first I want to speak in praise of the oft-undervalued stars of Virgo and the wonderful passes of solar system objects through the constellation.

The long, lovely, recumbent, and lambent maiden. Recumbent means lying back, usually in a leisurely fashion. Virgo seems to be doing just that on the ecliptic. Although Virgo's prime gem, 1st-magnitude Spica, lies a few degrees south of the ecliptic, the line of Virgo's head and body from Beta (β) Virginis through Eta (η), Gamma (γ), and Theta (θ) lies just north of the ecliptic. Again and again, we see the Moon and planets glide or step past one star after another in scenic sequence.

Lambent means shining with light that licks over an object as it flickers, the objects here being the stars of Virgo. Except for Spica, these stars are often dismissed as being dim. But Epsilon (ε) Virginis is brighter than magnitude 3.0, and seven more stars in Virgo, in addition to Spica, are brighter than 4.0. Twenty-three of Virgo's stars twinkle between magnitudes 4.0 and 5.0. In a dark sky or with binoculars, then, there are a lot of stars to see here. Of course, those totals are not as impressive when you consider that Virgo covers the second-largest area of the sky of any of the 88 constellations.

The names of Virgo's flames. In *A Dictionary of Modern Star Names*, our leading contemporary experts on the subject, Kunitzsch and Smart, seem strict about the proper names of stars. But they accept six stars and eight star-names in Virgo: Alpha (α) Virginis (*Spica* or *Azimech*), Beta (*Zavijava*), Gamma (*Porrima*), Epsilon (*Vindemiatrix* or *Almuredin*), Eta (*Zaniah*), and Iota (ι) (*Syrma*). They also give 14 star names from Antonin Becvar's 1951 *Atlas of the Heavens*, noting that the origins of only 2 of these names have been figured out. One of the unexplained 12 is *Heze* for Zeta (ζ) Virginis. Another is *Arich*, the superb double star Gamma Virginis, though *Porrima* is already in popular use for it. Another star, named neither by Kunitzsch and Smart, nor by Becvar, has been called *Auva*. This is Delta (δ) Virginis, also known by the supposedly Sumerian name, *Lu Lim*.

A fairly bright star without a proper name is Theta Virginis. It's a pretty triple star, but even R. H. Allen's classic *Star-Names and Their Meanings* included only one name reputedly applied to it alone, from ancient India: *Apami-Atsa*, "the Child of the Waters."

A gala for galaxies. Whatever else Virgo is, she's definitely the gal with the galaxies. Ever since the Dobsonian revolution, amateur astronomers have had access to thousands of them. We have the Messier marathons of March. Why not hold "Galaxy Gazes" in late April or early May? How many galaxies can you see in one night? Or one evening? Or, viewing the richest groups, in one hour?

■ Contributing Editor **FRED SCHAAF** has been writing about the skies above us for more than 40 years.

Jove Owns the Night

Jupiter puts on an overnight show, but Saturn soon approaches the stage.

Soon after sunset these May evenings, Jupiter beams prominently in the southeast. Much dimmer Mars must be hunted before it drops below the western horizon mid-evening. By the end of May, Jupiter culminates in the south before Mars sets. Saturn rises earlier and earlier as the days pass, appearing before the end of twilight toward the end of the month. Brilliant Venus comes up about two hours before the Sun.

DUSK

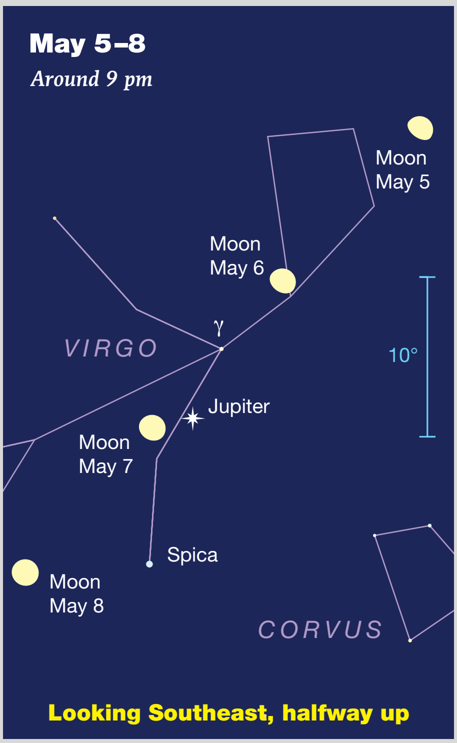
Mars appears slightly lower in evening twilight each week. The interval between sunset and Mars-set shrinks from just over 2 hours to about 1 hour and 20 minutes during May. This is the last full month of 2017 that the Red Planet is visible — it will be lost in the solar glare for almost the entire summer. Telescopes show it as a featureless orange dot less than 4″ across this month, and its meager magnitude dims from +1.6 to +1.7.

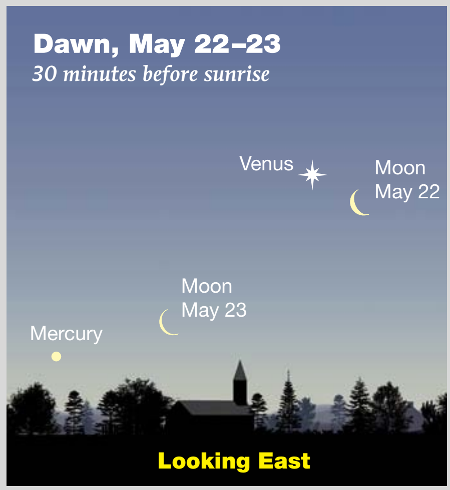
Mars does, however, form interesting patterns with bright stars in the evening this month. It passes about 6° north (upper right) of Aldebaran between May 5th and 7th. On the American evening of May 26th, Mars is 5° or 6° upper right of a very slender lunar crescent. That evening, binoculars show Mars 10° high about ½ hour after sunset. Look just a few degrees to the planet's right or upper right in the darkening sky to find the equally bright Beta (β) Tauri (El Nath).

ALL NIGHT

Jupiter is past opposition but still visible from dusk through most of the night. This month the regal planet fades slightly from magnitude –2.4 to –2.3. Jupiter's apparent diameter also shrinks a bit, from 43″ to 41″ measured across its equator. The good news is that Jupiter climbs higher earlier in the evening now, permitting sharper views at a convenient hour. Jupiter culminates after 11 p.m. daylight-saving time on May 1st but only a little after 9 p.m. on May 31st.

The giant planet is still retrograding (moving west relative to the stars) this month. It starts May just under 10° from Spica, but pulls slightly away from the bright star over the course of the month. It also moves away from much





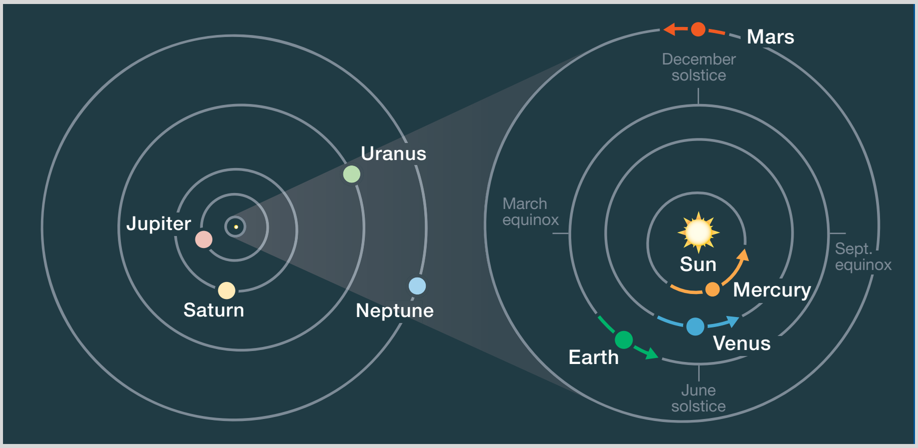
These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist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

dimmer Theta (θ) Virginis and closer to Gamma (γ) Virginis, the famous double star also called Porrima.

Saturn rises at almost exactly the same time Jupiter transits due south, a little before 11:30 p.m. daylight-saving time as May begins, a little before 9:30 p.m. as May ends. Saturn itself transits around 4 a.m. in early May and around 2 a.m. in late May. Saturn will reach opposition on June 15th, but it's already quite prominent in the sky this month, brightening from magnitude +0.3 to +0.1. Its globe grows slightly, from 17.8″ to 18.3″ in equatorial diameter. The rings span about 41″ in their long axis, remaining at virtually their most open, 26° from edge-on.

Saturn is retrograding now, leaving Sagittarius for Ophiuchus in the second half of May.



ORBITS OF THE PLANETS

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

DAWN

Venus comes up near the start of May's very early morning twilight. Venus is at its greatest morning brightness for the year — or, more precisely, maximum illuminated extent — on April 30th and reaches greatest elongation, 46° west from the Sun, on June 3rd. It dims a bit this month, from a bracing –4.7 to a still impressive –4.5. The view of Venus in telescopes remains fascinating: The planet's apparent diameter decreases from 38″ to 25″ while its disk increases from about ¼ to nearly ½ lit. Will you see Venus give the appearance of being exactly half-lit by the end of May or in the first days of June? The ecliptic tilts at a shallow angle to the horizon at spring sunrises, so even as Venus nears greatest elongation, it appears only about 23° high at sunrise for viewers around latitude 40° north.

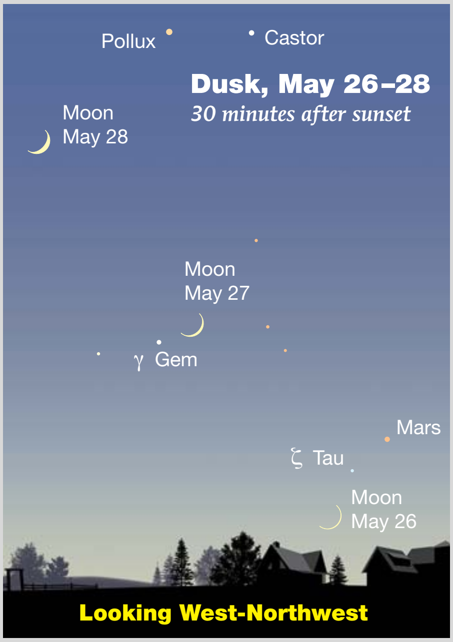
Mercury escapes observation this month, lost in the glare of sunrise.

Neptune, 8th magnitude, remains in Aquarius and is high enough to spot with a small scope just before morning twilight. **Uranus** reappears in the dawn sky in early May, but isn't well placed for viewing.

MOON PASSAGES

The waxing gibbous **Moon** is some 3° to 5° right of Regulus on the evening of May 3rd. At nightfall on May 7th, the Moon beams about 3° lower left of Jupiter and 9° above Spica. The waning gibbous Moon shines 7° or 8° right of Saturn at dawn on May 13th and 5° or 6° upper left of Saturn on May 14th. Seek the waning lunar crescent approximately 4° lower right of Venus at dawn on May 22nd, and well below Venus the next morning.

Back in the evening twilight, the waxing lunar crescent bows lower right of Mars very low in the west-southwest on May 26th. Mars that evening is between Beta and Zeta (ζ) Tauri, the horn-tips of departing Taurus; use binoculars. On the 29th, the waxing lunar crescent hangs 3° lower left of M44, the Beehive Cluster. On May 30th, the thicker Moon hangs 8° lower right of Regulus. By next night, the first quarter Moon has moved about 5° left of the same star.



■ Contributing Editor **FRED SCHAAF** welcomes your letters and comments at fschaaf@aol.com.

Saturn Has a Southern Apparition

With rings still tipped invitingly open, Saturn invites your most careful scrutiny.

If you could view through a 4,500-meter (180,000-inch) telescope above Earth's atmosphere, you could resolve features in Saturn's rings and on the 5-mile (8-km) moonlet Daphnis as sharply as the Cassini Saturn orbiter did on January 16th, as seen above. Daphnis clears the 26-mile-wide (42-km) Keeler Gap. It has collected a ridge-like pileup of dust around its equator, and its gravity raises waves in the gap's edges. The Keeler Gap, a black chasm here, went undetected by the best telescopes on Earth.

NASA / JPL-CALTECH

Disk and ring structures are abundant on every scale throughout the universe, from rings around planets to protoplanetary disks to debris disks to black-hole accretion disks to gas-rich galaxies. As different as these objects are, they all take their shape for the same reason: conservation of angular momentum in a rotating system of stuff that can't get rid of it.

Ringed planets must be abundant everywhere; all four gas giants in our solar system have at least slight rings. But the wide, dense rings of Saturn are unique among anything we can see.

Saturn has crept far south in recent years, in its 29.5-year circuit around the Sun and the zodiac. In 2017 it glows northwest of the Sagittarius Teapot, not far from the Lagoon Nebula, at about declination –20°. So northern telescope users will want to catch it at its (not very) highest near the meridian. In April that means before the first light of dawn, and in May between about 1 a.m. and 3 a.m. daylight-saving time. Opposition comes on June 15th. Not until July will Saturn shine its highest in the evening.

Saturn's globe remains about 18″ wide all the while, and its rings span about 40″, roughly a Jupiter-width. This year the rings are tipped their widest open: between 26.4° and 27.0° to our line of sight, a circumstance we see only twice in Saturn's 29.5-year orbit.

Here's a guide to help you make the most of Saturn from now through the coming months.

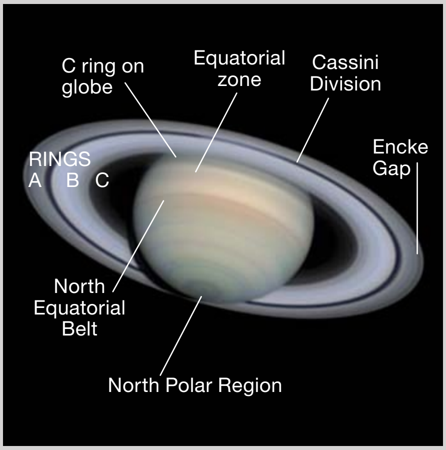
Markings on the Globe

Saturn is a gas planet with dusky cloud belts and brighter zones between them, like Jupiter. But Saturn is about twice as far and 16% smaller than Jupiter, and we see its markings through a high-altitude yellowish haze. Even so, with my 6-inch reflector I can almost always see some of Saturn's banding: the bright **Equatorial Zone,** the slightly darker **North Equatorial Belt** (the South Equatorial Belt is behind the rings now), and the dusky **North Polar Region**. Subtler banding is sometimes detectable in the mid-latitudes.

Can you detect any sign of **white spots**? In 2010 Saturn broke out with a massive white storm at about 45° north latitude that became obvious in amateur scopes. But such events are rare. Lesser, subtle spots are somewhat more frequent, but they generally require a large scope in good seeing, or stacked-video imaging.

Rings on Parade

A 2.6- or 3-inch scope should reveal the rings easily, and the dark **Cassini Division** between the A and B rings



▲ Saturn's rings were tilted 25°, almost as much as now, when Damian Peach took this very sharp image on March 10, 2015, using a planetary video camera on a 14-inch Schmidt-Cassegrain scope. South is up.

with a little more effort. Both the A and B rings **brighten toward their edges** bordering the Cassini Division.

The dusky **C ring** is more of a challenge where it appears against the dark-sky background. It's often fairly plain in my 12.5-inch but rarely in my 6-inch. Its dim gray veiling is easier to see where it crosses Saturn's bright face, just inside the B ring. Sometimes the C ring in front of Saturn's face is indistinguishable from the rings' dark shadow falling at the same latitude. But this season the rings'' shadow is hidden behind the rings themselves.

The hair-thin **Encke Gap**, near the outer edge of the A ring, is a severe challenge under any conditions. I can't say for sure that I've ever seen it with my 12.5-inch even in excellent seeing.

With the rings wide open, you have your best chance to see **Saturn's surface through the Cassini Division**. In very steady air, detecting the planet's light through the division — as opposed to black sky behind the division elsewhere — can emphasize the three-dimensional appearance of the view.

For several nights around Saturn's June 15th opposition, watch for the **Seeliger effect**: a noticeable brightening of the rings with respect to the globe. This is caused by the solid ring particles "backscattering" sunlight in the direction it came from — the inner solar system, home of Earth — more effectively than the planet's cloudtops do.

In the weeks and months away from opposition, note the **shadow of the planet's globe on the rings.** It's the narrow black gap right where the rings pass behind the globe's celestial west (preceding) side before opposition, and the east (following) side after opposition.

Marvelous Night for a Moon Dance

Saturn and its rings are surrounded by more moons for amateur scopes than any other planet.

Even a 60-millimeter scope will usually reveal Titan, a frigid, haze-shrouded world half again as big as our Moon. A 6-inch shows Titan's orange color: Its haze is photochemical smog, thick enough to hide Titan's rainclouds, rivers, dark hydrocarbon mudflats, and lakes of liquefied natural gas.

A 4- to 6-inch scope will also show Iapetus, Rhea, Dione, and (maybe with difficulty) Tethys. Fainter Enceladus closer in almost always eludes my 6-inch despite my best efforts, but the 12.5-inch fishes it up when the seeing is especially good. It helps to know in advance *precisely* where a difficult object you're looking for ought to be. You can identify the moons, or find exactly where to look for them, at any time and date using the interactive observing aid at **skyandtelescope.com/satmoons**. Or for handy use at the scope, get our *SaturnMoons* iTunes app from the iTunes App Store ($2.99).

May Meteors

◖The Eta Aquariid meteor shower runs for several mornings centered on May 6th. The time to watch is the hour before the first light of dawn. The waxing gibbous Moon will then be low in the west. The Eta Aquariids are usually the year's best meteor shower for the Southern Hemisphere. But those of us in the world's mid-northern latitudes see few if any, because the radiant, in the Water Jar of Aquarius, is still low when dawn begins.

Midday Aldebaran Occultation

◖ **If you have a deep blue** sky on Friday, April 28th, you have a shot at observing a challenging daytime event from nearly anywhere in the United States, Canada, or Mexico. The 2-day-old waxing crescent Moon will be in the eastern sky, about 30° lower left of the Sun, when the Moon's dark limb occults 1st-magnitude Aldebaran. A telescope *may* show the orange star, although daytime stars can be tough when they're this close to the Sun, especially when the Sun is higher than they are.

The farther east you are the better. In the Pacific time zone, the crescent Moon may be too low to find in the daytime sky. Seen from the Eastern time zone, it'll be much higher.

If you find the Moon, you'll know where to point your scope: Just east of the crescent's invisible dark limb. Once you're there, moderately high power may work best for picking up Aldebaran.

Some times of its disappearance: **Los Angeles,** 9:02 a.m. PDT; **Denver,** 10:11 a.m. MDT; **Austin,** 10:55 a.m. CDT; **Kansas City,** 11:11 a.m. CDT; **Chicago,** 11:19 a.m. CDT; **Miami,** 12:07 p.m. EDT; **Atlanta,** 12:08 p.m. EDT; **Washington,** DC, 12:23 p.m. EDT; **New York,** 12:28 p.m. EDT; **Boston,** 12:35 p.m. EDT.

In Western Europe the occultation happens in better circumstances: during late afternoon or in evening twilight, with the Moon now higher than the Sun.

Precise time predictions, and altitudes of the Sun and the Moon at the moment of occultation, are listed for over 1,000 cities and towns at **lunar-occultations.com/iota/bstar/0428zc692.htm**. (That page displays three long tables with less-than-obvious divides: for the disappearance, the reappearance, and the locations of cities. The two-letter abbreviations are for countries, not states.)

Comet 41P Is Ideally Placed

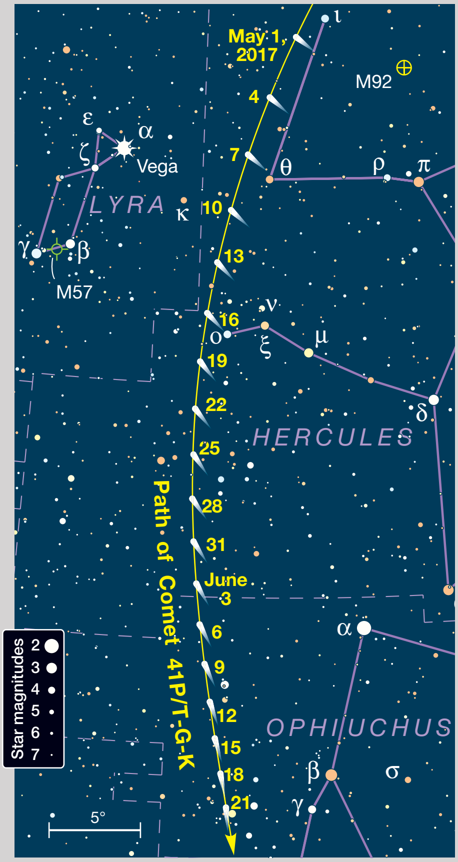
IF YOU HAVEN'T STARTED watching it yet, now's the time. Periodic comet 41P/Tuttle-Giacobini-Kresak may be reaching 6th or even 5th magnitude very high in the northern evening sky. Comet T-G-K, as it's being called, will probably remain about the same brightness from late March through the beginning of May. As the charts here show, the comet skims the lip of the Big Dipper's bowl (Alpha Ursae Majoris) near the end of March, sails past the Little Dipper's bowl and the head of Draco in April, and moves past Vega through Hercules in May. You can follow it with a small telescope or perhaps even good binoculars.

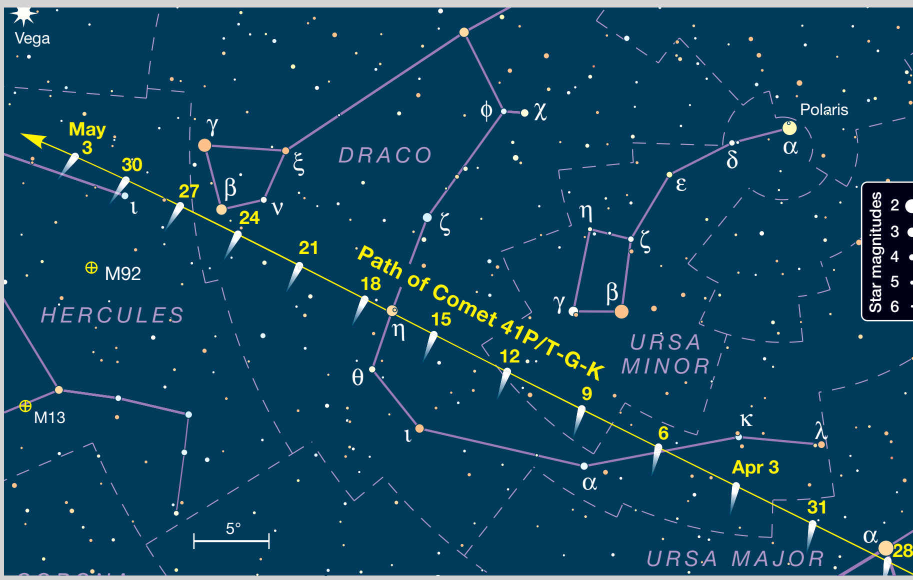
In May it's likely to fade from magnitude 6 to 8, then in June from 8 to 12.

As mentioned last month, the Planetary Science Institute has put out a call for high-quality amateur images of this comet. The goal is to ensure continuous monitoring of fast-changing activity in the inner coma. The comet is passing near Earth; its closest approach is 0.14 a.u. on March 27th. Read more about the campaign, and how to join it, at **https://is.gd/4pcometcampaign**.

Don't get your hopes too high, but during its 1973 return this comet flared by an astounding 10 magnitudes — a factor of 10,000 in brightness — twice. Each outburst lasted many days. That year the comet was having an unfavorable return, so it jumped from only about 14th magnitude to 4th, rather than the Jupiter-bright spectacle we would get if the comet were to do the same thing now.

And in 2001, two more outbursts brightened it by 4 and 6 magnitudes.





▲ Symbols at 0:00 Universal Time every three days show the comet's position, and the orientation of its gas tail if any, as it sails high across the northern sky from late March through June.

Action at Jupiter

JUPITER REACHES opposition on April 7th, remains 44″ wide all April, and shrinks only a little to 41″ by the end of May. Meanwhile it becomes more convenient to observe, passing high across the southern sky in the evening. See our telescopic guide to Jupiter in last month's issue, page 48.

Any telescope shows Jupiter's four big Galilean moons. Identify them at any date and time using the diagram at far right (where north is up).

The interactions in May 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.

April 1, 2:10, 12:05, 22:01; **2,** 7:56, 17:52; **3,** 3:47, 13:43, 23:39; **4,** 9:34, 19:30; **5,** 5:25, 15:21; **6,** 1:17, 11:12, 21:08; **7,** 7:03, 16:59; **8,** 2:54, 12:50, 22:46; **9,** 8:41, 18:37; **10,** 4:32, 14:28; **11,** 0:24, 10:19, 20:15; **12,** 6:10, 16:06; **13,** 2:02, 11:57, 21:53; **14,** 7:48, 17:44; **15,** 3:40, 13:35, 23:31; **16,** 9:26, 19:22; **17,** 5:18, 15:13; **18,** 1:09, 11:04,

Phenomena of Jupiter's Moons, May 2017

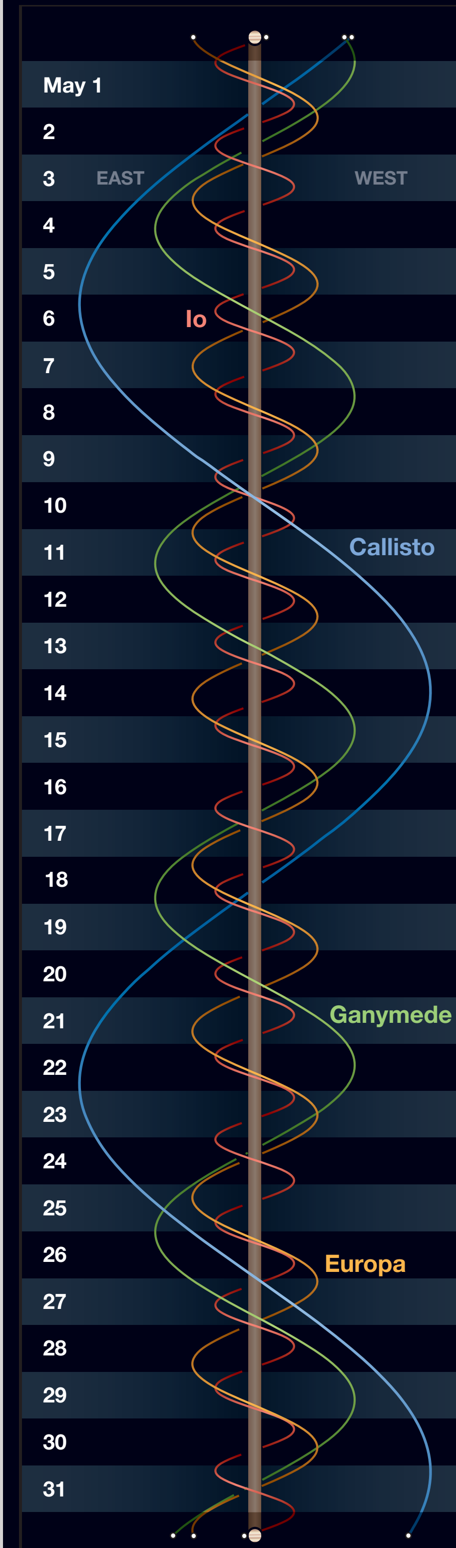
May 1	6:38	II.Tr.I
	7:43	II.Sh.I
	9:02	II.Tr.E
	10:10	II.Sh.E
	10:35	I.Tr.I
	11:07	I.Sh.I
	12:46	I.Tr.E
	13:19	I.Sh.E
May 2	7:44	I.Oc.D
	10:31	I.Ec.R
	18:18	III.Oc.D
	20:33	III.Oc.R
	20:34	III.Ec.D
	22:57	III.Ec.R
May 3	1:28	II.Oc.D
	5:02	I.Tr.I
	5:02	II.Ec.R
	5:36	I.Sh.I
	7:12	I.Tr.E
	7:47	I.Sh.E
May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

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.

21:00; **19,** 6:56, 16:51; **20,** 2:47, 12:42, 22:38; **21,** 8:34, 18:29; **22,** 4:25, 14:20; **23,** 0:16, 10:12, 20:07; **24,** 6:03, 15:58; **25,** 1:54, 11:50, 21:45; **26,** 7:41, 17:37; **27,** 3:32, 13:28, 23:23; **28,** 9:19, 19:15; **29,** 5:10, 15:06; **30,** 1:02, 10:57, 20:53.

May 1, 6:50, 16:46; **2,** 2:41, 12:37, 22:33; **3,** 8:28, 18:24; **4,** 4:19, 14:15; **5,** 0:11, 10:06, 20:02; **6,** 5:58, 15:53; **7,** 1:49, 11:45, 21:40; **8,** 7:36, 17:32; **9,** 3:27, 13:23, 23:18; **10,** 9:14, 19:10; **11,** 5:05, 15:01; **12,** 0:57; 10:52, 20:48; **13,** 6:44, 16:39, **14,** 2:35; 12:31, 22:26; **15,** 8:22, 18:18; **16,** 4:13, 14:09; **17,** 0:05, 10:00, 19:56; **18,** 5:52, 15:47; **19,** 1:43, 11:39, 21:34; **20,** 7:30, 17:26; **21,** 3:21, 13:17, 23:13; **22,** 9:08, 19:04; **23,** 5:00, 14:55; **24,** 0:51, 10:47, 20:42; **25,** 6:38, 16:34; **26,** 2:30, 12:25, 22:21; **27,** 8:17, 18:12; **28,** 4:08, 14:04, 23:59; **29,** 9:55, 19:51; **30,** 5:46, 15:42; **31,** 1:38, 11:34, 21:29.

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.

Napoleon's Comets

The world took notice when two "great comets" appeared four years apart in the 19th century.

It's certainly been a while since a truly "great" comet has been visible in the sky. Some of you might recall glimpsing Comet McNaught (C/2006 P1), but that was primarily a Southern Hemisphere object. We northerners are overdue.

Even more remarkable were the close-spaced appearances of comets Hyakutake (C/1996 B2) and Hale-Bopp (C/1995 O1), which dominated our skies 20 years ago, in 1996 and 1997. Comet Hyakutake's long, delicate, gossamer tail provided a stark contrast to Hale-Bopp's brilliant coma and broad double tail, which were visible even under heavily light-polluted skies.

To find a similar pairing of great comets, we have to go back nearly 200 years to the Napoleonic era of the early 19th century. This was a time of great conflict. Napoleon's armies held sway over much of Western Europe, while England's fleet blockaded the Continent. Yet despite the widespread devastation and political chaos, astronomy flourished under Napoleon's new world order.

After the recovery of Halley's Comet in December 1758, French astronomers dominated the study of these ephemeral visitors. The "comet ferret" Charles Messier redefined this visual genre by discovering 13 comets, co-discovering eight others, and spotting no fewer than 44 out of 50 observable comets between 1758 and 1806. Jean-Louis Pons would take comet hunting even further — he discovered 37 of them and remains the greatest visual comet hunter of all time.

Even Napoleon had a special interest in these objects, as he was born a week after the discovery of the Great Comet of 1769. He viewed them as his "guiding stars" and went to considerable lengths to adopt their symbolism. So when the Great Comets of 1807 and 1811 appeared, they not only were widely observed but also served as propaganda devices both by Napoleon and by the coalitions that opposed him.

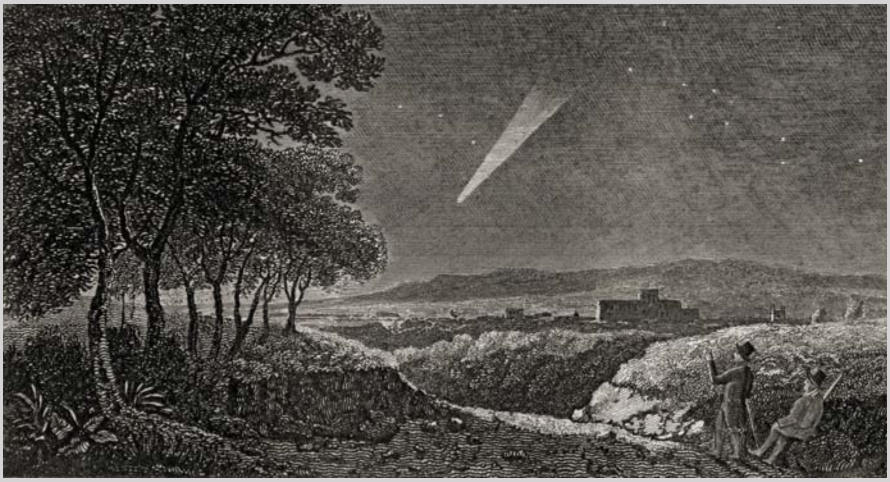
▲ A caricature by Thomas Rowlandson from November 1807 shows John Bull (representing England) looking on as a comet-entrained Napoleon ascends from the shore of France toward King George III. Bright 18th- and 19th-century comets often appeared in such satirical commentary.

The Great Comet of 1807 (C/1807 R1)

Although Messier and his countrymen were unparalleled comet hunters, it was an Augustinian monk in Sicily who first spotted a new one low on the western horizon on September 9, 1807. Rivaling the brightness of nearby Spica, it took another 1½ weeks to climb far enough from the Sun to be observed by other astronomers. By September 22nd, Pons and countryman Jacques-Joseph Thulis had observed the 1st-magnitude comet and made accurate positional measurements. It came closest to Earth on September 26, 1807, at 1.15 astronomical units, quite a distance for so bright an object and one exceeded by only two other great comets — C/1811 F1 and Hale-Bopp.

By early October, C/1807 R1 was a beautiful 2nd-magnitude object sporting a nice 5°-long tail. Similar to that of Hale-Bopp, this tail quickly subdivided into a long, narrow plasma tail and a shorter, curved dust tail. Both would continue to lengthen, and by October 20th they extended 10° and 4½°,

◀ Caroline Herschel's observing logbook for October 24, 1807, includes this delicate pencil sketch of C/1807 R1.



▲ This engraving by H. R. Cook shows how the Great Comet of 1811 appeared at daybreak on October 15th of that year from near Winchester, England.

respectively. A truly beautiful and graceful comet, C/1807 R1 was by then moving northward through Hercules toward the bright star clouds of the Milky Way.

Due to its great distance, the comet was slow to fade. It remained a 2nd-magnitude object throughout much of October and then slowly dimmed from naked-eye visibility from late November through December. William Herschel observed the comet on November 20th and noted a 2.5° tail, but a few weeks later the tail was essentially gone.

C/1807 R1 remained a telescopic object for a few more months, with the last observation made on March 27, 1808. With the ample positional data available, Friedrich Bessel computed the comet's orbit. Unlike most comets, C/1807 R1 proved to be a periodic comet like Halley's, with an elliptical (not parabolic) orbit and a period of more than 1,700 years.

By itself, C/1807 R1 would have been the best comet of that generation. But in four scant years, it would be overshadowed by a truly spectacular visitor that would shatter records for naked-eye and telescopic visibility.

The Great Comet of 1811 (C/1811 F1)

By the spring of 1811, Europe once again braced for a new round of war. Napoleon was planning his next great adventure: the invasion of Russia with his Grande Armée. Meanwhile, on March 25th, French astronomer Honoré Flaugergues discovered a 5th-magnitude comet deep in the old constellation Argo Navis. This interloper slowly brightened to easy naked-eye visibility throughout the spring before getting lost in the glow of twilight around mid-June.

C/1811 F1 re-emerged from the Sun's glare on the morning of August 22nd, and though very close to the horizon it was quite bright and sported a short tail. The *real* show had just begun, as the comet continued to move northward. By early September its brightness had surged and the tail had lengthened to 10°, making the comet clearly visible despite a nearly full Moon. On September 12th, the comet attained perihelion, 1.04 a.u. from the Sun, implying that it was very large and intrinsically bright.

By early October, then cruising near the Big Dipper, the comet remained visible throughout the night for much of the Northern Hemisphere. It had brightened to at least magnitude 0, and many observers reported a bright, forked tail 20° to 25° long. The coma was also unusually large, 20 to 28 arcminutes in diameter, and thus at least 1 million miles across — even larger than the Sun!

C/1811 F1 took a long time to fade from naked-eye visibility, finally dimming from view by mid-January 1812. So it remained a naked-eye object for an amazing 260 days, easily surpassing the 4 months achieved by the Great Comet of 1807 and setting a record that would hold until the appearance of Hale-Bopp in 1997. Telescopically, C/1811 F1 was followed much longer, for almost 17 months.

In many ways, the Great Comet of 1811 and Hale-Bopp were quite similar. Both were extremely large for comet nuclei (30 to 40 km in diameter), had large perihelia (the latter's was 0.91 a.u.), and long orbital periods.

Impact on Society

Both of these Napoleonic comets had an impact on everyday society — even though astronomers of the time knew they were merely celestial objects. The Great Comet of 1811 was seen as a portent of the upcoming war against Russia, while Napoleon took its appearance a step further and used it as a sign of impending victory. Without doubt, its continued presence in the sky inspired a dramatic rise in "comet art," as British political artists and writers had fun mocking the Emperor's connections to comets. Tolstoy's *War and Peace* makes mention of this comet, and there was even an exceptional French vintage of 1811 "comet wine."

Although Comet Hale-Bopp's 18-month run shattered the naked-eye visibility records established by the visitors in 1807 and 1811, the latter certainly left their mark on history. So when will there be another close paring of Great Comets crossing the sky? Only time will tell — but their passing will no doubt be equally memorable.

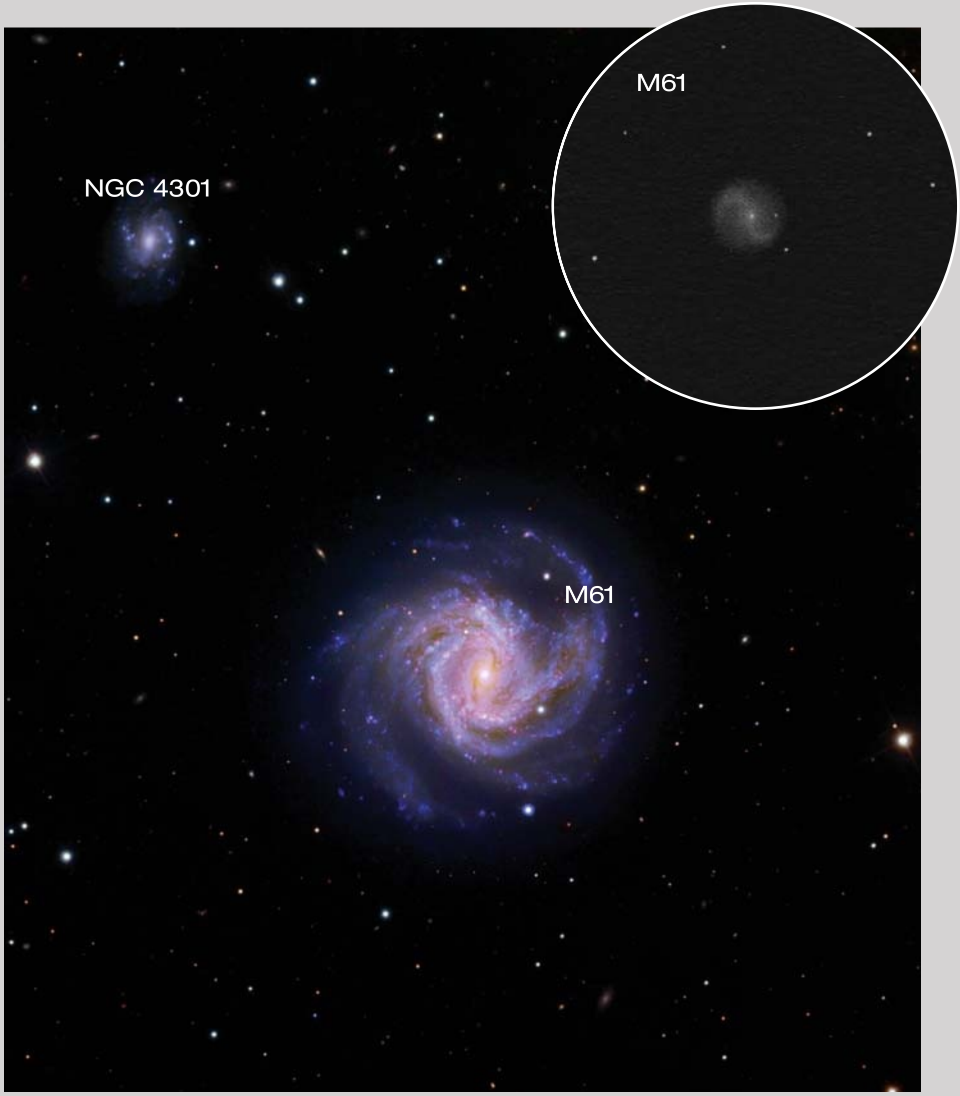
■ **RICH JAKIEL** has contributed to *Sky & Telescope* since 1999. Although primarily a deep-sky observer, he's always been fascinated by comets.

FURTHER READING:

Fire in the Sky: Comets and Meteors, the Decisive Centuries, in British Art and Science (Cambridge, 1998) and "The Comets of Caroline Herschel (1750–1848), Sleuth of the Skies at Slough" (2010 conference presentation; **arxiv.org/abs/1212.0809**) — **both** by Roberta J. M. Olson and Jay M. Pasachoff.

The Spring Goddess

Stars shimmer and galaxies glimmer in the vest of Virgo, the Virgin.



▲ Drop 51 arcminutes south of 17 Viriginis to find the spiral galaxy M61. *Inset:* At 120× in an 8-inch reflector, M61 shows two distinct arms curling around a very bright core.

ROBERT GENDLER; SKETCH: JEREMY PEREZ

Her lovely tresses glow with starry light;
Stars ornament the bracelet on her hand,
Her vest, in ample fold, glitters with stars,
Beneath her snowy feet they shine; her eyes
Lighten, all-glorious, with the heavenly rays.
— Capel Lofft, *Eudosia*, 1781

The constellation Virgo is sometimes identified with Persephone, the beautiful daughter of the harvest goddess Demeter. In one version of her myth, Persephone was spirited away by Hades to make her his queen of the underworld. Demeter was distraught, and in her sorrow she abandoned her stewardship of the fruits of the Earth. Cruel winter reigned, crops failed, and famine loomed nigh. Zeus, king of the gods, thought to return Persephone to her mother, but he was too late. Having taken food in the underworld, Persephone could not live permanently in world above, so a compromise was reached. Persephone would spend part of every year in each world. When we see her constellation in the sky, she is with her mother in the world above, and the Earth is green and growing. When Persephone returns to the underworld, her mother lapses into sadness, and the Earth grows cold and barren.

With the lands at mid-northern latitudes now greening and Virgo spread wide in the evening sky, let's turn our gaze toward Virgo's starry vest and its filigree of galaxies. We'll concentrate our attention on an area of the sky within 2° of 17 Virginis, one of the sequins glittering on the vest.

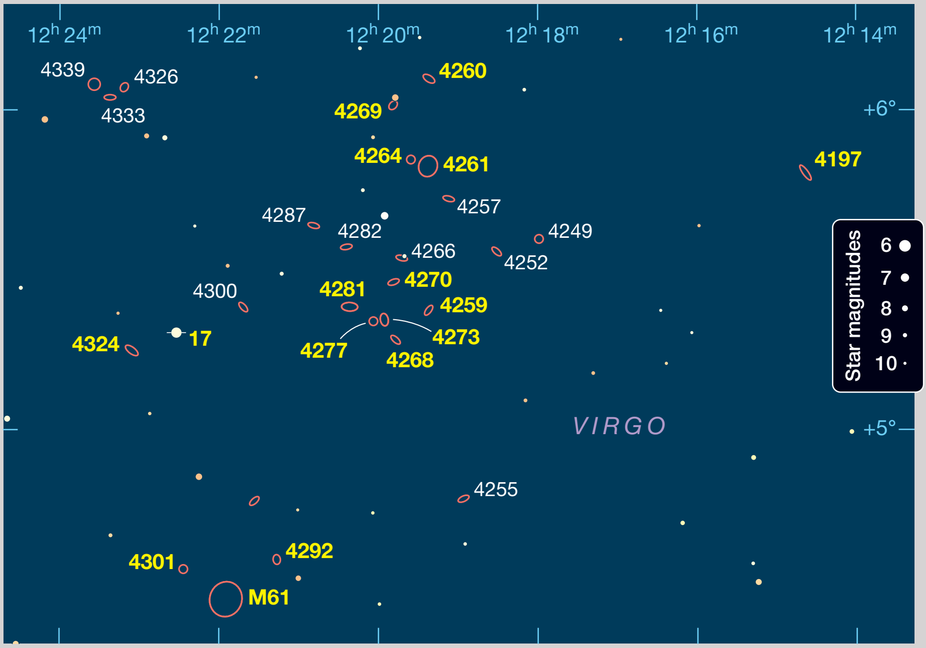
A colorful double star, **17 Virginis** is well worth a visit. The stars are widely separated through my 105-mm refractor at 47×, presenting a light-yellow, 6.5-magnitude primary accompanied by a 9.3-magnitude pale-orange attendant to the north-northwest. At 87× the lenticular (lens-shaped) galaxy **NGC 4324** materializes in the field. Its oval glow leans northeast, sporting a brighter core and stellar nucleus. The view offers a wonderful sense of depth when you realize that 17 Virginis is only 98 light-years away, while NGC 4324 is about a million times as distant. In my 10-inch reflector at 166×, the galaxy is 1½′ long and half as wide, with a very faint star near its southwestern tip. Images show that the outer part of the bright region is actually a ring. Can those of you with a very large telescope resolve it?

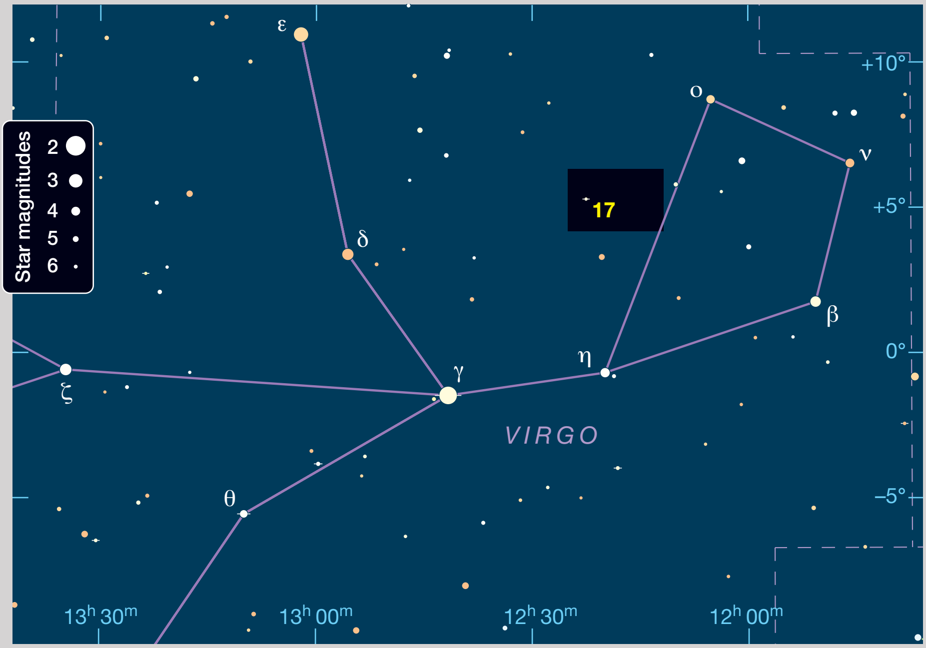
The brightest galaxy in our tour is **Messier 61**, which sits 51′ south of 17 Virginis. An orange, 7.6-magnitude star lies about halfway between them. Although M61 can be picked out at low power through the 105-mm scope, 87× gives a much nicer view, exposing a slightly oval, very patchy glow with a bright core. At 127×, a starlike nucleus appears. In the 10-inch scope at 70×, M61 displays a bright, 2′ × 1½′ ring, and the pallid halo beyond fades into the background sky. At 118× the ring begins to look patchy. The halo spans about 3½′, and a faint star watches over its southwestern edge. At 171× the patchiness gives the impression of two spiral arms that unwrap counter-clockwise. The arms are clearer through my 15-inch reflector at 192×, springing forth north and south of the galaxy's center. At 216×, the northern arm appears wider at its base than its counterpart in the south does, undoubtedly because there are two arms emerging in the north. However, I couldn't separately distinguish them.

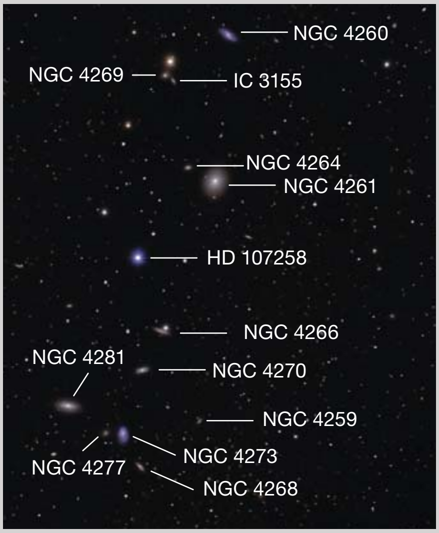
Two smaller galaxies attend M61. **NGC 4292** is faintly visible though the 105-mm refractor at 87×, just south-southeast of a 10th-magnitude star. Averted vision helps. The 10-inch reflector at 118× shows NGC 4292 and **NGC 4301** together in the field of view, but the latter is tough. At 171× both galaxies are small. NGC 4292 is a north-south oval with a brighter center, while NGC 4301 is an ethereal ball of mist guarded by a 13th-magnitude star 2.4′ due east.

The second-brightest galaxy in our foray, **NGC 4261**, rests 56′ west-north-west of 17 Virginis. Through a 50-mm finder, you can see a north-south curve of five 7th- to 9th-magnitude stars in the area. At low magnification through a telescope, the line's brightest star shares the field of view with our quarry. In my 105-mm scope at 47×, NGC 4261 exhibits a bright core, and the smaller galaxy **NGC 4260** is visible to its north as a faint smudge. At 87× NGC 4260 becomes an elongated haze containing a somewhat brighter core, while NGC 4261 unveils a starlike nucleus and a slightly oval face. Very small, very faint, and round, **NGC 4264** joins the scene, 3.5′ east-northeast of NGC 4261. I was puzzled by a "star" of about magnitude 11½ that I saw close to NGC 4264. It wasn't in any of the star catalogs in my software atlas. I noted the position and sketched the field. When I went inside for the night, I couldn't find it on any of the Digitized Sky Survey images either. Checking further, I learned that minor planet Artemis just happened to be in my field of view. What a pleasant surprise!

Looking at the same trio of galaxies the next night with the 10-inch scope, I spotted Artemis, which had moseyed along to visit NGC 4260 by then. At 115× NGC 4260 is about 2½′ long and one-third as wide, leaning approximately northeast. A faint, star-







▲ Several small galaxies stretch between elliptical galaxy NGC 4261 and lenticular galaxy NGC 4281, as shown in this image captured in 16 six-minute exposures through a 152-mm f/4.8 Maksutov-Newtonian.

like nucleus pins the galaxy's heart. NGC 4261 is a chubby oval about 2½′ long, tipped north-northwest. Tiny **NGC 4269** joins the group, just south of the curve's second-brightest star. It appears faint, slightly oval northwest-southeast, and has a brighter center. I didn't notice IC 3155, the considerably dimmer galaxy cozied up to its southwestern flank. Will you?

Pushing the little refractor a bit south from NGC 4261 brings another clump of galaxies into the field of view. At 87× **NGC 4281** is a fairly easy, east-west oval, floating 5.6′ north of a close pair of 12th-magnitude stars. **NGC 4273** is a fainter oval, surveilled by the ashen blimp of **NGC 4270** hovering 7.4′ above (north of) it. At 127× NGC 4281 houses a large, slightly brighter core and a conspicuous, starlike nucleus. With averted vision, I see **NGC 4268** as a northeast-southwest glow sitting 4.1′ south-southwest of NGC 4273.

My 10-inch reflector at 166× adds two galaxies to the tableau. **NGC 4277** is a ghostly, round spot close to the eastern side of NGC 4273. A very faint star dangles beneath it. **NGC 4259** surfaces as a difficult little smudge west of the collected galaxies. With study, it seems elongated toward NGC 4268. An extremely faint star intermittently pops out quite close to NGC 4259, northeast of the galaxy's center. NGC 4273 tilts north-northeast and bears a large, brighter core. NGC 4270 points toward NGC 4281 and grows brighter toward a small core with a faint, starlike nucleus. NGC 4268 brightens only gently toward the center.

Somewhat divorced from the rest of the crew, we find the flat galaxy **NGC 4197** perched 1.2° west of NGC 4261. Flat galaxies are disk-like galaxies that have little or no central bulge and are seen nearly edge-on from our vantage point on Earth. I've always enjoyed viewing these slender needles of light and go out of my way to check them out. NGC 4197 is nicely visible even at 70× through my 10-inch reflector. At 118× its slivery form stretches across 3′ of sky, and its elongated core is off-center toward the galaxy's northeastern tip. Observers with large telescopes should seek out the peculiar split in that end; it looks as though someone started to slit it lengthwise with a knife. Images show that the western shaft of the split is a discrete spiral arm that stretches well beyond the bulk of the galaxy. NGC 4197 makes a lovely needle for stitching up the end of our deep-sky tour.

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

Deep-Sky Objects in Virgo

Object	Type	Mag(v)	Size/Sep	RA	Dec.
17 Vir	Double star	6.5, 9.3	21″	$12^h\ 22.5^m$	+5° 18′
NGC 4324	Lenticular	11.6	2.8′ × 1.2′	$12^h\ 23.1^m$	+5° 15′
M61	Spiral	9.7	6.5′ × 5.8′	$12^h\ 21.9^m$	+4° 28′
NGC 4292	Lenticular	12.2	1.7′ × 1.1′	$12^h\ 21.3^m$	+4° 36′
NGC 4301	Spiral	13.0	1.5′ × 1.3′	$12^h\ 22.5^m$	+4° 34′
NGC 4261	Elliptical	10.4	4.1′ × 3.6′	$12^h\ 19.4^m$	+5° 49′
NGC 4260	Spiral	11.8	3.3′ × 1.0′	$12^h\ 19.4^m$	+6° 06′
NGC 4264	Lenticular	12.8	1.2′ × 1.0′	$12^h\ 19.6^m$	+5° 51′
NGC 4269	Lenticular	12.9	1.1′ × 0.8′	$12^h\ 19.8^m$	+6° 01′
NGC 4281	Lenticular	11.3	3.0′ × 1.5′	$12^h\ 20.4^m$	+5° 23′
NGC 4273	Spiral	11.9	2.3′ × 1.1′	$12^h\ 20.0^m$	+5° 21′
NGC 4270	Lenticular	12.2	2.1′ × 0.9′	$12^h\ 19.8^m$	+5° 28′
NGC 4268	Lenticular	12.8	1.6′ × 0.7′	$12^h\ 19.8^m$	+5° 17′
NGC 4277	Lenticular	13.4	1.1′ × 0.8′	$12^h\ 20.1^m$	+5° 21′
NGC 4259	Lenticular	13.6	1.2′ × 0.5′	$12^h\ 19.4^m$	+5° 23′
NGC 4197	Spiral	12.8	3.2′ × 0.6′	$12^h\ 14.6^m$	+5° 48′

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.

JIM THOMMES

NGC 5529

Spend some time with a most excellent edge-on galaxy this spring.

You may have never heard of **NGC 5529** or looked at it in your own telescope. But you should find the time to do it this season, because it's a beautiful galaxy in a beautiful setting.

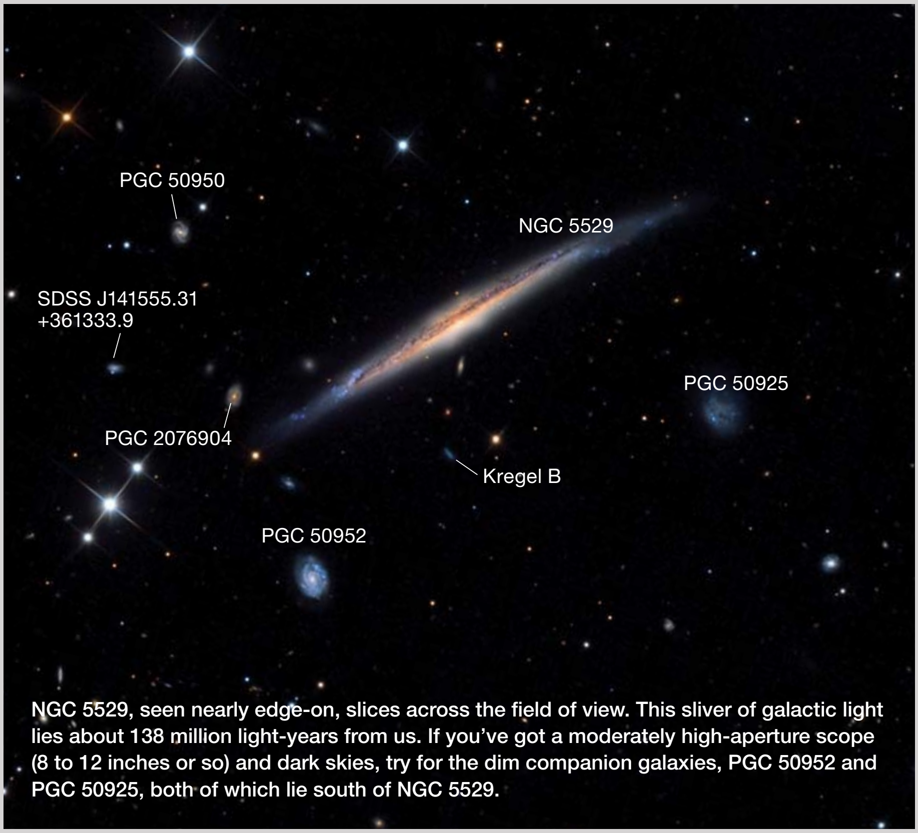
More specifically, it's a wonderfully long and thin edge-on galaxy with a subtle dark lane — just by itself it's a lovely sight. A lovely foreground triplet of bright stars in a straight line and a flotilla of companion galaxies make the overall view even more irresistible.

Look closely at the image to the right. The stars are in our Milky Way galaxy, relatively close by in the context of the photo. NGC 5529 and its companion galaxies are situated about 138 million light-years away, and the really faint galaxies in the background are at least twice as far away. The depth of the field is mindboggling.

I can't see everything in the photo in my telescope, unfortunately. But I did see a quite a bit with the help of dark, transparent skies and lots of patience — and so can you.

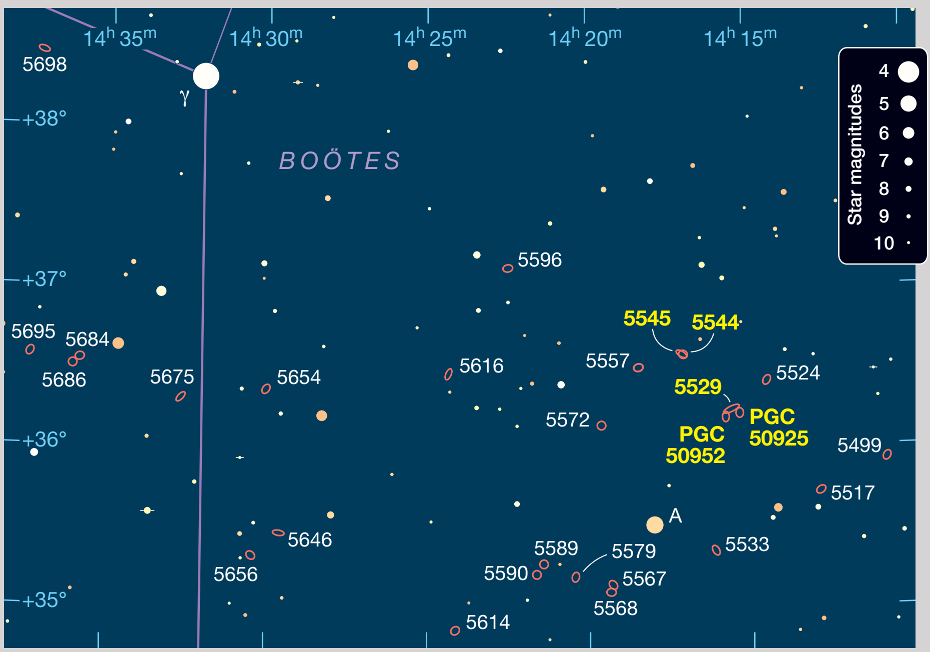
In 2015, while observing from Likely Place in northern California, I returned to NGC 5529, which I'd observed briefly the year before at the Golden State Star Party. Observing it several nights in a row, I was able to see not only the galaxy's major features, but also eight companion galaxies in the same field of view. They became easier to see each night, too. This seldom fails — knowing where the companions are and what they look like makes them easier to see again. Ever notice this effect yourself?

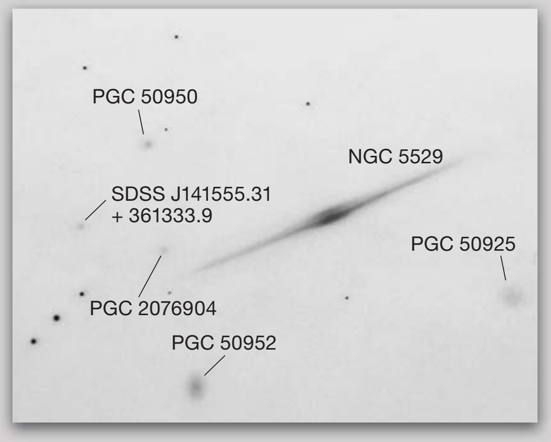
Each night, I slowly built up my sketch, starting with the bright foreground stars, then working on NGC 5529, and finally adding the fainter and apparently smaller companion galaxies. Each detail added a layer of distance and time and helped me visualize the extreme depth of this wonderful view.



NGC 5529, seen nearly edge-on, slices across the field of view. This sliver of galactic light lies about 138 million light-years from us. If you've got a moderately high-aperture scope (8 to 12 inches or so) and dark skies, try for the dim companion galaxies, PGC 50952 and PGC 50925, both of which lie south of NGC 5529.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA





▶ Magnifications of 408× and 476× were used to make this sketch. The three bright stars in a line off the southeastern end of the galaxy form a distinctive part of NGC 5529's field of view, and are the brightest part of the scene, ranging in magnitude from 11.1 to 13.8. Out of the five companion galaxies shown, only PGC 50925 is physically associated with NGC 5529 and is probably responsible for warping the galaxy's northwestern end. The other three galaxies observed by the author are just outside this field of view.

HOWARD BANICH

Thin and Beautiful

Under a dark, transparent sky NGC 5529 looks great in scopes 6 inches and larger, and if you're observing with friends, you may be tempted to call them over for a look. At magnitude 12.9 it's fainter than the better-known NGC 4565 — perhaps the most famous edge-on galaxy — and is less than half its apparent length (6.2 arcminutes versus 15.9). But that only means you'll have to look a little more closely to see the details, which are more abundant than those of NGC 4565.

The real treat of observing NGC 5529 is that it's presented almost exactly edge-on to us, long and slender. It's huge, too: With an approximate diameter of 250,000 light-years, it's nearly twice the length of our Milky Way galaxy.

The ends of the galaxy fade quickly, and even in my 28-inch scope it's difficult to say exactly where they stop. I haven't been able to see the subtle warp on the northwest tip of the galaxy yet, perhaps because contrast decreases rapidly toward each end.

The central dust lane also has low contrast and is rather subtle despite my large scope. I've seen it best with averted vision, although it does suggest itself with direct vision. The dark lane extends some 50% of the full length of the galaxy and is a bit off-center, suggesting the galaxy is ever so slightly tilted to our view.

The peanut-shaped central bulge of NGC 5529 indicates it's a barred spiral, similar to our Milky Way. Interestingly, we know the northwest end of the galaxy is rotating toward us. The central bulge is the brightest part of the galaxy, but it barely extends beyond the disk. It looks rather elongated and somewhat boxy, with flat sides. The southern half is the brighter of the two and is a little wider than the northern half, with the dark lane being the most obvious here. Both sides of the central bulge are subtly brightest at the midline of their borders with the dust lane.

The overall effect of all this is that NGC 5529 looks long and slender, which makes it an enormously appealing sight.

NGC 5529 Galaxy Group Members

Object	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
NGC 5529	13.5	12.9	6.2′ × 0.8′	14^h 15.6^m	+36° 14′
NGC 5533	13.6	12.2	3.1′ × 1.9′	14^h 16.1^m	+36° 21′
NGC 5544	12.9	13.6	1.1′ × 1.0′	14^h 27.1^m	+36° 34′
NGC 5545	12.6	14.0	1.5′ × 0.5′	14^h 03.5^m	+35° 01′
NGC 5557	12.6	11.7	2.3′ × 1.9′	14^h 18.4^m	+36° 30′
NGC 5589	13.3	13.6	1.1′ × 1.1′	14^h 21.4^m	+35° 16′
NGC 5590	13.5	12.5	1.8′ × 1.8′	14^h 21.6^m	+35° 12′
NGC 5596	13.2	13.6	1.1′ × 0.8′	14^h 22.5^m	+37° 07′
NGC 5614	13.4	12.2	2.5′ × 2.2′	14^h 24.1^m	+34° 52′
NGC 5656	12.8	12.7	1.9′ × 1.5′	14^h 30.4^m	+35° 19′
NGC 5675	13.8	13.0	2.8′ × 1.0′	14^h 39.7^m	+36° 18′
NGC 5684	13.3	15.9	1.5′ × 1.3′	14^h 35.8^m	+36° 33′
NGC 5695	13.2	12.9	1.5′ × 1.1′	14^h 37.4^m	+36° 34′
PGC 50925	14.4	16.8	0.9′ × 0.7′	14^h 15.3^m	+36° 12′
Kregel B	—	18.9	—	14^h 15.6^m	+36° 12′
IKPM 1	—	19.8	0.2′ × 0.2′	14^h 15.7^m	+36° 13′
IKPM 2	—	17.0	0.5′ × 0.5′	14^h 16.0^m	+36° 17′

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.

The Companions

At last count, NGC 5529 had 16 companion galaxies, 12 of them with NGC numbers. Together, they provide as much, if not more, of an observing challenge as our main target. Surprisingly, only one of the NGC companions, NGC 5527, is close enough to NGC 5529 to be shown in the photo on page 57 or my drawings, and that NGC number is in doubt.

Actually, two galaxies near NGC 5529 have muddled identities. Discovered in 1855 by R. J. Mitchell using the 72-inch at Birr Castle, NGC 5524 and NGC 5527 are sometimes cataloged as the same galaxy. The original descriptions are confusing enough to make their designations uncertain, so for clarity I'll use PGC numbers.

PGC 50925 (NGC 5527's actual designation) could be the galaxy that gave the northwest end of NGC 5529's disk its elegant warp. Intriguingly, PGC 50925's redshift is nearly identical to NGC 5529's (z=0.0099 versus z=0.00986, respectively) and both translate to a distance of approximately 138 million light-years. Also similar are their radial velocities (2,942 km/s versus 2,953 km/s). These measurements, along with an H I bridge between the two objects, certainly suggest it's the disrupting galaxy (not to mention PGC 50925's unsettled appearance). PGC 50925 is a low surface brightness object, though, and at magnitude 16.8, you'll need excellent dark-sky observing conditions and perhaps a 16-inch scope to see it for yourself.

NGC 5529 Non-Related Companions

Object	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
PGC 50952	—	15.1	0.7′ × 0.5′	14^h 15.8^m	+36° 11′
PGC 50950	—	16.8	0.3′ × 0.3′	14^h 15.8^m	+36° 15′
SDSSCGA 240.3	—	16.4	0.8′ × 0.5′	14^h 16.3^m	+36° 13′
PGC 2076843	—	15.1	0.8′ × 0.5′	14^h 16.3^m	+36° 13′
PGC 2076761	—	15.8	0.4′ × 0.4′	14^h 16.2^m	+36° 13′
PGC 2076904	—	17.1	0.4′ × 0.2′	14^h 15.8^m	+36° 13′
SDSS J141555.31+361333.9	—	17.9	—	14^h 15.9^m	+36° 14′

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.

The much smaller galaxy **Kregel B** (or NGC 5529B) also has an H I bridge to NGC 5529, along with a nearly identical distance and radial velocity. However, at magnitude 18.9, it takes a really big scope to see this one.

By far the most visually obvious of NGC 5529's apparently closest companion galaxies is 15.1-magnitude **PGC 50952**. It's the first one I spotted before realizing there were many companions. It seems odd that it doesn't have an NGC number, especially when the much fainter PGC 50925 may be NGC 5527, but that's the way it goes sometimes.

PGC 50952 is located just south of NGC 5529's southeast end and a triplet of bright foreground stars. It's far in the background, though, at more than twice the distance of NGC 5529.

All the NGC companion galaxies are listed in the accompanying table, and you'll notice that the closely interacting galaxies **NGC 5544** and **NGC 5545** (also cataloged as peculiar galaxy Arp 199), are also included — be sure to have a look while you're in the neighborhood. Note that most of the NGC companions are well outside a 2° field of view centered on NGC 5529, so plan to look far beyond the edges of my sketch if you want to see them all.

I'm not finished observing NGC 5529 yet. I'd love to see the gentle warp to the northwest end of its spiral disk. I'm also determined to try detecting the brighter area within the galaxy near the southeast end of the dust lane.

I'll give my best shot to seeing Kregel B, too, but at magnitude 18.9 it's almost certainly beyond my 28-inch scope. But half the fun is trying, because you never really know what can be seen without looking for yourself.

The dust lane is slightly off center, and the southern half of the core is not only brighter, but wider. The northwestern end of the galaxy is rotating toward us. Given the prominence of the warp of the northwestern end in images, it's disappointing that the distortion is not more visible in the eyepiece.

HOWARD BANICH

■ Spring galaxies are a rare treat for Contributing Editor **HOWARD BANICH**, who lives under the cloudy skies of western Oregon. He can be reached at howard_banich@nike.com.

Smart Astronomy: The NexStar Evolution 9.25

Celestron changes the game with complete Wi-Fi controls.

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What We Like

Excellent optics
Robust Wi-Fi interface

What We Didn't Like

Confusing manual
Less stable than double-armed fork mounts

WHETHER I'M SURFING Facebook or just talking to friends, my smartphone and I are inseparable — that is, until it's time to use a telescope. There are ways to use an iPhone or Android device to send a computerized telescope to sky objects, but until recently add-on cables and boxes were required. That's changed with the introduction of Celestron's NexStar Evolution series of Schmidt-Cassegrain telescopes.

Fork-mounted Schmidt-Cassegrain telescopes have long been a mainstay in the amateur market, offering portability and generous aperture in a compact package. One of the big attractions of mass-produced Schmidt-Cassegrains is that they tend to be in the forefront of technological advances, and that is certainly true of Celestron's Evolution line of SCTs. This new series fully integrates the company's computerized Go To telescopes with the electronic devices most everybody owns these days. The next step in the "evolution" of the SCT? We looked at the Evolution 9.25 to see.

◀ The Celestron NexStar Evolution series of Schmidt-Cassegrain telescopes provides generous aperture in a compact package, with the addition of fully integrated smart device control.

ALL PHOTOS COURTESY OF THE AUTHOR.

The Setup

The Evolution 9.25 ships in two boxes: one containing the tripod, and the other with the optical tube assembly (OTA) attached to its single-arm fork mount. The OTA box also contains a hand control paddle, 40- and 13-mm Plössl eyepieces, a plastic-bodied star diagonal, a zero-power red-dot finder, an AC adapter, and an instruction manual plus an addendum sheet.

The Evolution tripod is a hefty model with 2-inch-diameter stainless-steel extendable legs equipped with two metal spreaders. The upper spreader is tightened against the tripod legs with a knob on a threaded rod that extends from the underside of the tripod head and doubles as an accessory tray, while the other folds out near the leg extensions to provide additional stability.

The combination of telescope and fork mount weighs in at 36 pounds and is a bit awkward to handle, with the tube being considerably longer than that of Celestron's 8-inch model. The scope is easiest to set up by first removing the OTA from the fork and assembling the three parts in stages. The tube attaches to the mount via a Vixen-style dovetail bar and saddle, and is held securely in place with a single knob. Most users will mount the fork assembly directly onto the tripod and use the scope in alt-azimuth fashion as I did. An optional wedge allows the telescope to be used in equatorial mode for deep-sky imaging, and could also mitigate an issue I discovered later on.

Lifting the light fork and its drive base to the tripod isn't a strain, but getting the base properly positioned on the tripod head can be. There's a central pin on the head that goes into a hole on the underside of the mount's base. With practice, it became easier to position the base properly onto the pin, but it was never easy. Once the base is properly positioned, the remainder of the assembly is pretty straightforward.

After admiring the attractiveness of the scope for a while, I took stock of the accessories. Although most owners will use the telescope with a smartphone or tablet, Celestron includes the latest version of its NexStar+ hand control. Not only does it allow the telescope to be operated without a smart device, it enables control of the Evolution with a laptop computer. But at first, it wasn't clear to me how that worked. The new hand control doesn't have a serial port like previous models. Instead, there is a mini USB jack, and I was afraid that would make it impossible to use the Evolution with my astronomy software, which requires a serial connection. I discovered, however, that the USB connector on the hand control is followed by an internal serial-to-USB converter, and a laptop sees the Evolution as a normal serial device.

The Evolution has a built-in lithium iron phosphate rechargeable battery in its base, and the included AC adapter serves as its charger. The manual warns that the battery must be charged before using the telescope for the first time. Unfortunately, it doesn't explain exactly how to do that.

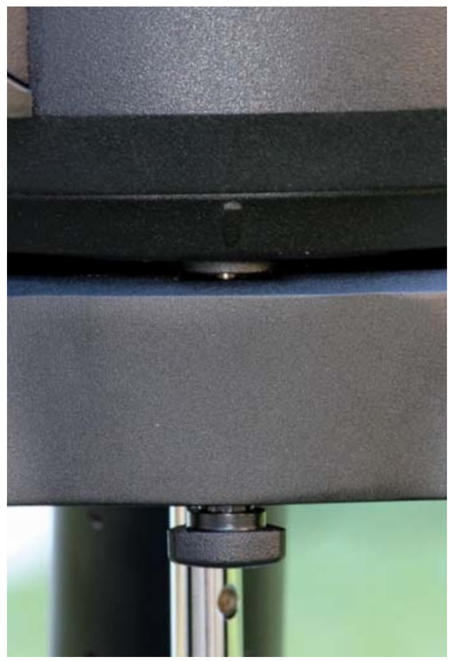
A table in the back of the instruction book clued me in. The Celestron-logo power LED indicator on the fork arm indicates battery charge, among other things. Rapid blinking warns of a low battery, while slow pulsing means charging is in progress, and a steady light means fully charged. Plugging the charger into the power receptacle on the telescope's control panel resulted in half an hour of LED pulsing before the battery was topped off.

Under the Stars with SkyPortal

It was time to get the Evo into the backyard, where the first challenge was balancing the tube by sliding it back and forth in the saddle with the attachment knob slightly loosened. When the telescope was perfectly balanced, its star diagonal bumped into the base when the scope was pointed higher in altitude than about 70°. I could improve on that 70° somewhat by moving the tube forward in the saddle.

This minor imbalance didn't cause problems, but I was reluctant to use the scope way off balance — in addition to straining the altitude motor, accidentally unlocking the altitude lock on the mount might result in disaster if the front end of the tube slammed into the base. Thus, with the scope reasonably balanced, targets near the zenith are off limits. Owners of the Evolution 9.25

▲ The Evolution tripod includes a handy bubble level to quickly level the tripod before attaching the fork mount. A central pin helps to center the fork base.



▲ Once the drive base is seated, the fork is rotated until alignment marks line up with the tripod's 3 tool-free mounting bolts.

should consider adding a counterweight to the rear of the tube, or purchase the optional equatorial wedge, which changes this "zone of avoidance" to the area surrounding the celestial pole.

Ready to go, I prepared myself for an adventure in wireless Wi-Fi telescope control. I installed Celestron's free *SkyPortal* app, which is based on the popular *SkySafari* app, for my iPhone as well as my Android tablet. While *SkyPortal* only includes a couple of hundred deep sky objects, the Plus and Pro versions of *SkySafari* are compatible with the Evolution and include tens of thousands of objects in their databases.

I initially tested the Evolution with my iPhone, though results were identical with my Android tablet. The process of getting aligned and going to targets is amazingly simple. Turn on the telescope and connect to it in the Wi-Fi setup of the smart device (it will show up as "SkyLink-E5" in the list of available networks). A pulsing Wi-Fi LED indicator shows the scope is communicating with your smart device.

▲ Like most Celestron NexStar telescopes, the 9.25 is attached to the fork arm via a convenient Vixen-style dovetail system that allows users to remove or re-balance the OTA, though attaching the tube can be challenging due to the dovetail's position on the side of the tube.

Once in *SkyPortal*, click on the telescope icon. To perform a Go To alignment, select "connect and align" on the screen and follow the instructions, which will lead you through Celestron's *SkyAlign* procedure. The Evo gets the time, date, and location automatically from your phone or tablet.

SkyAlign requires you to center three bright objects, either stars or planets. You don't have to know the names of these objects; you only need to center them. I thought I'd have a hard time using my iPhone's touch-screen instead of real buttons on a hand control, but it was doable from the beginning and became easy with experience.

The app's virtual buttons are very responsive; there is no time-lag between pushing one and the telescope beginning to move. I did find the initial rough-centering speed to be a little too fast, but a speed-slider onscreen allows you to adjust that and the eyepiece-centering speed to suit your comfort. I lined up the first star in the red-dot finder, pressed the onscreen "Enter" button, and then positioned the star in the eyepiece and pressed "Align." I followed that with another star, then Saturn, and I was done.

The app said my alignment was successful, and indeed it was. Any object I requested the telescope to point to, from one side of the sky to the other, was in the 40-mm eyepiece at 59×, and sometimes even in the 13-mm at 180×.

The Evolution can also be aligned with the hand control, which includes several alignment options not available in *SkyPortal*. Performing the alignment with my phone or tablet seemed to produce the most accurate pointing. The scope can be operated with either Wi-Fi or with the hand control, though both cannot be used at the same time.

So how do you point to objects with *SkyPortal*? You can select a target by clicking on it in the displayed star chart and then clicking the Go To button, or you can use *SkyPortal*'s versatile search function to find an object of interest and then tap Go To. There's also a list of the night's best objects if you can't decide on what you want to see.

The reliability of the Evolution's Wi-Fi connection impressed me. I could control the telescope from as far as 60 feet away on a wide-open observing field. The manual warns that competing Wi-Fi signals may cause problems, but that never happened to me. The only time my iPhone or Android tablet disconnected was when I let the devices go into power-saving sleep mode. When I woke them, *SkyPortal* reconnected automatically in a few seconds.

Accurate pointing is a good thing, but how did the objects look? The Celestron 9.25's 235-mm aperture, 2,350-mm focal length f/10 optics have a reputation for excellence, and I was certainly impressed by them. Despite only so-so atmospheric steadiness, the scope produced satisfying views of Saturn when highest in the southern sky. The 9.25 is a powerful performer on the deep sky, too. In my light-polluted backyard, its generous aperture allowed me to resolve brighter globular star clusters into hordes of tiny pinpoints.

Mediocre seeing conditions prevented me from doing a definitive star test, but from what I could tell, the appearance of the diffraction pattern of a slightly out-of-focus star was similar on both sides of focus an indication of well-corrected optics.

When I began observing with the Evolution, I was concerned I might accidentally bump the star diagonal into

▲ The base of the fork mount includes the charger port, two RJ-11 auxiliary ports to attach the hand controller or a StarSense alignment unit, a USB power output port, and the power switch.

▲ **Left:** Although the scope comes with Celestron's NexStar+ hand controller, the telescope can be completely controlled using a smartphone or tablet running the *SkyPortal* app. A laptop computer can be connected to drive the telescope via a mini-USB input at the bottom of the controller. **Right:** The Celestron logo on the fork arm lights up to indicate the status of the internal battery charge. Not shown on the rear of the arm at right are two additional RJ-11 auxiliary ports, the Wi-Fi on/off switch, and a Wi-Fi reset button.

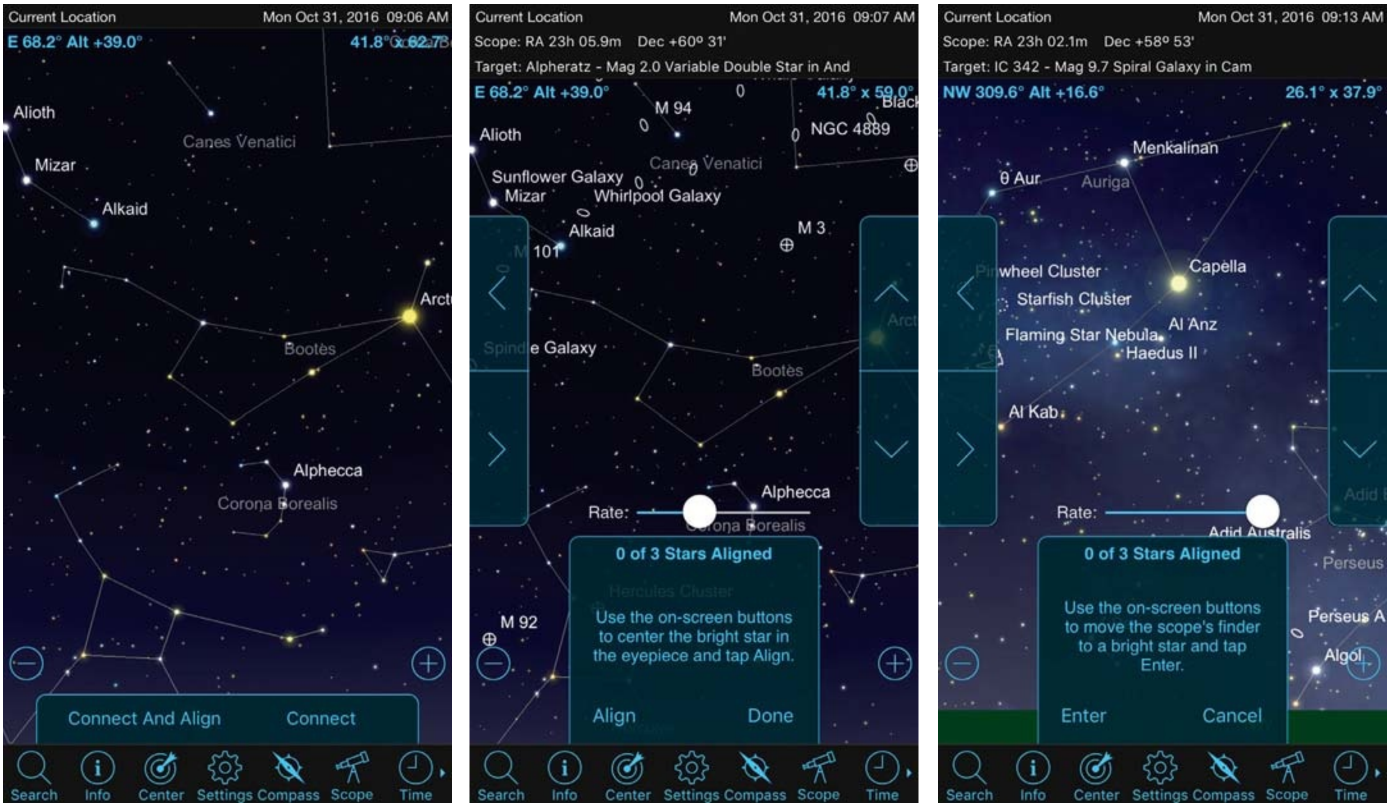
the telescope base if I chose an object too close to the zenith. Fortunately, the *SkyPortal* app and the hand control both include an altitude limit that is adjustable, and this always prevented the diagonal from hitting the base.

In addition to its Wi-Fi capabilities, the Evolution is different from most other fork-mount SCTs in this aperture range because of its single, rather than double, fork arm. Some prospective owners have expressed concern about that, and I did find the Evolution mount somewhat less stable than heavier, double-arm forks. Nevertheless, the Evolution is still quite useable, even at high power. With the tripod legs retracted, a rap on the tube produced vibrations that took up to 4 seconds to die out at 180×. Focusing at high power without creating excessive vibration is easy if you use a light touch on the knob. The advantage of the single-arm fork is that this nearly 10-inch SCT is far easier to transport and assemble than similar size double-arm SCTs.

Imaging Performance

Many new amateurs looking for a telescope want to know "Can it take pictures?" Due to its light single-arm fork mount, this would not be a telescope I'd choose for the most demanding deep-sky imaging, but you can take pictures with it. It's more than adequate for high-resolution planetary photography, and also good enough to let new imagers get their feet wet with some deep-sky imaging.

As a trial, I shot images of a few bright objects at the Cassegrain focus on the Evolution. The telescope as deliv-



▲ **Left:** Aligning the Evolution using the *SkyPortal* app begins by touching the telescope icon, then choosing "Connect and Align" to proceed. **Middle:** The app will then instruct you to center a bright star in the telescope's finder, and then in the eyepiece using the on-screen buttons at the side of the screen. **Right:** After centering the third object, tap "Enter", and the alignment process is complete.

ered only works in alt-azimuth mode, and the inherent field rotation of computerized alt-azimuth tracking doesn't allow for long exposures. Nevertheless, I could expose for 30 seconds in many areas of the sky. Stacking 20 of these exposures into a single image resulted in respectable photos of bright objects, including the globular cluster M13 and the Ring Nebula, M57.

The modular nature of the Evolution makes the scope particularly attractive for users who consider upgrading the mount in the future, whether it's by purchasing the optional equatorial wedge, or by replacing the mount for deep-sky astrophotography at a later date.

Battery Life

How long will the built-in battery run the Evolution? Celestron says it will allow up to 10 hours of operation, but the exact figure will depend on how much Go To slewing you do, as well as the outside temperature. The Evolution naturally draws considerably more current when slewing at high speed than simply tracking the stars. Despite doing a lot of slews, I never ran the battery down during several 4-hour observing sessions. If you do get a low-battery warning, operation can continue with the AC charger plugged in or with an optional DC power source.

What I liked most about the Evolution 9.25 wasn't just the wireless control, or the built-in battery, or the great optics. It was the combination of all of these things that resulted in a telescope that is enjoyable and convenient to use. Not having to lug a big battery and rustle up a hand control meant I was willing to take the Evolution into the backyard for short observing sessions. What Celestron has in the Evolution 9.25 is a powerful, user-friendly, high-tech telescope that encourages its owner to get out under the stars.

■ **ROD MOLLISE** has used more Schmidt-Cassegrain telescopes than you can shake a Go To controller at.

▲ As supplied, the NexStar Evolution 9.25 telescope in proper balance can only point about 70° up before its star diagonal hits the drive base. Adding a tube weight to the rear cell can alleviate the issue.

CAMERA TRACKERS Shooting deep images of the Milky Way is easiest when using a tracking mount that makes your camera follow the movement of the sky. Here's a roundup of the most compact of these little drives on the market today. Unless otherwise noted, all photos were provided by the respective manufacturers.

Portable Star Trackers

Tracking is the next step on your journey to capturing the beauty of the night sky.

Getting started in basic astrophotography is easy using just a camera on a tripod. But if you get bitten by the imaging bug, you're going to want to record more than conjunctions or constellations.

To capture fainter targets such as star clusters, large emission and dark nebulae, or the Milky Way itself in a low-noise image, you'll need to shoot longer exposures. But the stars above will trail in longer exposures, because the world continues to turn no matter how hard we try to stop it. As Earth rotates on its axis, the Sun, Moon, and stars appear to rise in the east and set in the west.

To compensate for Earth's spin, you need to use an equatorial tracking mount. When the device's axis of rotation is aligned with our planet's rotational axis, the mount turns at the exact same rate that Earth turns, in the opposite direction, canceling out the motion of the heavens and making celestial targets sit still for your close-up.

Assuming you already have a tripod, the least expensive way to get into these longer, tracked exposures is with a homemade "barn-door" mount that you can make for about $20. It's not much more than two boards connected by a hinge aimed at the celestial pole. A simple ¼-20 bolt and wingnut provide its drive mechanism. Placed at the right distance from the hinge (11½ inches), one turn per minute results in a sidereal tracking rate that will follow the stars.

But if you're like me, you'll soon tire of turning that bolt on the homemade barn-door mount by hand. You can build a motorized version as described by Gary Seronik (*S&T*: June 2007, p. 80). But if you aren't very mechanically inclined, you'll want to take a look at the commercially available star trackers described here.

All star trackers work the same way: You put one on a sturdy tripod and aim its axis toward at the celestial pole. Attach your camera with a ball head, frame the part of the sky you want to shoot, and start taking pictures.

Some use a sight hole to roughly aim the mount toward Polaris, while more advanced models have a small polar-alignment telescope with a built-in reticle, which is either included or available at additional cost. Others work in conjunction with handy smartphone apps that show you exactly where to place Polaris on the reticle in the polar-alignment scope using your precise location, date, and time obtained from the smartphone's GPS.

Most of these star trackers work great, allowing you to shoot exposures up to several minutes long with wide-angle lenses without requiring additional guiding. A general rule of thumb with these drives is the shorter your lens's focal length, the longer your exposures can be before periodic error elongates the stars in your images. Some will also let you shoot with moderate telephoto lenses of up to about 100-mm focal length, though once you start using telephoto lenses, you'll find the longest successful exposures without elongated stars will go down.

Each of these units is very compact and easily fits into a suitcase if you are traveling and are pressed for luggage space.

Note that, with all of these trackers, you'll need a sturdy tripod and ball head to aim the camera. Except for the iOptron StarTrackers, and the Sky-Watcher Star Adventurers, the polar alignment scopes are an additional (though in my opinion essential) accessory, so factor that into the total cost also.

Of course, you could make the argument that once you spend $100 for a tripod, $50 for a ball head, and $300 to $1,000 for a tracker, you're easily into the price range of a true equatorial mount that could also hold a telescope. The difference is the *portability* of these trackers. You can literally carry an iOptron SkyTracker or Vixen Polaire in your camera bag — or the pocket of your winter coat. They are perfect if you are flying on vacation to a place with dark skies where you might want to shoot some spectacular night-sky pictures, and they are also great for shooting total solar eclipses with longer telephoto lenses. Their portability and compactness really helps in carrying them on the airlines, which these days often have carry-on size and weight limitations and charge additional baggage fees.

BABAK TAFRESHI

StarSync Tracker

starsynctrackers.com • Starting at $239.95

The StarSync Tracker is essentially a barn-door mount, constructed of aluminum and stainless steel weighing 3¾ lbs. A bare-bones version is aligned by sighting along the hinge; a green-laser-pointer accessory, available to provide more accurate polar alignment, might be a problem at public dark-sky star parties. It's powered with 12 volts DC (also an additional accessory) and can track for up to 2½ hours before its drive mechanism has to be reset. The unit has a built-in alt-azimuth camera swivel mount with a ¼-20 tripod thread.

Sightron Nano Tracker

omegon.eu • Starting at $308

This compact drive is about as big as your fist and weighs less than 1 lb. but can bear a load of about 4½ lbs. It's powered with three AA batteries and attaches to standard ¼-20 tripod threads. The unit is aligned using a simple peep-sight hole. The Nano Tracker can be operated in both Northern and Southern Hemispheres and includes drive rates of sidereal, 0.5× sidereal, and 50× sidereal to aid in slewing to targets. An optional ball head is available at additional cost.

iOptron SkyTracker Pro

ioptron.com • Starting at $299

This new and improved redesign of the SkyTracker seen on page 69 sports a much more refined alt-azimuth adjustment for dialing in polar alignment, and it uses the same (excellent) polar-alignment scope that also works with the *iOptron Polar Scope* app. It's powered with an internal rechargeable battery that can drive the mount for up to 24 hours and recharges in 5 hours through a micro USB port. Its polar-alignment scope has adjustable brightness levels, and the unit includes both ¼-20 and ⅜-inch threaded attachments. Like its predecessor, the SkyTracker Pro includes four tracking rates and can be used in both Hemispheres. It also features a 180× slewing mode in RA to help frame your subject. The SkyTracker Pro weighs 2.53 lbs. with a maximum payload capacity of 6.6 lbs.

iOptron SkyTracker

ioptron.com • $299

This compact rectangular tracker weighs 2.6 lbs. and is rated to bear a load of up to 7.7 lbs. (*S&T:* May 2013, p. 64). Its built-in alt-azimuth adjustments work in conjunction with an included illuminated polar-alignment scope and an optional *iOptron Polar Scope* smartphone alignment app to achieve very accurate alignment. The SkyTracker can be used in both Hemispheres and has four tracking rates: sidereal, 0.5× sidereal (good for nightscapes), solar, and lunar. The unit can run for up to 24 hours on four AA batteries. Optional accessories include a counterweight package, tripod, AC adapter, and ball head. Although recently discontinued, this model is still readily available.

Sky-Watcher Star Adventurer

skywatcherusa.com • Starting at $319

Sky-Watcher's Star Adventurer is a versatile tracker with lots of options that can even be expanded to be a complete, lightweight equatorial mount. Weighing 2.2 lbs., it can handle a payload of 11 lbs. and includes an illuminated polar-alignment scope. The mount can operate in both Hemispheres and includes sidereal, lunar, and solar tracking, as well as 0.5×, 2×, 6×, and 12× sidereal rates to assist with nightscape time-lapse animations. It can also connect to your Canon or Nikon DSLR to trigger exposures with an appropriate cable. You can slew in either direction in RA at 12× to assist with framing your subject. The unit operates for up to 72 hours on 4 AA batteries, or it can be powered through a mini-USB port.

The mount also has an RJ-12 port that supports standard autoguiders to permit even longer exposures when shooting with long telephoto lenses.

Optional accessories include a Latitude (EQ) Base, a declination bracket, and a counterweight kit.

Sky-Watcher Star Adventurer Mini

skywatcherusa.com • Price unavailable

Sky-Watcher recently announced a new star tracker, the Star Adventurer Mini. Weighing just 1½ lbs., it's smaller and lighter than the Star Adventurer and can carry up to 7 lbs. The mount includes the same drive modes as the Star Adventurer, with some innovative additional options that allow you to program multi-panel panoramas. It can also connect to your Canon or Nikon DSLR to trigger exposures with an appropriate cable. The Star Adventurer Mini can operate for up to 72 hours on an internal rechargeable battery or be powered through a mini-USB port. Additionally, it can be controlled via a Wi-Fi connection and free smartphone app. The base model includes a polar scope, illuminator, and a ball head, and it accepts all accessories for the original Star Adventurer.

Vixen Polarie Star Tracker

vixenoptics.com • Starting at $399

The sleek Polarie Star Tracker is a compact, rectangular drive that attaches directly to your tripod with a ¼-20 threaded socket (*S&T*: March 2012, p. 58). Weighing just 1½ lbs., it can handle cameras of up to 3½ lbs. The base model is aligned using a peep sight to point toward Polaris, which is accurate enough for exposures up to a couple of minutes with a wide-angle lens. A built-in inclinometer (tiltmeter) helps you accurately set the altitude adjustment. It can be operated in both Hemispheres and offers sidereal, 0.5× sidereal, lunar, and solar drive speeds. The unit is powered using 2 AA batteries that last about 4 hours; it and can also be powered via a mini-USB port.

Additional options for the Polarie include an unilluminated polar-alignment scope, ball head, time-lapse adapter, and a Polar Fine Adjustment Unit that's very useful for exact altitude and azimuth adjustments. Vixen also offers a Polar Meter with a built-in bubble level and altitude scale for daytime alignment (as when shooting solar eclipses).

Fornax Mounts LighTrack II

fornaxmounts.com • Starting at about $458

This mount appears similar to the AstroTrac seen below, but it's driven using a flat-wheel friction drive with a claimed peak-to-peak drive error of 2 arcseconds over an 8-minute period. Like the AstroTrac, the drive needs to be reset about every 2 hours. The LighTrack II weighs 2.9 lbs. and can carry 13.2 lbs. It will operate in both the Northern and Southern Hemispheres at sidereal, 0.5× sidereal, lunar, and solar rates. It also has an autoguider input for right ascension corrections. The LighTrack II is powered via a 12V DC cigarette-lighter cable. Additional accessories include a Sky-Watcher HM5 polar scope and adapter thread and the FMW-200 adjustable wedge.

AstroTrac TT320X-AG

astrotrac.com • Starting at $619

The AstroTrac is a futuristic-looking drive that doesn't use a traditional gear and worm drive. Instead, it utilizes a "worm rod" that is actually a section of screw with fine threads in a tangent arm that will track for 2 hours before the screw needs to be reset. The unit weighs 2.2 lbs. and can carry a hefty payload of up to 33 lbs. It operates in both the Northern and Southern Hemispheres with sidereal, lunar, and solar rates electronically controlled for accuracy.

AstroTrac claims an unguided peak-to-peak tracking error of about 5 arcseconds over a 5-minute period. The TT320X-AG also has an ST-4-compatible autoguider port for autoguiding in right ascension.

While the drive comes with a DC power cord, an 8-AA battery holder is an additional option, as is an illuminated polar-alignment scope, a ball head, and various accessories to make the drive into a complete equatorial mount capable of bearing small telescopes with ease.

• Follow Contributing Editor **JERRY LODRIGUSS** as he discusses astrophotography techniques in a monthly blog at **skyandtelescope.com**.

Brent's Beauties

Not everything beautiful about astronomy is up in the sky.

I THINK WE WOULD all agree that the things we look at through our telescopes are generally beautiful. The Moon, planets, star clusters, nebulae, galaxies — all provide a sense of aesthetic pleasure along with their intellectual attraction. The telescopes themselves, though, are most often utilitarian tubes, or even just open frameworks reminiscent of scaffolding around an unfinished building. They might be outstanding examples of their kind, but inherently beautiful? Naaah.

This holds true save for a special class of scopes that are themselves works of art. Every now and then you'll see a telescope that rivals the night sky itself for its sheer eye-stopping beauty. Brent Burton has built such an instrument. Made of several different species of exotic hardwoods, with an inlaid dragon swirling up the mount, this scope is a panacea for cloudy days. Who cares what's in the sky when this gorgeous creation is set up right there in front of you, begging to be admired?

And as if the scope weren't enough, Brent has built an accessory tray to match it. Together they rival Saturn as the main attraction at a star party.

What made Brent decide to build such a vision? In his own words: "I love woodworking and I love astronomy. Seemed like a match made in heaven."

The scope took about a month to build, working on it every day. The tray took about as long, mostly in carving the accessory tray's hand out of ironwood. He used the project to keep himself busy when his family was abroad to visit his in-laws, and their absence helped him avoid his wife's annoyance at the mess he was making. Brent reports that "Half the fun was actually finding all the right exotic woods used in the construction of the scope and learning how to best work with the wood with the limited tools I had in my one-car garage."

▲ The OTA and mount are made with several exotic hardwoods, including African bubinga, bloodwood, and various exotic burlwoods.

◀ Brent Burton with his attractive telescope and accessory tray.

The scope uses an eclectic mix of spalted curly maple, walnut, western pine, beefwood, curly Australian eucalyptus, African bubinga, bloodwood, and various exotic burlwoods. The tray incorporates Samoan ifilele, ironwood, curly maple, African bubinga, and bloodwood.

The inlaid dragon is made of African bubinga and Amboyna burlwood. To make it, Brent first drew out a pattern, then cut the inlay on a scroll saw, traced the shape on the wood to be inlaid and routed that out with a Dremel tool. Once he got it to fit well, he glued it in and sanded flat the inlay. Any gaps he filled with wood glue mixed with sanding dust from the inlay wood.

That's the only pattern used on either the scope or the tray. Brent says, "A lot of people ask where I got plans or if I made plans for it before I started. I've never made plans or ever put much onto paper before I get started on my projects. I just think of it in my head, start building, and make adjustments as I go to make it work. I actually see them as mental exercises to get my creative juices going."

The optics came from a 100-mm f/4 Orion SkyScanner. Brent took the primary mirror, mirror cell, and spider assembly from the old scope and integrated them into the wood OTA. He also reused the Teflon bearings and the altitude bearing.

The focuser started from a solid block of claro walnut hollowed out to accommodate the metal focuser tube, bearings, and drive shaft of a standard Crayford. The end plate is of African bubinga. Brent reports that "It all works really well and is as smooth as any other Crayford I've used."

Brent admits that this scope is more of a showpiece than an observing scope, but it does work as well or better than

ALL PHOTOGRAPHS PROVIDED BY BRENT BURTON

▲ The accessory tray is held by a hand-carved ironwood hand.

the original SkyScanner he got the optics from. And it turns heads at every star party he takes it to. He reports: "People's reactions are mostly of amazement and admiration. Sometimes it can be rather embarrassing. It sort of makes me feel like a celebrity at times when people look at it, leave, and then bring someone else over to see it. I do love to see the reactions and smiles it brings to people that come to look at it, though."

Brent entered the scope into the Washington State Fair and won Grand Champion for woodworking with it. That's no surprise. It certainly wins my grand prize, too, for its sheer fun and immense creativity.

■ Contributing Editor **JERRY OLTION** has built a couple of nice-looking scopes, but none as beautiful as this.

SHARE YOUR INNOVATION
Do you have a telescope or ATM observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at j.oltion@sff.net.

◁ GREEN-HEADED COMET

Gerald Rhemann

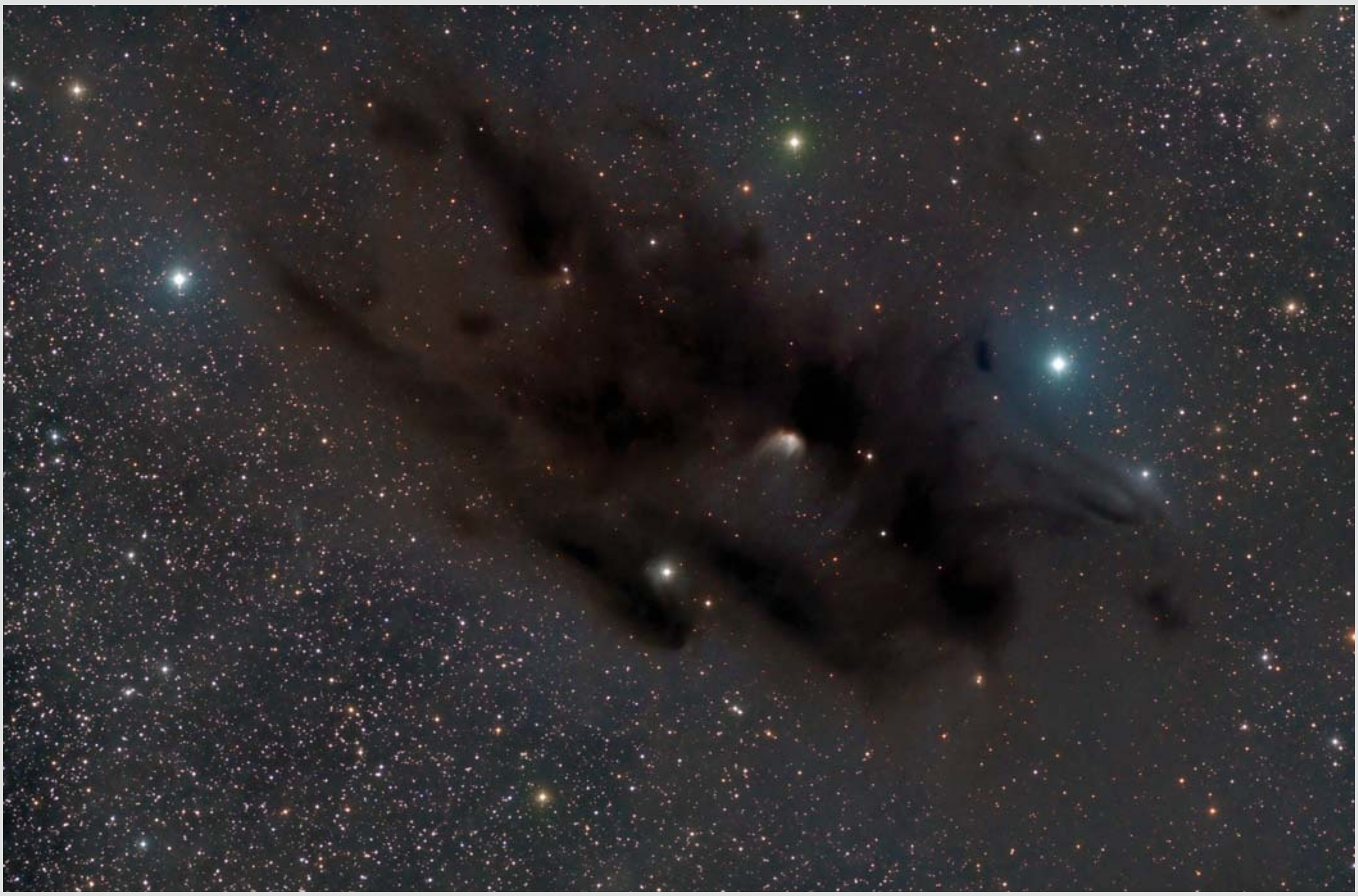
Although Comet 45P/Honda–Mrkos–Pajdušáková came closest to Earth in mid-February, it was just 3 days from perihelion when captured here on December 28, 2016. Its green head arises from diatomic carbon in the coma. **DETAILS:** *Astrosysteme Austria ASA 12-inch N astrograph and FLI MicroLine ML16200 CCD camera with LRGB filters. Total exposure: 30 minutes.*

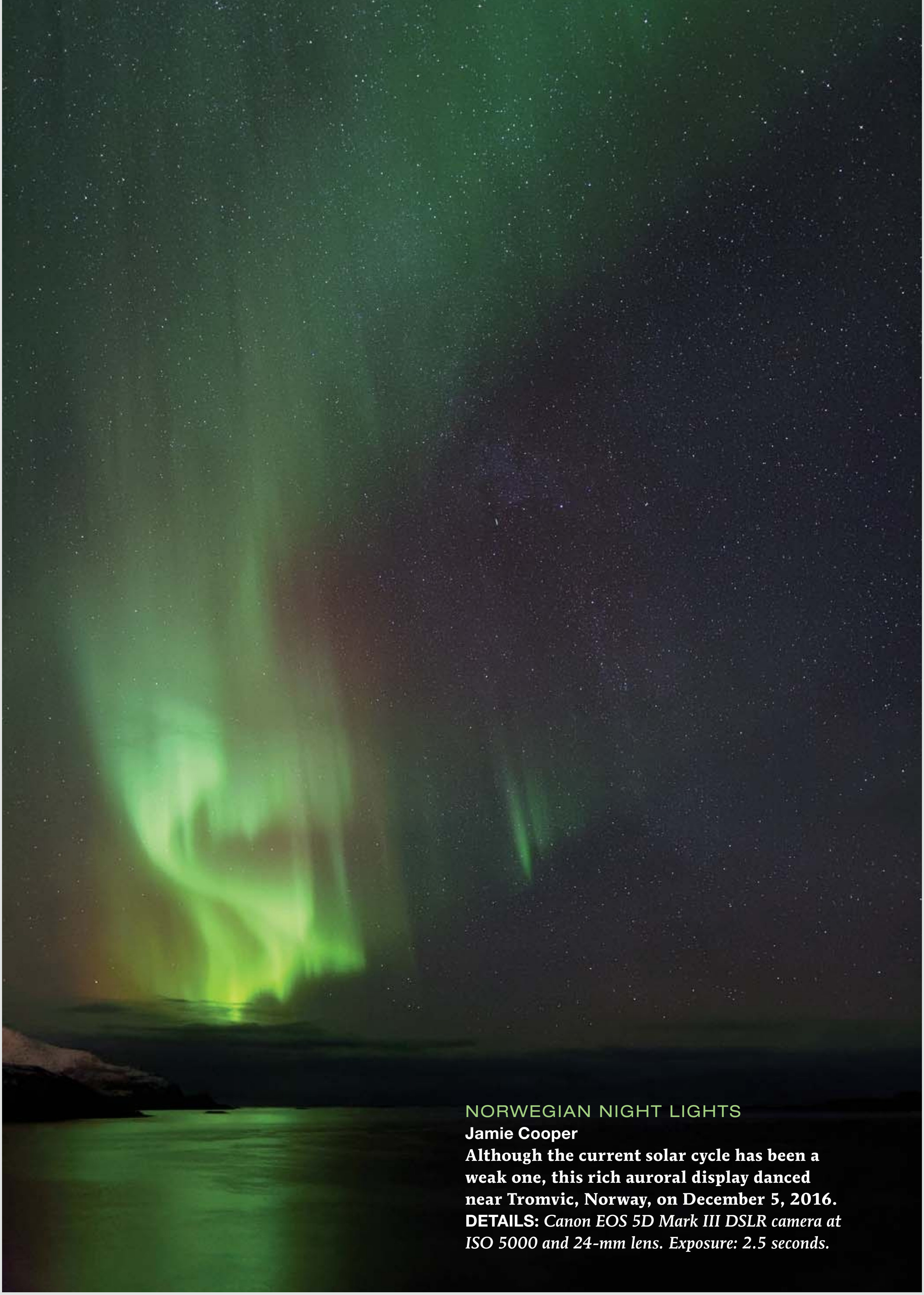
▽ TINY FLAME AMID CELESTIAL SMOKE

Gordon Wright

Barnard 22 is a large, mottled dark nebula in northern Taurus that hosts a small, glowing patch, the Little Flame Nebula (IC 2087), near its center. East is toward the top. **DETAILS:** *RGB frames: Vixen VSD100 astrograph refractor and Moravian G2-8300 CCD camera; Luminance frames: TEC 140 apochromatic refractor and Moravian 11000 CCD camera. Total exposure: 13 hours.*

Gallery showcases the finest astronomical images submitted to us by our readers. Send your best shots to gallery@skyandtelescope.com. For submission tips, see skyandtelescope.com/aboutsky/guidelines.





NORWEGIAN NIGHT LIGHTS
Jamie Cooper
Although the current solar cycle has been a weak one, this rich auroral display danced near Tromvic, Norway, on December 5, 2016.
DETAILS: *Canon EOS 5D Mark III DSLR camera at ISO 5000 and 24-mm lens. Exposure: 2.5 seconds.*

△THE WOLF'S CAVE

Craig & Tammy Temple

Van den Bergh 152, a blue-tinged nebula in Cepheus, sits at one end of a long, dark streamer designated Barnard 175. This pairing is known as the Wolf's Cave.

DETAILS: *Stellarvue SVR102T apochromatic refractor and QSI 683wsg-8 CCD camera with Astrodon E-Series Gen II LRGB filters. Total exposure: 3.8 hours.*

▷A SPIRAL'S ARMS AKIMBO

Ian Gorenstein

Astronomers aren't certain, but the dusty, star-filled arms of spiral galaxy NGC 2146 might have become bent and contorted after a close encounter with another galaxy.

DETAILS: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope, Atik 460EX monochrome CCD camera, and LRGB filters. Total exposure: 4.2 hours.*

• For more astrophotos, visit skyandtelescope.com/gallery.

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Event Calendar

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Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months. For a more complete listing, visit https://is.gd/star_parties.

April
GLOBAL ASTRONOMY MONTH
Everywhere!
astronomerswithoutborders.org/global-astronomy-month-2017.html

April 8–9
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

April 22-28
INTERNATIONAL DARK SKY WEEK
Everywhere!
darksky.org/dark-sky-week-2017

April 26-29
MID-SOUTH STAR GAZE AND ASTRONOMY CONFERENCE
French Camp, MS
rainwaterobservatory.org/rainwater

April 27-30
SOUTHERN STAR
Little Switzerland, NC
charlotteastronomers.org/southernstar

April 27-30
STARGAZE STAR PARTY
Laurel, DE
delmarvastargazers.org/event/2017-stargaze-star-party

April 29 (also September 30)
ASTRONOMY DAY
Everywhere!
astroleague.org/al/astroday/astroday.html

May 19-21
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org/index.php/msp9

May 21–28
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 25–29
RTMC ASTRONOMY EXPO
Big Bear City, CA
rtmcastronomyexpo.org

June 17–24
GRAND CANYON STAR PARTY
Grand Canyon, AZ
nps.gov/grca/planyourvisit/grand-canyon-star-party.htm

June 21–25
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 21–25
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

June 22–25
CHERRY SPRINGS STAR PARTY
Coudersport, PA
astrohbg.org/CSSP

Arecibo Under the Gun

The future of this iconic radio telescope hangs in the balance.

GETTY IMAGES / UNIVERSALIMAGESGROUP

WELL KNOWN TO the general public through the Hollywood films *Contact* and *GoldenEye*, the 53-year-old radio telescope at Arecibo, Puerto Rico, continues to do cutting-edge science that no other facility can match.

Covering the 1-10 GHz range of the radio spectrum, Arecibo observes galaxies, quasars, pulsars, and interstellar gas. It also boasts a 1-megawatt radar transmitter that helps astronomers establish the orbits of Earth-threatening asteroids. This NASA-funded program serves as the first line of planetary defense. Although China's FAST dish is physically larger, it covers a limited frequency range of 1-1.8 GHz and has no radar capability (*S&T:* Feb. 2017, p. 26).

National Science Foundation funding for Arecibo will drop in the next few years, and the observatory is threatened with closure. The current cooperative agreement with NSF runs only through March 2018, even as the telescope is proving that it is far from obsolete.

Paramount is Arecibo's recent discovery of the first repeating *fast radio burst*. This finding — all other FRBs have been one-time occurrences — demonstrates that the source survives the energetic events that cause the bursts and rules out catastrophic explosions as an explanation. In concert with other telescopes, Arecibo located the source of the signal in a dwarf galaxy 3 billion light-years distant (*S&T:* Apr. 2017, p. 10).

> It is clear that Arecibo Observatory has many more discoveries to make.

Other recent astronomical findings from Arecibo are also impressive. Observations are obtained regularly in conjunction with RadioAstron, a 10-meter radio telescope the Russian space agency launched into orbit in 2011, for example. One set of these joint observations has shown that the temperature of quasar 3C 273 is so high that it forces astronomers to reconsider the mechanism invoked decades ago to account for its strong radio signals.

In another example, when ground-based and Hipparcos measurements of the distance to the Pleiades disagreed, astronomers conducted a very long baseline interferometry campaign to resolve the controversy. These observations used Arecibo's large collecting area to chart the motions of ultra-weak radio stars and derive a new, independent distance. Results support the ground-based measurements.

Much seminal work remains ongoing. Extensive monitoring of dozens of millisecond pulsars, for instance, relies heavily on the Arecibo dish's large size. The North American Nanohertz Observatory for Gravitational Waves, or NANOGrav, measures the arrival time of these faraway objects' radio pulses. In doing so, it looks for evidence of gravitational waves that supermassive black holes in distant galaxies have emitted, detectable as rippling spacetime between us and the pulsar. The NANOGrav consortium is optimistic that it may be on the verge of its first detection.

Arecibo pulsar observations include a triple system in which timing measurements will lead to new tests of general relativity. Add the puzzling discovery of pulsars that are invisible most of the time, and it is clear that Arecibo has many more discoveries to make.

NSF plans to decide on the future of this iconic radio telescope in June. We believe that a decision to close Arecibo would have detrimental effects on the local economy, the observatory staff, and the user community. But the biggest loser of all would be science.

■ **JOAN SCHMELZ** is the Director of USRA Operations at Arecibo Observatory. **GERRIT VERSCHUUR** is an Arecibo Observatory Astronomer Emeritus.