Arecibo Endures
STEVE MURRAY
After surviving Hurricane Maria, the observatory is weathering different kind of storm.

Into the Abyss
MIKA MCKINNON
We’ll soon see what a supermassive black hole really looks like. PLUS: “Inside the Event Horizon Telescope,” Jeff Mangum

The Interstellar Visitor
IAN O’NEILL
‘Oumuamua came from another star system to deliver a message.

Astronomy in the News
IAN O’NEILL
A rundown of some of the most exciting developments in space and time.
Hello, Mercury

I think it’s fair to say that we live in a “Golden Age” for astronomy. While I’d normally roll my eyes at these kinds of statements—after all, wouldn’t science communicators in every age say this about their current state of astronomical affairs?—as this is my first editorial for Mercury, I’m standing by it.

The last couple of years have seen some incredible advances in astronomy, not least the discovery of gravitational waves and the advent of “multimessenger astronomy” where scientists can use these space-time ripples in conjunction with conventional telescopes to learn revolutionary things about a previously invisible realm of the cosmos (see column, page 16).

Observatories around the world and in space are winning technological challenges to become our most powerful eyes to the universe. And we’re now on the verge of seeing something truly spectacular: an international team of astronomers are turning our planet into a virtual telescope so they can, for the first time, resolve a picture of the supermassive black hole in the center of our galaxy (see feature, page 33). It’s for these points that you will notice a rather black hole-heavy theme in this first issue of 2018, but I think it’s for good reason.

So, it’s on this note that I want to thank the Astronomical Society of the Pacific for entrusting me as Mercury editor, especially Executive Director Linda Shore and the entire ASP staff and board for making me feel so welcome. I also want to thank outgoing editor Paul Deans and designer Leslie Proudflit for nurturing such a wonderful publication this past decade. I will endeavor to continue their sterling work. Inevitably there will be tweaks as we evolve with the changing digital publishing environment, but Mercury will always be the ASP’s destination for exclusive news and mind-blowing views of our ever expanding universe. I’m excited for this new adventure and looking forward to sharing this journey with you all.

Ian O’Neill
Editor, Mercury
A New Era for Mercury

As we welcome a new editor for the magazine, a look back at the publication's 46 year history.

The Astronomical Society of the Pacific (ASP) launched Mercury in 1972, a year that was particularly momentous for space exploration. NASA's Mariner 9 sent images of the Martian surface back to Earth, the Soviet unmanned spaceship Luna 20 landed on the Moon, Pioneer 10 was launched from Cape Kennedy in Florida and was slated to become first spacecraft to leave the solar system, President Nixon ordered the development of the Space Shuttle program, and with the launch of Apollo 17, NASA successfully sent astronauts to the Moon’s surface and returned them safely back to Earth for the last time in the 20th century.

Mercury was established during an era when there were few ways for the public to get information about the latest news or current discoveries in astronomy. The Internet was decades away and there were no cable channels dedicated to science coverage. Astronomy enthusiasts relied on newspapers and magazines for information, in particular veteran publications, like Sky & Telescope, which launched in 1941. As James White (Mercury editor, 2004-2007) described it, Mercury was conceived as a publication to bring the joy, awe, and wonder of astronomy discovery to its readers, “reaching from mountain top and orbiting observatories into living rooms and classrooms.”

For most of its history, ASP published just one journal, the Proceedings of the Astronomical Society of the Pacific (PASP). The first issue of PASP published in 1889 was modest; just a circular describing the inaugural meeting of the new society, its vision, and its bylaws. Within a few years, PASP became an important vehicle for disseminating research techniques, findings, and theories to the growing community of professional astronomers working in universities, observatories, and laboratories around the world. By the 1970s, the ASP had become committed to increasing public science
literacy through astronomy and as a result, its growing membership included K-12 science teachers, college instructors, professionals and amateurs involved in public outreach, and enthusiasts interested in increasing their own understanding of astronomy. This new community turned to the ASP for resources and support to help them increase their own understanding of astronomy and capacity to share their knowledge with others.

From its inception, Mercury took a unique approach to covering astronomy. Authors took readers on journeys to the great observatories of the world and described the wonders of the cosmos these instruments discovered, science educators provided the magazine with innovative hands-on activities that astronomy teachers could bring to their students, and the magazine included articles about the history of astronomy, astronomy in art and literature, multicultural astronomy, and space exploration. Each editor of Mercury has brought their unique perspective to shaping the magazine—most recently Paul Deans (2008-2017) who announced his retirement last year. Among his numerous contributions, Paul brought Mercury into the digital age. Under his leadership, Mercury successfully transitioned from a beloved glossy magazine delivered to ASP members at great expense to the ASP to a digital publication that retained all its quality and reputation for excellence. Working alongside ASP’s talented designer, Leslie Proudfit, Mercury was both visually awe-inspiring and intellectually rich.

This issue is the first to be published by Mercury’s new editor, Ian O’Neill, and I am deeply honored and pleased to introduce him to you. Ian brings an enormous amount of experience to Mercury. He is an astrophysicist, science communicator, science writer and editor and has a great deal of expertise in on-line publishing and social media marketing. For over a decade, Ian worked as senior producer, science writer and editor for Discovery Channel’s Discovery News and Seeker.com, space blogger for Universe Today and collaborated with many online and TV channels including Discovery, Al Jazeera and Science Channel. I have every confidence he will lead Mercury to an even more successful future.

So what’s next for Mercury magazine? I leave this in Ian’s very capable hands. Certainly you can expect to continue to enjoy thought provoking articles and awesome images that inspire you, spark your imagination, transform your thinking, and increase your appreciation for the celestial wonders of the universe. I will also work with Ian to expand Mercury’s readership and use social media to bring the magazine’s content to people around the world. I can’t wait to see what Mercury becomes! Please join me in welcoming Ian O’Neill to the ASP family and enjoy his first issue as editor.

LINDA SHORE is the Executive Director of the Astronomical Society of the Pacific.
A Resounding Success: The ASP’s 129th Annual Meeting

“Beyond the Eclipse: Engaging Diverse and Underserved Communities in Astronomy and STEM”

A Personal Perspective
by Theresa Summer

The ASP’s 129th Annual Meeting (held Dec. 5-8, 2017, in St. Louis, MO), was not like any other scientific or educational conference I have ever attended. With its focus on diversity and how we share astronomy, it was a chance to pause, look honestly at where we are, what we are doing well, and how we can be better. I’d like to relate some of my experiences and takeaways with you from the general sessions and two workshops.

The opening session was Luis Chavarría Garrido: “Chile, the Eyes of the World.” With Chile poised to have the most and the largest research based telescopes in the world, listening to this insider’s view of the nation’s developing astronomy outreach program was a real treat. How can the influx of astronomers impact and benefit the existing community? And since they are having two upcoming solar eclipses in 2019 and 2020, our eclipse experience from coordinating the 2017 eclipse is being put to use as a template for their ongoing preparations.

I attended Erika Labbe’s workshop, “Exploring Accessible Astronomy in Chile.” Having presented astronomy to blind and visually impaired people since April of 2016 with the University Diego Portales, Erika started the workshop with the participants donning blindfolds. Being both temporarily blind and led around the room exploring her tactile solar system was a new experience. She then shared some best practices with us.

The afternoon panel was Annette Lee, Robert Winglee, Jennifer Godfrey: “Engaging Native American and Other Underserved Communities in Astronomy and the 2017 Eclipse.” Annette Lee is the Director of Native Skywatchers and did a terrific presentation on valuing the importance of both indigenous knowledge and western science knowledge as a dual learning system. So much of our...
work in the scientific community is interdisciplinary but doesn't fully honor the work of other cultures or examine the effects of colonialism, so this was a refreshing and valuable attitude. Robert Winglee spoke about developing relationships among rural Native Americans in the Pacific Northwest. He brought 8 teams of Native American students to launch high altitude balloons with artifacts they had chosen as special to their community.

In his words: “With little or no training these students were able successfully take unique picture of Native American artifacts at the edge of space with the shadow of the Moon on the Earth. For these students the phrase ‘I can’t possibly do not that’ is no longer relevant.”

Jennifer Godfrey’s talk about the Oregon Park System’s outreach to underserved groups made me want to attend her workshop. Entitled “Building a Framework for Inclusive Astronomical Education,” she shared the Oregon Parks and Recreation Department’s “Engage, Relate, Adapt” methodology for encouraging use and employment in Oregon State Parks in such a way that both reflect state populations. We did an activity that explored our commonalities and differences in our small groups. She gave us a handout, which had a scale from 1 to 6 with one being exclusionary organizations and 6 being fully inclusive which you can explore here (PDF).

All of us discussed where we thought our home institutions were and what steps we could take to move closer to being organizations that welcomed everyone.

The next day opened with a panel discussion on “Engaging Girls in Astronomy and STEM” with Lynn Cominsky, Jessica Henricks, and ASP’s own director, Linda Shore. The panel discussed not only the ways girls can be excluded from STEM fields, but some of the ways astronomers can actively welcome girls. Jessica Hendricks and Lynn
Cominsky gave examples of terrific programs that are creating more welcoming environments for girls to do real science through “Girls STEAM Ahead With NASA,” and “Reaching for the Stars: NASA Science for Girl Scouts.”

The final plenary was exceptional. Hakeem Oluseyi gave a talk “Bringing Astronomy To The World – A Personal Journey.” This was not a PowerPoint snooze-fest, but a gripping personal narrative of overcoming adversity. He simply spoke to the attendees. His life story would make an excellent movie and everyone in the audience was visibly moved.

After another round of workshops, we were treated to a special screening of “Black Suns: An Astrophysics Adventure.” Jarita Holbrook, the film’s creator, skyped in for a Q&A. With all of the work and reflection that had occurred during the meeting, the audience was ready to listen. Holbrook pulled no punches and her words were a call to action. Astronomy has been exclusionary for too long—it is time for all of us to even the playing field and welcome every person to our science family.

In a time of division and despair in our country and in science, there was a lot of hope and excitement palpable at this meeting. There were a lot of important conversations occurring that have needed to happen for a while. Now that the meeting is over, let’s make 2018 a new year, and keep taking actions to make our astronomy community more inclusive!

THERESA SUMMER loves being an Astronomy Educator for the Astronomical Society of the Pacific. She has worked in science education since 1998, mainly in planetariums, but also in high school classrooms, teacher trainings and running programs. Her secret mission in life is to help people to understand that science is not just for crazed geniuses in lab coats, but is for everyone, and is an important part of being an active citizen in today’s world.
Sunspots: A Surprisingly Controversial History

Before we had high-resolution observations of the Sun, explanations for sunspots ranged from the ridiculous to the sublime. In a roster of great and important scientific papers, one cannot include Sir William Herschel’s work on sunspots. The British astronomer was widely ridiculed for his attempt in 1801 to discover a correlation between the number of sunspots and the price of wheat in England, but it was his 1795 claim that sunspots are depressions on the surface of the Sun that concerns us here.

The famed Professor of Astronomy at the University of Glasgow, Patrick Wilson, sent a letter to Herschel asking why he made this claim since Patrick’s esteemed father, Alexander, had already made that discovery a decade earlier—a phenomenon that became known as the “Wilson effect.”

Herschel could hardly have been unaware of it, as Alexander had been awarded a gold medal in 1772 by the Royal Danish Academy of Sciences for an essay on the nature of sunspots. In his 1795 paper, Herschel equivocates, saying sunspots might be either openings in the solar atmosphere exposing a solid surface (which was inhabited by intelligent life), or mountains more than 300 miles high, even suggesting “there can be no doubt but that a mountain much higher would stand very firmly.” The mountain theory of sunspots had also been published earlier, by French astronomer Jérôme Lalande in 1779, which prompted Alexander to write a rejoinder in 1783, categorically stating “the spots are cavities or depressions in that imme-
diately resplendent substance which invests the body of the Sun to a certain depth.”

On February 21, 1796, Herschel wrote to Patrick Wilson with a mea culpa in which he “avowedly disclaimed every merit as a first discoverer” of the sunspot depression idea.

Herschel did not want to wade into this field of land mines. It would have forced him to mention, he wrote to Patrick, “the answer that has been made by Mr. De la Lande. I must in the next place have turned to a tedious treatise on the solar spots written but lately by Mr. Schroeter, which must infallibly have brought on a controversy.”
The book Herschel refers to, “Observations of the Solar Faculae and Sunspots,” was published by Schröter in 1789. Richard Baum and William Sheehan, in their book on the search for a planet closer to the Sun than Mercury, identify the chaff in the book. Schröter was “convinced sunspots had independent motion, and that a few moved with unusual rapidity.” This led several German astronomers to look for such rapid spots, and it resulted in something that psychologists later had a field day in analyzing as the “power of suggestion.”

Even though such spots (or intra-Mercurial planets) did not exist, observations were soberly reported by German astronomers for decades afterwards. Heinrich Schwabe, after studying sunspots for 12 years, decided in 1838 such rapidly moving spots were not real, but his careful records led him to deduce the periodicity of sunspots. This great discovery was duly recognized in 1858 when he was awarded the Gold Medal of the Royal Astronomical Society, so that wild goose chase ending up bagging a ‘golden’ goose for Schwabe!

As for the Wilson effect, it was widely accepted in the 19th century. The truism that a photograph does not lie was put to the test in 1861 when the first stereographic pictures of the Sun were touted as proof that sunspots really were depressions! It was not until 1908 that George Elery Hale (whose name is attached to the famous 200-inch telescope at Palomar Observatory in California) discovered the so-called depressions are due to strong magnetic fields that inhibit the convection of hot gas to the solar photosphere. For further reading about the Wilsons and the sunspots I recommend a great book by David Clarke, “Reflections on the Astronomy of Glasgow.”

CLIFFORD J. CUNNINGHAM is editor of a book The Scientific Legacy of William Herschel published by Springer, including contributions by six world experts with a foreword by Dr. Michael Hoskin of Cambridge University.
Tiny Galaxies Predict the Milky Way’s Doom

Ancient ultra-faint dwarf galaxies are being studied so astronomers can better understand when our galaxy will stop birthing new stars.

Regardless of your profession, you probably agree that galaxies are downright gorgeous. As a physics graduate student at the University of California, Irvine, I research galaxy evolution and I’m lucky to work with galaxies every day. I’m currently finishing up my first project investigating the role a specific set of galaxies plays in the big cosmological picture to better figure out the fate of our own galaxy, the Milky Way. This set is known as ultra-faint dwarf galaxies, the smallest and most elusive of galaxies—like the one pictured here, Horologium I. We call this little friend of the Milky Way a “satellite galaxy.”

Smaller galaxies are characterized as satellites when they are gravitationally bound to another, larger galaxy. This is the same idea as the Moon being gravitationally bound to the Earth, but instead of two small rocky bodies, we’re talking about entire galaxies dancing around one another!

So, out of the billions of galaxies seen, we call less than 100 ultra-faint dwarf galaxies. Why? Well, their name says it all—they’re ultra-hard to see. They are vastly different from our own galaxy; their mass compared to ours is the same magnitude difference as the Earth compared to a large marble, the Milky Way has spiral arms (whereas ultra-faints are irregularly shaped) and the Milky Way is continuing to birth new stars (while these dwarf galaxies generally have only ancient stars and are unable to make new ones).

Despite their obvious differences, there’s a lot we can learn about the Milky Way’s fate from these little galactic neighbors. The theory of galaxy evolution tells us how galaxies live their lives from their
formation to what happens when they stop birthing new stars. We are currently trying to understand the mechanisms behind galactic evolution and, once we figure it out, this theory will help us understand when the Milky Way itself might stop creating new stars, like its ancient ultra-faint cousins did a long time ago.

Now, the question is: How do we study an entire population of hard-to-find galaxies when we only know of a handful? Astronomers have come up with some creative solutions for doing just that and one strategy is to compare the population of known ultra-faint galaxies with predictions from computer simulations of the universe. And this is exactly the type of research I’m currently doing for my PhD!

Let me put on my “Indiana Jones” hat for a moment and discuss space archeology. We have reason to believe these tiny galaxies are essentially cosmic artifacts that may have formed only 400 million years after the Big Bang. We currently measure the age of our universe to be 13.8 billion years old; so, 400 million years compared to the age of the universe is like 42 minutes compared to 24 hours. In this tiny blip of time after the Big Bang, the universe entered what’s called the Reionization Age. This is when the very first stars and galaxies began to form. We think ultra-faint dwarfs may be the ancient fossils of the first galaxies to emerge from the Reionization Age.

With no time machine and not knowing the ultra-faint dwarf galaxy family tree, we cannot directly determine the fossil-hood of these tiny neighbors, however. But what can be done is to eliminate other possible scenarios to hone-in on their fossil status.

To understand the history of these apparently ancient galaxies, another question we must ask ourselves is: What happens when a small galaxy becomes a satellite of a larger galaxy?

When one large galaxy has a bunch of satellites gravitationally bound to it, they are known as a cluster. Sometimes gravitational interactions between the large galaxies (like our Milky Way) and the smaller ones (say, the ultra-faint dwarf galaxies) keep at a distance from one another. Sometimes the smaller galaxies get flung out of the larger one’s gravitational pull—or they may just seem to get bored and drift away... Either way, this cosmic hang-out can end by the two separating. On the other hand, the party can end in a much more, um, intimate way: the two galaxies can merge into one.

There are, however, subtler interactions that occur between galaxies in clusters, many of which can have dramatic consequences and

Star-forming regions, like the Carina Nebula shown here in this Hubble Space Telescope observation, require vast quantities of molecular hydrogen to birth new stars [NASA/ESA/STScI]
can make satellite galaxies appear much older than they are. One of the most common is that the smaller galaxy may lose its ability to make new stars. New stars need a supply of interstellar gas to form—these space clouds are basically fuel for galaxies to create their own stellar nurseries. When a satellite galaxy falls into the gravitational pull of a larger galaxy, its fuel supply can be cut off. In this case, it can keep forming stars until it runs out of its fuel reserves, like a car running out of gas on a long stretch of desert highway.

We now understand that some of these larger galaxies have a shell of hot gas surrounding them and, should an unfortunate satellite galaxy drift through this shell, the physical interactions between the satellite's fuel reserve and the hot gas strips away the reserves. So, not only is the tiny galaxy stuck in the middle of the desert with no gas station around, but now there's a hole in the gas tank, meaning star formation will come to a rapid halt.

These are the “star formation ending” scenarios that should be eliminated as possibilities to provide evidence for the ultra-faint dwarf galaxies being true cosmic fossils. Now, this is where comparing real observations of these tiny galaxies to simulations of the universe comes into play.

My very first research project as a physics graduate student is comparing the ages of the ultra-faint galaxy population from analyzed observations to the average length of time the smallest galaxies in simulated universe have been satellites of Milky Way-like host galaxies. Since we can see that these tiny galaxies are no longer forming stars, the results of my work will allow us to be pretty sure about which mechanisms didn’t shut-off star formation in ultra-faint dwarf galaxies, hopefully taking us a small step closer to a complete theory of galactic evolution and, thus, a solid prediction of our own galaxy’s fate.

KATY RODRIGUEZ WIMBERLY is an NSF Graduate Research Fellow in the Astronomy & Physics Department at University of California, Irvine, and the ASP’s Jr. Board Fellow. She studies galaxy evolution using both optical telescopes and dark matter-only cosmological simulations.

This 360 degree panorama of our galaxy includes some of the many of the Milky Way’s satellite galaxies [ESO/S. Brunier]
What (Spectral) Line Is That Anyway?

On the hunt for the origins of a mysterious broad absorption feature at 6565 Angstroms in the galactic halo.

Spectroscopy is to astrophysics what the “Rosetta Stone” is to Egyptology. Spectral lines are used to determine chemical compositions, radial velocities, temperatures, and densities. These lines also reveal rotation rates of stars and the presence of magnetic fields. Some “mysterious” spectral lines have also been detected, resulting in profound discoveries. Recall that helium was discovered in the solar spectrum before being found on Earth.

Other spectral lines are produced by unusual processes, such the long unidentified emission features at the wavelengths of 6825 and 7082 Angstroms in symbiotic stars, which were ultimately shown to result when ultraviolet photons of highly ionized oxygen atoms produced near the hot star in the binary are Raman scattered by neutral hydrogen near the cooler star.

The latest mystery line was discovered in a composite spectrum produced by stacking the spectra over 700,000 galaxies from the Sloan Digital Sky Survey (SDSS): this composite exhibits an unusually broad absorption feature at 6565 Angstroms in halo of the Milky Way. The observed absorption is broad and appears to be isotropic and present along nearly all lines of sight in the galaxy. This line is very close to the wavelength of the hydrogen alpha (H-α) that is produced when an electron transitions from the n=2 state to the n=3 state. Since hydrogen is by far the most abundant element in the universe, this initial identification seemed to make sense.

The spectra used in this study cover large portions of the sky, depicted here as a map wrapping around the observer. The colors code for spectral emissions from diffuse hydrogen gas in the Milky Way’s halo [H. Zhang and D. Zaritsky]

The absorbing hydrogen gas must already be in the n=2 excited state, so there has to be some way of maintaining a large population of hydrogen atoms “pumped” to the n=2 excited state. Additionally, these atoms don’t remain excited for long, which means there will be emission observed from the excited states. Astrophysicists Shiv Sethi, Yuri Shchekinov and Biman Nath examined all the pos-
sible mechanisms that could populate the 2s and 2p excited states of hydrogen. Their study, published in the Astrophysical Journal Letters, calculated sky brightness is inconsistent with observations in the ultraviolet and the required column density—the number of H-α particles per square centimeter along a line of sight—in each case was unrealistically large. This therefore makes it very unlikely that H-α is the source of the observed 6565 Angstrom absorption feature.

Could these lines be produced by any other elements? Sethi and colleagues examined nitrogen, carbon and oxygen lines, since these three elements are the next most abundant after hydrogen and helium. It turns out that there are two spectral lines from singly-ionized nitrogen that lie close to 6565 Angstroms. However, the observed line strength requires an absorbing column length that is much larger than the size of the Milky Way’s halo!

What now? The interstellar medium contains a plethora of complex molecules. Most of these are carbon compounds: carbon chains, polycyclic aromatic hydrocarbons (PAHs), and hydrogenated carbons. Collectively, they are responsible for the diffuse interstellar bands (DIB)—spectral bands that are typically much wider than interstellar gas lines that are broadened by Doppler effects. DIB features are certainly more consistent with the 700 kilometer per second line-width observed for the 6565 Angstrom feature.

Currently, most observations of DIB are from lines of sight in the plane of the galaxy. These observations are contaminated with H-α absorption from nearby stars, making detection of any DIB near the 6565-region impossible. In other words, there is currently an observational bias against detecting DIB near H-α in the current database. However, observations of the Red Rectangle Nebula (pictured here) from regions that exclude the central star exhibit two broad features at 6552 and 6563 Angstroms.

Although Sethi, Shchekinov, and Nath did not determine the origin of the 6565 Angstrom feature observed in the Galactic Halo, they were able to eliminate H-α and other atomic and ionic species. It seems most likely that this feature arises from the DIB, possibly even being PAH. Laboratory observations of PAHs provide four possible PAH candidates with spectral bands near 6565 Angstroms: one of these is a cation of naphthalene (the key ingredient in mothballs!) and another is protonated pyrene (pyrenes are used in fluorescent dyes). Future observations of bright extragalactic sources could prove useful in the quest to identify the nature of this mysterious absorption feature.

JENNIFER BIRRIEL is Professor of Physics at Morehead State University in Morehead, Kentucky. She loves a good mystery. Her dissertation was an investigation of the origin of the unidentified optical emission features at 6825 and 7088 Angstroms in symbiotic binary stars.
Neutron Star Merger Forms a Cosmic Cocoon

A newly discovered—and highly mysterious—phenomenon comes courtesy of gravitational waves washing over our planet.

A great irony in science is how breakthroughs so often lead to more mysteries. Many had predicted that the direct detection of gravitational waves would open a new window to the universe. Well, that window has opened—three physicists, in fact, won the 2017 Nobel Prize in Physics for their “decisive contributions to the LIGO [Laser Interferometer Gravitational-wave Observatory] detector and the observation of gravitational waves.” But now that we have more windows, we’ve stumbled on more questions than answers.

The latest fun started in August 2017. NASA’s Fermi Gamma Ray Telescope saw a flash of gamma rays, too fleeting to localize. But moments later, two gravitational wave observatories—the twin LIGO detectors in the United States and the Virgo detector in Italy—felt passing waves. The gravitational wave signal, the fifth ever detected, indicated this was a neutron star merger. The four previous detections were generated by black holes colliding and merging.

As the first gravitational wave event to include data from Virgo, the European-based detector helped astronomers triangulate the event, dubbed GW170817, to better determine its location about 130 million light-years from Earth. Thanks to this tip, dozens of “traditional” observatories started to collect data old-school-astronomy style, via electromagnetic radiation. This was the first time any astronomical event had been detected with both gravitational waves and electromagnetic waves, beginning an exciting new era of “multi-messenger astronomy.”

The initial finding was a big one: Astronomers detected hundreds of Earth-masses-worth of heavy metals such as gold and platinum in the ejecta of the merger. This was the first direct evidence that about half of all elements heavier than iron are produced in neutron star collisions.
mergers via a nucleogenesis process called “rapid neutron capture,” or “r-process.” Supernovae can forge them, but neutron stars may be a primary source of these elements, coined in catastrophic collisions.

What was to come next was a routine confirmation. For the past two decades, astronomers have speculated that short gamma-ray bursts—the type lasting under two seconds and often just a few milliseconds—were caused by neutron star mergers. Being so fleeting, however, these mergers have not been studied in detail. But now we had one, and dozens of observatories on Earth and in space were watching. The ultraviolet, optical and near-infrared emissions could be explained by the radioactive decay of heavy elements (such as all that gold and platinum) that were ejected during the merger. But that initial flash of gamma rays detected by Fermi was about 10,000 times less bright than what’s typically seen in a short gamma-ray burst. Maybe, astronomers pondered, the jet of matter producing the gamma rays was simply off-axis in relation to Earth?

Clues might be in the X-ray data. Bright, but then slowly fading X-rays in the days and months after the merger would support the theory of a short gamma-ray burst in which an ultra-relativistic (nearly at light speed) jet of matter plows through the debris from the merger, creating these high energy photons. So, astronomers waited … and waited … until NASA’s Chandra X-ray Observatory data was processed months later.

“On December 7, the Chandra results came out and the X-ray emission had brightened,” said Gregg Hallinan, an assistant professor of astronomy at the California Institute of Technology (Caltech) in Pasadena. Hallinan and his colleagues developed a new theory after observing the merger in radio waves, which also had been brightening, not fading, in the aftermath of the merger. The X-ray observations confirmed it.

In the December 20 issue of Nature, Hallinan coauthored a paper (with first author Kunal Mooley at the University of Oxford) describing a scenario in which gamma rays may be smothered by a more slowly expanding cocoon of radio-emitting matter.

“The agreement between the radio and X-ray data suggests that the X-rays are originating from the same outflow that’s producing the radio waves,” Mooley said in a statement.

In any event, astronomers detected a neutron star merger for sure but not, for certain, a gamma-ray-producing jet, leading Hallinan to conclude that “we can’t say there’s a definite link between merging neutron star mergers and short gamma-ray bursts; the jury is still out.”

The good news is that LIGO and Virgo have demonstrated they can detect and localize neutron star mergers, so we patiently await the next neutron star collision so we can hopefully resolve this mystery soon. And, if it’s any consolation, at least we know where gold comes from. ✤

CHRISTOPHER WANJEK is a freelance writer based in Baltimore still looking for a pot of gold.
The Centrality of Phenomena

The quest for relevance and equity in science education.

Those of us who work in science education and outreach, including the staff at the Astronomical Society of the Pacific, do so out of a sense of hope and belief our efforts make a difference in the lives of learners of all ages. At times that hope takes a hit when we hear about the wide range of discredited ideas and misconceptions people hold.

With the amount of evidence available, one would think that the contentions for the Moon landings being a hoax, the Earth being flat, that a mysterious dark planet is set to collide with our planet, or a periodic alignment of planets is somehow a portent of doom, would have disappeared for good. Over the past several months, however, these have reappeared in a variety of news media, raising fears amongst those who are uncertain of who to trust, and consternation from educators and scientists who thought the last time they debunked these ideas was indeed, the last time.

Much discussion has taken place about how to address ideas and misconceptions such as these, some of it in past editions of this column. Experts and commentators acknowledge it is a difficult thing to change someone’s core beliefs, and the presentation of facts and evidence may only serve to further entrench the belief. It appears some sort of transformative experience is required for those who have held their ideas for a long period of time. For younger learners, ensuring they have access to an education which promotes collecting and reasoning about evidence, and the communication of evidence-based explanations of natural phenomena may serve to create a culture where ideas at odds with the evidence fail to find fertile minds in which to grow.
The current transformation of science education places an emphasis on learner investigations of compelling natural phenomena, rather than the traditional curriculum of teaching a series of topics. The establishment of an anchoring phenomenon leading to a driving question that guides a series of student investigations where they incrementally build an evidence-based model for the phenomenon in some ways is a more accurate portrayal of how science works, rather than the traditional sequence of the “scientific method.”

So, why the focus on phenomena rather than a set of core topics? In short, because it helps make science education more relevant and equitable for students. For most of human history, people have attempted to explain the natural phenomena they found themselves immersed in. It was relevant to them to discover something about the nature of shadows, and how different materials affected a beam of light. It was relevant to utilize the patterns they observed in the day and night skies to navigate, or to know when they should plant crops, or hunt, or get ready for a time when resources were scarce. For many people in our modern society, these past explorations and explanations are irrelevant, and perhaps even contrary to what they believe. The suggestion is if they can make a personal observation to share with everyone else it is more valid than those made in the past as a scientific explanation of the universe was under development. In other words, it is their personal experience of a phenomenon that is paramount and trustworthy.

As noted by STEM Teaching Tools: “The most powerful phenomena from an educational perspective are culturally or personally relevant or consequential to students” and “A good phenomenon builds on every day or family experiences: who students are, what they do, where they come from.”

In other words, students are more apt to engage productively with, and incorporate a scientific explanation for a phenomenon when they feel a sense of connection. A further implication for the centrality of phenomena in science instruction is it makes the science more accessible to learners, and more equitable, supporting the engagement of all.

Creating science educational experiences for young learners centered on phenomena may provide the means for ending the recurring cycle of false ideas and misconceptions. When confronted with eternal recurrence, Zarathustra reacted with nausea. As science educators, we would like nothing more than to not cover old ground time and again.

Galileoscope

Thanks to a grant from the Gordon and Betty Moore Foundation, the Astronomical Society of the Pacific is developing a suite of resources to support educator professional development focused on utilizing the Galileoscope to teach about telescopes. The professional development is taking place both at in-person workshops, and virtual webinars. In-person events have taken place in San Francisco as a part of the Teacher Learning Center’s Summer Astronomy Institute, and in St. Louis, Missouri right after the ASP’s Annual Meeting. Future workshops are scheduled for Stockton and Fresno, California, and Portland, Oregon. The first virtual workshop will start in February 2018. The workshops, “From Pinholes to the Hubble Space Telescope: How Telescopes Work,” actively engage participating educators in exploring how pinholes and lenses create images, modeling how these components work together in larger telescopes to investigate astronomical phenomena. Participating educators receive a resource kit for their use during activities, as well as a set of 24 Galileoscopes to use in their classrooms or educational outreach. Additional resources include a set of short videos in support of the workshops. For more information, and/or to discuss hosting an in-person workshop, contact the ASP’s Director of the Teacher Learning Center Brian Kruse, bkruse@astrosociety.org.

BRIAN KRUSE manages the formal education programs at the ASP and is the Director for Region F of the National Science Education Leadership Association.
An Astronomical Wager

The long story behind why I now have purple hair.

I’ve only ever had to dye my hair purple once. And to be fair, it was only half my hair, as I lost the bet to only one of my two classes.

No, it wasn’t a wager about the outcome of a football game or an election, it was about the shape of Earth’s orbit. More specifically, it was about whether all of my students could successfully answer a multiple choice exam question about the shape of Earth’s orbit. If they did, I would dye my hair purple.

Getting 200 introductory astronomy students to agree that Earth’s orbit is nearly perfectly circular with the Sun almost exactly in the center doesn’t seem like it should be the Herculean task that it is. Just tell them, right?

Sadly, it’s not that easy. My students have had at least eighteen years of personal experience learning that “close = hot,” and since kindergarten have seen many lessons and standardized tests that rely on a two-dimensional sketch to convey a three-dimensional situation. For instance, in the state of Texas, the 2013 science test for students exiting 8th grade contained in the question shown here (pictured right).

By the time students reach my university-level class, this diagram has featured heavily in their science classrooms as teachers try—often in vain—to persuade students that seasons are a matter of axial tilt, not distance. Along the way, they also unintentionally convince students that our orbit is highly elongated.

Tragically, a significant fraction of Texas students graduates high school knowing neither the reason for the seasons nor the general shape of Earth’s orbit. Hence the wager.

In the first few weeks of my solar system astronomy class, we explore observational evidence for various models of the solar system. What causes something as simple as night and day, for
instance? What could account for seasons? And we don’t simply dis-
cuss what these things are like on Earth, but also what the day might
be like on, say, Mercury, or what the seasons on Mars are like (and
why). Along the way, we get to the shape of Earth’s orbit.

They employ various simulators, seeing Earth’s orbit from different
perspectives. They engage in discussions about what the Sun would
look like if, in fact, the orbit was as weirdly elongated and the Sun
positioned the way it is in the standardized test question. They tend
to agree that it would be really big and bright in September and
March. Then I say, “Here’s a question that will be on the exam. It’ll be
#40, in fact.”

It’s fashioned as a personal response question, one that they must
show me the answer by using their hands as a response device (one
finger for choice a; 2 fingers for choice b; etc.) They then discuss it
with each other. Then I flat out tell them: “The answer is B.” I typically
don’t explicitly tell my students the answers to personal response
questions in class. In fact, not giving out the answers is one of the
most frequently commented-on practices in my classroom, and yet
I persist. (I do give them a host of reasons why I want them to come
to me to find out if they are getting the questions right.) Then I say,
“This question will be on the exam. About twenty percent of you will
miss it anyway. Most of those missing it will choose A. And you know
what else? It’ll also be on your second exam. Even more people will
miss it then, but they’ll choose C or D then. And it’ll also be on your
final exam. About five percent of you will still miss it.”

They laugh, disbelieving. How, they wonder, could anyone miss
this question? She literally just told us the answer! And how could
more people miss it half way through the semester?

Then the exam comes along. As I predicted (well, as I’ve experi-
cenced in over 20 years of giving this question), about one in five of
them miss it. Many face-palms ensue. Some students tell me that
they swear I said in class that it was A.

Before the second exam comes along, we have covered Kepler’s
Laws of Planetary Motion with several active learning strategies,
simulations, and two entire lab exercises. Now they know that planet
orbits are ellipses, and the Sun is not actually at the center of the
ellipse. For illustrative purposes, elliptical orbits are almost always
shown with high eccentricities so that you can actually see objects
speed up and slow down, illustrating Kepler’s Second Law. But they
also model the actual planetary orbits in the solar system, noting
that Mercury and Mars are the only planets whose orbits seem par-
ticularly “offset” from the Sun.

There is also a deeper discussion about the process and history
of science. The reason that we needed a genius like Kepler, coupled
with the unparalleled observational prowess of Tycho Brahe, to
demonstrate that Earth’s orbit was not a perfect circle with the Sun
in the center is that Earth’s orbit is so close to being a perfect circle
with the Sun in the center! Options A, C, and D would result in such

40. Which of the following most closely resembles Earth’s orbit and the Sun’s position as seen
from directly above the plane of the solar system?

a. b. c. d.

Question 40 from the 8th grade test on Earth’s orbit [Source]
obvious changes in the Sun's apparent size and brightness that it wouldn't take centuries of tweaking models to get to the right answer. It would be obvious to everyone.

As promised, the orbit question appears on exam two. And, as “predicted,” more students miss it this time around, and some of those students are the ones who receive the highest exam scores. Of those who miss the question, a quarter stick with A, but a quarter now pick C, and about half go for D. They tell me afterwards that they know Earth’s orbit is basically circular, but they also now have it in their minds that an ellipse’s focus points must appear visibly and wildly offset from the center.

In other words, they actually know more astronomy, and this makes them more likely to get the wrong answer.

After the exams are graded, I try to unpack the situation for them. My goal is not to make anyone feel stupid, nor is it to replicate an experiment with a known outcome. I want to make a point to them. How often have you seen things on the internet that contradict what scientists are saying? They’ve got seemingly valid logic, and maybe some numbers and science-y sounding things, and they wind up drawing conclusions like “vaccines cause autism” or “global climate change is a hoax” or “Earth is flat.” And if you dig around a little, you might find yourself agreeing with them. If you do, try to remember this question. What has happened with this incredibly simple question should tell you something important. It should tell you that learning something about a subject can actually make you more likely to make a mistake. Just like the poem goes, “A little learning is a dangerous thing.” So, before you think that a few hours on Google can somehow give you a better understanding of a subject than decades of dedicated research, remember what happens with a question as simple as this one, a question that you are literally given the answer to.

Then comes the kicker: “This question will show up on the final. It will be number 40. In fact, you could get an answer sheet now, fill in B for number 40, and you’ll get it right. And if everyone gets this question right on the final exam, I’ll dye my hair purple.”

“What about half black, half white? What about yellow and blue stripes? What about ... ?” They start asking excitedly.

“Look, guys, I’ll go full Rainbow Dash if you can do this,” I respond. Semesters have come and gone, and my hair has mostly stayed disappointingly natural and monochrome.

Mostly.

The only exception happened after the fall semester of 2015, when I posted word of my challenge to the Astronomy Education Facebook group. Dr. Philip Sadler, the eminent astronomy education researcher who’s eye-opening teacher’s guide “A Private Universe” changed my entire approach to teaching, assured me that I would forever be safe. The concept of the shape of Earth’s orbit is too deeply embedded, he said.
I, of course, conveyed his skepticism to my classes. “Some guy at Harvard doesn’t think you can do this,” I said. “He doesn’t think you’re good enough.” (Which is, admittedly, nothing like what he said.) Now the gloves were off.

That same semester, I included the question in every single presentation. For four entire weeks leading up to the final, they saw it as a personal response question. “What’s the answer?” I would ask after each vote. “B” they’d all respond in unison.

Could they all bubble in the right answer on the final? Could they show up that “guy from Harvard?”

Final exam day came and went. I looked as each exam paper was placed on the front podium. Ten… twenty… thirty students had all chosen B.

I began to wonder how much it cost to color one’s hair.

Forty…

Good grief! They just might do it! I checked to see if I had any important meetings with administrators coming up.

Fifty…

Would my mother hate me for ruining this year’s family picture?

Then about halfway through, I noticed that someone had chosen A. Again. After all was said and done, a handful of the hundred or so students in that section had missed the question. Encouragingly, though, nobody in the second section missed it. Their performance was unprecedented.

I sent out an email and posted the news to the class Facebook group, congratulating one section for achieving perfection on the infamous question. “You should at least dye half your hair!” came a dozen responses.

So, I did.

Neither the administration nor my mother banished me for life, and for once my son even wanted to take a picture with me. To be honest, I kind of wish another section would win the bet. I think blue would be a pretty cool color. Unfortunately, Dr. Sadler and an army of other astronomy education researchers are right. There are some alternative conceptions that are immensely difficult to dislodge. But perhaps knowing about that difficulty is the most important lesson for students.

DR. C. RENEE JAMES is a science writer and professor of physics at Sam Houston State University, where she has taught introductory astronomy relatively purple-free since 1999. She is the author of two books, “Seven Wonders of the Universe That You Probably Took for Granted” (2010) and “Science Unshackled” (2014), plus dozens of popular astronomy articles.

One of the most pervasive misconceptions is that the Earth is flat, but this certainly isn’t a new idea, as shown in this classic 1893 map by Orlando Ferguson [Courtesy of the Library of Congress].
The Heart of the Great Red Spot

Jupiter's Great Red Spot — a giant rust-colored hurricane that could engulf Earth with plenty of room to spare — is one of the most well-known planetary features in the solar system. It has been observed by astronomers for over 150 years and was likely around for hundreds of years before that.

But as famous and well-studied as it is, there's a lot we still don't know about Jupiter's distinctive storm. NASA's Juno spacecraft, launched in August 2011, has been in orbit around the gas giant since July 4, 2016, and has been using its suite of science instruments to investigate the planet's complex atmosphere deeper than ever. Thanks to Juno, scientists are now able to “see” below Jupiter's dense swirling clouds to find out what's happening inside the Great Red Spot. What they've discovered is the storm plunges hundreds of miles into Jupiter's sky and has a hot base that powers its winds.

This image (originally processed by Gerald Eichstadt and further edited by myself) is a color-composite made from publicly-available raw data captured by Juno's Junocam instrument on July 11, 2017. It's a look into the heart of the Great Red Spot — and if you look closely you can actually see a heart shape in the center! Although the data was acquired in visible-light wavelengths, this image has much more saturation and contrast than you would see with your own eyes, but that's only to help bring out as much detail inside this iconic storm as possible. After all, there's really nothing subtle or understated about Jupiter!
Capturing Baily’s Beads

This photograph shows a phenomenon called Baily’s Beads, caused by the last bits of the Sun peeking between mountains along the limb of the Moon during the final moments before totality during the Aug. 21, 2017 total solar eclipse.

In order to capture Baily’s Beads on camera you have to shoot fast—that is, with a fast shutter speed. They are parts of the Sun and thus are very bright and easy to overexpose. During this event I was at Fort Johnson in Charleston, South Carolina, and had my tripod-mounted Nikon D810 set to ISO 400 with an f-stop of 8, and had my (unfiltered) Sigma 150-600 lens pre-focused on the Sun and Moon. I was shooting at a speed of 1/6000, which resulted in what I initially thought were very underexposed images but later realized had allowed me to capture the finer details of solar prominences visible beyond the Moon’s silhouette, as well as Baily’s Beads.

Baily’s Beads are named after Francis Baily, a 19th-century British astronomer who described them in detail after observing a solar eclipse in 1836. Baily didn’t discover them or even be the first to correctly explain them—that distinction goes to Sir Edmond Halley over a century before. But Baily’s awed description made a lasting impact on his astronomical peers and his name has ever since been associated with the effect.

Now that we have a complete map of the Moon’s surface thanks to NASA’s Lunar Reconnaissance Orbiter, scientists can accurately predict how Baily’s Beads will appear during an eclipse. But that doesn’t make these brilliant lunar jewels any less beautiful.

JASON MAJOR is a graphic designer and space enthusiast living in Rhode Island. He has written online articles for Discovery, National Geographic, Universe Today, and has had processed images featured by The Atlantic, Astronomy Magazine, Science Channel, and NASA. You can find more of his work at LightsInTheDark.com.
Arecibo Endures

After surviving Hurricane Maria, the observatory is weathering different kind of storm.

By Steve Murray

This photograph shows damage to the observatory's main antenna post-Hurricane Maria. It's estimated that repair costs for the facility could be up to $8 million. [The NAIC - Arecibo Observatory, a facility of the NSF]
The last few months have been filled with drama for Arecibo Observatory. Even as its staff cleaned up after Hurricane Maria, they knew that another threat was on the horizon. For years, the National Science Foundation (NSF) had been anxious to reduce its funding support for the facility and a November 2017 board meeting was set to discuss the observatory’s future with a decision soon to follow.

Arecibo may have weathered a major storm, but would it weather governmental money debates?

Still Special After All These Years
The construction of Arecibo Observatory was completed in 1963. With a 1,000 foot (305 meter) dish resting in the karst hills of northwestern Puerto Rico, it operated as the world’s largest radio telescope until 2016 when the 1,600 foot (500 meter) dish of the Chinese Five hundred meter Aperture Spherical Telescope (FAST) Observatory was finished. Arecibo will still claim bragging rights as the largest operational dish, however, until all FAST checkout tests are concluded.

A 900-ton receiver platform containing secondary reflectors and four-line feed radar antennas is suspended over the dish by cables. Moving the platform around a bow-shaped track gives astronomers an observing cone of almost 40 degrees over its zenith by focusing on different parts of the spherical dish.

Arecibo was originally built as a tool for U.S. defense studies into properties of the upper atmosphere. Scientists were quick to realize its broader potential, however, and pushed for additional uses. Today, the observatory supports research projects in atmospheric science, radio astronomy, and planetary (radar) science.

Atmospheric scientists measure emissions like airglow with passive optical instruments and light scattering with active LiDAR (laser) systems. Studies of plasma in the ionosphere, however, brings the world’s most powerful incoherent scatter radar into play.

“The radar and the big collecting dish can make incredibly precise measurements of waves in plasmas,” says Herbert Carlson, research professor at Utah State University. “Arecibo allows us to study the fundamental physics of plasmas better in space than in the lab. You send up radar energy to ‘kick’ the plasma, then measure how it responds. Arecibo’s radar gives you a time lapse movie of basic processes.”

James Cordes, George Feldstein Professor of Astronomy at Cornell University, uses the facility in support of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) program, which searches for gravitational waves by measuring their
effects on pulsars.

“Arecibo is one of the major elements of the North American Pulsar Tracking Array,” says Cordes. Unlike the Laser Interferometer Gravitational-wave Observatory (LIGO) program, which detects the high-frequency space-time ripples generated as black holes collide and merge, “we’re looking at [gravitational] waves from an earlier phase of their inward spiral, so the waves are weaker and at a higher frequency. They’re as different [from the phenomena sensed by LIGO] as radio waves are from X-rays.”

Victoria Kaspi, professor of physics at McGill University, relies on the sensitivity of Arecibo to look for new pulsars that can be added to the NANOGrav network and to study Fast Radio Bursts (FRBs). Although these extremely brief high-energy pulses have been discovered before, Arecibo was the first instrument to detect a repeat-

ing FRB in 2016.

“Nobody knew they could repeat,” says Kaspi, “but when you have a big dish you have great sensitivity. We wouldn’t know about if we didn’t have Arecibo.”

Some of the observatory’s most critical work, however, may be the detection and tracking of near-Earth objects (NEOs) that could cross Earth’s orbit. “It’s the bulk of what Arecibo does with its planetary radar,” says Lance Benner, planetary scientist at NASA’s Jet Propulsion Laboratory. “In recent years, they’ve been observing between 70 and 100 near-Earth asteroids per year. The observatory can get images of near-Earth asteroids that are comparable to what you can get with a spacecraft flyby—at a very small fraction of the cost of a space mission, of course.”

Time to Move On?

Despite its powerful and varied capabilities, Arecibo must still compete with other projects within tight government budgets. Its primary sponsor, the National Science Foundation (NSF), has been trying to cut back its support for several years so it can fund newer telescopes like the Large Synoptic Survey Telescope (LSST) that’s being constructed in Chile. The foundation currently provides about $8.3 million a year to Arecibo, and NASA throws in an additional $3.6 million to support the search for hazardous asteroids and other NEOs. While NSF would like to keep Arecibo open as a science facility, it wants to gradually—but significantly—reduce its support.

The observatory is now operated under a cooperative agreement by a consortium of SRI International, the Universities Space Research Association (USRA) and Universidad Metropolitana (UMET) in Puerto Rico. Funding under that agreement, however, will end in March 2018. Other partners will need to step forward and cover the difference, if the observatory is going to stay viable.
NSF is in a difficult position. Only so many instruments can be funded and, as radio telescopes go, there are only a handful of operational observatories in the entire world older than Arecibo. Nevertheless, the observatory still has very unique capabilities and a strong group of astronomers who rely on them. About 200 scientists use the facility each year for their research. Arecibo’s two selling points are its powerful radars and its enormous dish. “To astronomers, the only difference between radar and radio is that you can at will enhance the brightness of what you want to look at for nearby sources,” says Carlson. “We are, in effect, shining a searchlight on an object in the sky.

“For atmospheric science, it’s totally unique,” he adds. “There aren’t any discussions anywhere in the world even starting to think about a capability that would approach Arecibo’s. All other radars in the world are miniscule compared to this observatory.”

Cordes sees Arecibo as essential to NANOGrav’s purpose. “Arecibo and Green Bank are really the best telescopes for doing pulsar timing, at least for now. We’re skeptical that any of the new telescopes will fill the need and NANOGrav would be in very bad shape if they went away.”

Loss of Arecibo would be devastating “to the whole small body community,” says Lance Benner, “Using radar we can identify very close approaches much further into the future than if radar were not available. Arecibo is the best facility in the world for doing that.” Some trajectories can be mapped up to a century ahead.

Any change to Arecibo’s status would also have an economic and cultural impact on the island. “Over 80 percent of our staff is from Puerto Rico,” says Francisco Córdova, director of Arecibo Observatory. “We host over 90,000 visitors each year,” he adds, “many of whom are local students who benefit from access to a world class research facility like Arecibo, and our Angel Ramos Science and Visitors Center is one of the few informal STEM education facilities in...
Puerto Rico. The facility has even been listed with the U.S. National Register of Historic Places and Puerto Rico’s State Historic Preservation Office.

**Hurricane Alert**

On Sept. 20, 2017, as NSF wrestled with long-term budget issues, Hurricane Maria struck Puerto Rico. Parts of the island got hit with 30 inches of rain in a single day (the same amount that Houston received in three days of Hurricane Harvey). Maximum winds of 155 miles per hour (135 knots) destroyed some National Weather Service sensors, forcing meteorologists to measure the storm entirely by satellite.

Arecibo is no stranger to storms, however, and the staff had time to prepare the facility. Observatory staff locked down the telescope, dismantled a portion of the antenna, put up storm shutters and checked generators and fuel supplies. Operations were then suspended to allow staff members to prepare their homes. A small group of workers rode out the hurricane at the observatory with water, food and diesel supplies. “The observatory is designed to withstand a direct hit from a major hurricane,” notes Benner. “It’s one of the safest places on the whole island.”

Anticipating that the tree-lined road to the observatory would likely be impassable for several days after the storm, short-wave radios were set up so staff members who lived near Arecibo could communicate with each other if Internet and telephone access were lost.

One staff member used the short-wave system to send out the first damage reports late on Sept. 21. Fortunately, things weren’t as bad as expected from such a powerful storm. The sinkhole underneath the dish was flooded and a 430 MHz line feed radar antenna fell into the dish and damaged some panels. Otherwise, the telescope was operational.

Observatory staff soon turned to assisting others, a role they’ve taken on before. With its deep water well and generator power, Arecibo has been a place where people from nearby towns could gather, reorganize, and recover.

About 14,000 gallons (53,000 liters) of drinking water were distributed each day to surrounding neighborhoods from a standpipe at the observatory gate. “Our staff used their own time to distribute food and bottled water, provided by FEMA and the Coast Guard, to more than ten surrounding communities,” says Córdova. “We continue to provide water to the community as needed.”

The entire facility was offered to FEMA and, for a time, became the agency’s headquarters for recovery efforts.
Police and power authorities made early use of the observatory’s radio repeaters for emergency response and the Arecibo helipad served as a logistics point for supply distribution to the island’s hard-to-reach central areas.

After the receiver platform was inspected and its reflectors were aligned, the observatory then got back to science work using diesel-powered generators. Drift scan astronomy was restarted on Sept. 29, although a Twitter post from the observatory announced Nov. 7 as the first day of tracking work. Only its radar projects were still curtailed, as the diesel generators needed to power its high frequency transmitting equipment took a back seat to more essential fuel requirements elsewhere around the island.

“Many staff still don’t have power at home, although most now have water,” says Robert Minchin, Group Lead for Radio Astronomy at the observatory. “The water supply is still under a ‘boil advisory’ across the entire island, so our tap water is not actually potable. There are three families still living on-site at the observatory in our visiting scientists’ quarters.”

Herbert Carlson had been a former director of the Ionospheric Research Department at Arecibo Observatory and wasn’t at all surprised by the stories coming out of the facility. “A unique aspect is the staff, which is something that gets very little attention,” he notes. “They’re bright, they’re educated, and they really care about the place. I’ve been to a lot of observatories, but there’s something special about the staff at Arecibo; they really go all out to support the mission. It’s hard to quantify but it’s something that I’m always impressed with.”

Rescued
With the NSF already working on plans to reduce funding and potentially close the observatory, big repair bills might have been the last straw in its decision-making. NSF estimated the repair costs between $4 million and $8 million, however, which it appears willing to pay.

On Nov. 16, the NSF released a public statement regarding its Arecibo decision. Its board could have selected from alternatives that ranged from maintaining current funding to completely mothballing the site. The foundation issued the welcome news that they would continue science operations “with reduced agency funding,” and would search for new collaborators. NSF specified in their decision that any new operators would have to continue support for the radio astronomy and aeronomy science activities at the observatory.

James Ulvestad, director (acting) of Mathematical and Physical Sciences at NSF, stated that this was only possible because one or more viable partners had made proposals in response to the agency’s solicitation earlier in the year. A new cooperative agreement will
The Next Chapter

Demand for the telescope remains strong. “There’s massive competition for Arecibo time,” notes Kaspi. “That’s the sign of a healthy observatory that’s doing great science—when everybody wants to use it.” After an emotional fall, Arecibo’s staff can begin long-term planning again. It looks like its 54 years of operation will now be extended for another five years. Some scientists wish for an even longer life for the observatory.

“The worst case would be if Arecibo and Green Bank went away in five to ten years,” he says. “NANOGrav would be in very bad shape. We’re getting a lot of time on these instruments, and it would be very hard to get an equivalent amount of time on other telescopes. Our plan A is that we’d like to keep both scopes for the whole next decade. In fact, what we’d really like to have is an Arecibo for sampling the southern sky, too.”

Even a few weeks without Arecibo’s radar has pinched some current work. “During the time they’ve been offline they’ve missed at least 10 near earth asteroids they were planning to observe,” says Benner. “We have a whole bunch of really scientifically compelling targets coming in the next one to two months, and I really hope Arecibo will be back up in time for those.”

Someday, of course, technology and scientific interests will change and the research community will move on to other instruments. But for Arecibo Observatory, that day is still in the future. Like Mark Watney, the stranded astronaut in “The Martian,” organizations decided that they needed to save a valued resource.

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be awarded on or after April 1, 2018 with an anticipated duration of five years. In that time, NSF support for Arecibo will begin to ramp down to $2 million as new management partners pick up the difference. The agreement could be renewed for an additional five years, following a successful future review.

“I think the decision was very positive,” says Córdova. “It clearly defines the future of the site, and that is what we really want at the end of the day. It also takes off the table any concerns over potential destruction or mothballing of the facility.

“I see it as an opportunity to increase the scope of research programs at Arecibo and obtain funding from some less traditional sources.”

The sinkhole beneath Arecibo’s dish was flooded after Maria [Arecibo Observatory Staff]
Into the Abyss

The Event Horizon Telescope is taking data and 2018 will be the year that we see what a supermassive black hole really looks like.

By Mika McKinnon

Based on astrophysical models, this is what we think an accreting black hole should resemble—the dark silhouette of the black hole’s event horizon, surrounded by a turbulent disk of superheated plasma [Bronzwaer/Davelaar/Moscibrodzka/Falcke/Radboud University]
What does a black hole look like? An international collaboration of astronomers is transforming the planet into an enormous virtual telescope to find out.

“For the first time in the history of astronomy we’ll be able to resolve the event horizon of known supermassive black holes,” says Avery Broderick, a researcher at the Perimeter Institute for Theoretical Physics in Ontario, Canada.

Broderick is part of the Event Horizon Telescope (EHT) project that is seeking to take the first image of a black hole’s event horizon, the point where its gravitational pull is so strong even light can’t escape. In April 2017, they coordinated observations between eight telescopes to observe two supermassive black holes—Sagittarius A* at the center of the Milky Way, over 25,000 light-years from Earth, and the active black hole in the center of the massive elliptical galaxy M87, located 50 million light-years away.

“The Event Horizon Telescope project is a voyage of discovery,” says Broderick.

While researchers have a good handle on what a black hole looks like from theory and indirect observations, this is the first dedicated effort to directly image the event horizon—the final photon orbit and gravitational point of no return—of a black hole. “It's someplace we've never really looked before and we've never had the ability before,” he says. “It is still a possibility for something being absolutely completely different.”

Apart from some good theoretical guesses, Broderick adds, “we have no idea what we're going to see.”

Black Hole Shadow Play

“One of the central paradoxes of a black hole is that despite the fact that they have such a strong gravitational pull that even light can’t escape from them, they wind up being some of the brightest objects in the universe,” explains Shep Doeleman, a researcher at Harvard University and Director of the EHT project.

“For the physicist, the black hole is this perfect absorber: stuff goes in and it doesn’t go out,” says Broderick. “But for the astronomer, black holes are the engines of industry: the brightest things in the universe.” That's because the traffic jam of material rushing headlong into the black hole is ripe with collisions that produce heat and light, he adds.

“Black holes are indeed black,” laughs Sera Markoff, professor at the University of Amsterdam and a member of the EHT’s science council who contributes to how the data is collected, processed, and used. But they’re shadows superimposed against glaring light, she says, an absence of light that draws a picture in the gas and dust...
whirling around the event horizon. “Black holes cast a silhouette against the surrounding emission,” says Broderick. “The shape of that silhouette is determined entirely by the structure of the black hole—the stage on which the drama unfolds.”

That final photon orbit as light is bent during its last swirl around the black hole before gravity becomes too strong to escape even at the speed of light is the closest outline of the black hole’s event horizon, and the fine detail the team hopes to capture with the EHT.

“The Event Horizon Telescope is an Earth-sized telescope made virtually by stitching together radio dishes across the globe that has the magnifying power required to take the first picture of a black hole,” says Doeleman.

The virtual telescope needs to be the diameter of our planet because the supermassive black hole in the center of our galaxy is such high density that all its mass is crammed into a very small space, making it too small to see with traditional telescopes.

“If you were to take the Earth and compress it to a black hole, you’d get an object [with an event horizon] a few centimeters across,” says Broderick. “Even with 4 million solar masses in Sagittarius A*, it’s still solar system scale.” Because the black holes are so far away, their event horizons appear extremely small in the sky, far smaller than the resolving power of any single telescope.

But a quirk of physics makes black holes a bit more visible than their raw size suggests. The same gravitational pull that drags matter into their maw also produces gravitational lensing—an optical distortion courtesy of Albert Einstein’s general relativity that magnifies that region of space.

“It’s almost as though the black hole is a puffer fish,” says Doeleman. “One of the reasons we can actually see the event horizon at all is because the black hole helps us by making it look larger than it actually is.”

An Epic Data Collection Challenge

By coordinating telescopes from around the world to take observations simultaneously, the project can create a virtual telescope that has the effective size of the entire planet, or a resolution good enough to image features as small as 50 microarc-seconds across.

“That’s equivalent to being able to count the dimples on a golf ball in Los Angeles if you’re standing in New York,” says Doeleman. “The smallest object you can see with a telescope is equal to the wavelength of light you observe with divided by the size of the telescope.”

When looking in radio—one-millimeter wavelengths—then a telescope needs to be the size of the entire Earth to have sufficient resolution to detect the event horizon of a black hole. “We should not be seeing blobs anymore,” says Broderick.
In April of last year, the team had a window of ten days to coordinate simultaneous data collection at observatories including the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile along with observatories in the South Pole, Hawaii, Arizona, Mexico, and Spain. Because the antennas are located in different climates, astronomers had a complicated process of checking the weather at each station every night; only when the conditions were right at all could the observations be triggered in concert, Markoff explains.

Each telescope is equipped with special 64-terabyte recording modules to capture not just the radio signal from the target black holes, but also the complicated background noise and calibration targets. A petabyte of data was collected at each antenna, or roughly the equivalent of every book, photograph, and recording archived in the Library of Congress.

“It’s really not practical to try to send all that raw data around,” says Markoff. Instead, the physical recording modules were removed from the telescopes, packaged, and shipped via FedEx to a central location. “This is way too much data to send it back on the Internet,” says Doeleman. “It is far faster to cram a 747 filled with disk drives.”

The data collection was complicated by the remoteness of the South Pole Telescope, however. “There was a thing called ‘winter’ there,” laughs Markoff. “You can’t actually get planes in or out during that period.”

But going digital wasn’t an option, either. “Given the Internet connectivity to the bottom of the Earth it would have taken us over 25 years to get all the data back that we recorded in April of 2017,” says Doeleman. Instead, the team had to wait: It took until December to get all 17 petabytes of data from all the EHT’s locations to the MIT Haystack Observatory in Cambridge, Massachusetts and the Max Planck Institute for Radio Astronomy in Bonn, Germany.
A Slow Process

Even now the team has the data, it’s going to take time to process it and find out if they successfully imaged a black hole’s event horizon. “It’s a very slow process because it’s the first time this has ever been done at this frequency for this many telescopes,” says Markoff. “It’s pathfinding.”

“Radio astronomy is a very tricky business,” she says. Unlike optical astronomy that records individual photons as they strike the telescope, radio astronomy requires observing the entire sky then processing it to determine where the radio signals are coming from—the EHT team can’t simply look at Sagittarius A* and M87, they need to observe the entire sky along with their science and calibration targets. “You’re effectively taking a Fourier Transform of the sky,” she says. This makes it easy for noise to obscure the signal, or, worse yet, create false patterns. “You can actually see things that aren’t really there.”

This means the team needs to be extremely careful while processing data, ensuring they identify real event horizons and not optimistically seeing patterns that don’t exist.

By collecting the full sky data, the team will be able to play back the observations. “The light was frozen when it was collected at those sites,” says Doeleman. “We can align those data streams and times so they line up just the way they need to interfere constructively.” This allows the radio data to be processed akin to how a parabolic mirror focuses light in an optical telescope, helping the team analyze what they’re seeing and hopefully create images of the event horizons of black holes.

“We are now in the process of very, very carefully going through the data, understanding it in great depth, and making sure that we have multiple lines of analysis,” says Doeleman. “This is very important that we do this properly, slowly, carefully, and that nothing is released until we have a peer review of our results by the community.”

“You have to be careful when you do something new and you’re going to make a big claim,” Markoff says. “You really don’t want to make a false alarm.”

Doeleman admits that they don’t really know what the EHT is going to show. “All we know is that we put ourselves in a position to see something that many people have thought for years is unseeable and just the fact that we’ve gotten here is testament to the work of many, many people across the globe,” he says. “You can get the best camera in the world, but the only image you can take is what nature presents to you.”

“If there is an event horizon to be seen, we think we have the technology and the algorithms to extract that kind of feature from the data that we have,” says Doeleman.

Broderick is hopeful that not only did the team capture the image of black hole event horizons last April, but they will again when observing new targets in April 2018. “There is this great hope that we’ll be able to build a lexicon,” he says. “We’re going to get this image of the dark side of the universe.”

“The event horizon telescope is the means for me to get to those far flung places, to get to the vicinity around black holes and see something that’s fundamentally different from anything we’ve seen before,” says Broderick. “We’re finally being able to ask questions that people just relegated to assumptions.”

MIKA MCKINNON is a disaster-obsessed geophysicist and scientist for fiction. Follow her work on Twitter: @mikamckinnon.
**the anatomy of a black hole**

*Courtesy of ESO, ESA/Hubble, M. Kornmesser/N. Bartmann*

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**Singularity**

At the very centre of a black hole, matter has collapsed into a region of infinite density called a singularity. All the matter and energy that fall into the black hole ends up here. The prediction of infinite density by general relativity is thought to indicate the breakdown of the theory where quantum effects become important.

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**Event horizon**

This is the radius around a singularity where matter and energy cannot escape the black hole's gravity, the point of no return. This is the “black” part of the black hole.

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**Photon sphere**

Although the black hole itself is dark, photons are emitted from nearby hot plasma in jets or an accretion disc (see below). In the absence of gravity, these photons would travel in straight lines, but just outside the event horizon of a black hole, gravity is strong enough to bend their paths so that we see a bright ring surrounding a roughly circular dark “shadow”. The Event Horizon Telescope is hoping to see both the ring and the “shadow”.

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**Relativistic jets**

When a black hole feeds on stars, gas or dust, the meal produces jets of particles and radiation blasting out from the black hole’s poles at near light speed. They can extend for thousands of light-years into space. The GMVA will study how these jets form.

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**Innermost stable orbit**

The inner edge of an accretion disc is the last place that material can orbit safely without the risk of falling past the point of no return.

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**Accretion disc**

A disc of superheated gas and dust whirs around a black hole at immense speeds, producing electromagnetic radiation (X-rays, optical, infrared and radio) that reveal the black hole’s location. Some of this material is doomed to cross the event horizon, while other parts may be forced out to create jets.
Inside the Event Horizon Telescope

A global interferometer will allow us to take pictures of the black hole in the core of our galaxy—but how?

By Jeff Mangum, National Radio Astronomy Observatory (NRAO)

The global network of radio telescopes that comprises the Event Horizon Telescope, or EHT, uses interferometry, a technique that is applied to make very high-resolution observations of many distant objects in the universe. Interferometry using radio telescopes is done by having all of the antennas point to a target source in the sky at the same time. Depending on how detailed an observation astronomers want to make, the antennas can be grouped close to one another, or separated by thousands of kilometers—a technique known as Very Large Baseline Interferometry, or VLBI.

The resolution of an interferometer is proportional to $\lambda/d$, where $d$ is the separation of antennas in the interferometer and $\lambda$ (lambda) is the wavelength of the observations being made.

Interferometry Basics

Now, because you ultimately need to combine the signals received from each of your radio interferometer antennas, you must decide how you are going to connect them. If the antennas are grouped close to one another, you may decide to connect them with wires so the signals can be combined in real-time. But in the case of the EHT—which is a globally-distributed VLBI network with antennas in some of the world’s most remote locations—the antennas are too far apart to connect electronically, so each of the antennas use a very sophisticated system to record radio signals for later combination with recordings from the other antennas in the EHT.

Another factor that is important in an interferometer is the size of the antennas used. The sensitivity to faint radio signals is proportional to the total amount of collecting area available in the interferometric measurement. This means that you can either use many small antennas or a few larger antennas to attain the same level of sensitivity to weak radio signals. The radio signal sensitivity of an
interferometer is proportional to the total collecting area of the interferometer.

These principles of resolution and sensitivity of an interferometer are explained by the graphic below, developed by the National Radio Astronomy Observatory (NRAO). On the horizontal axis of this figure is the distance between radio telescopes, which is referred to as the “baseline.” As the baseline increases, smaller structures in the astronomical objects that you are observing can be resolved. On the vertical axis of the diagram, if the number of antennas in the interferometer are increased—which is equivalent to increasing the collecting area of your interferometer—the sensitivity to weaker radio signals increases.

Now, why do we need the EHT to take a picture of the region around the black hole near the center of our galaxy?

The “Exciting” History of Sgr A*
Called Sagittarius A*, or Sgr A*, for its association with a bright radio source, the supermassive black hole near the center of our galaxy has a mass of 4.3 million times that of the mass of the Sun and is located about 25,000 light years away.

As supermassive black holes go, Sgr A* is fairly unremarkable on the cosmic stage. There are many more massive black holes located near the centers of other galaxies that can top several billion solar masses. Since more massive black holes are easier to observe than less massive black holes, and the ease at which it is to measure a black hole is proportional to how close it is, it turns out that, despite its underwhelming bulk, Sgr A* is the best candidate for imaging a black hole.

Why, then, do we use measurements of radio waves to study black holes? This part of the story goes back to 1974 when astronomers Bruce Balick and Robert Brown discovered a bright radio source near the center of the Milky Way, which was then given the name “Sagittarius A**” in 1982. Its name was chosen because the radio source is in the direction of the constellation Sagittarius; the “A” comes from the fact that it was the first radio source detected in that constellation; and the “**” was added because it was, as its discoverers noted, “exciting” (adopting the “**” designation used for excited states of atoms).
In the 1990s astronomers were able to make time-lapse videos of stars moving near the center of our galaxy, and found that the stars’ motions indicated they were orbiting around an unseen (at optical wavelengths) massive object, centered on Sgr A*. Astronomers then used Newton’s laws of gravity to study the motions of these stars and found that the optically-invisible object at the location of Sgr A* had to have a mass of at least four million solar masses.

But why can’t we see this very massive object near Sgr A*? First, since Sgr A* is in a direction in our galaxy that corresponds to the direction with the largest amount of gas and dust, optical light must penetrate through a lot of material to reach our telescopes. The region is so opaque that essentially all optical wavelengths are blocked from our view of Sgr A*. Radio waves, on the other hand, are not blocked as efficiently due to their longer wavelengths, making Sgr A* detectable by radio telescopes.

The second reason is that black holes swallow everything, even light. Therefore, the radio waves that we see coming from Sgr A* are not really coming from the black hole itself, but from a region immediately surrounding the black hole that is comprised of the dust and gas that the black hole is pulling into its center. This hot region, called an accretion disk, is very energetic, due to the effects of the intense gravitational pull of the black hole. This highly excited gas and dust emits radiation at a wide range of wavelengths, including radio waves.

**Imagining What a Black Hole Looks Like**

If we can create an image of the radio emissions coming from Sgr A*, what would it look like? This is where we must rely on theory, guided by some calculations that astronomers Orest Khvolson, Frantisek Link and Albert Einstein made in the 1920s and 1930s. It turns out that light can be deflected by gravity, which means that light bends whenever it passes by an object that has mass. The larger the mass of the object, the larger the bending. If you then draw a picture of what you think a radio wave-emitting black hole (with accretion disk) looks like, you get a bright, swirling pattern of radio wave emissions (pictured below).

What else might we see with the EHT? Remember how we determined that the more massive and closer a black hole was, the easier
it is to detect? Also, the bigger a black hole gets, the larger its accretion disk becomes. It turns out that there is a very massive black hole near the center of a relatively nearby galaxy called M87. This black hole is about 6 billion solar masses, or about 1,500 times the mass of our galaxy's black hole. M87 is our best bet for being able to image a black hole outside of our galaxy.

So why do we go to all of this trouble to study the black holes near Sgr A* and M87? We believe that most, if not all, galaxies have black holes near their centers. Since astronomers want to understand everything we possibly can about how galaxies form and evolve, one needs to understand how all the parts of a galaxy work. Supermassive black holes appear to be a fundamental ingredient of all galaxies, so the EHT will help us to understand this important component of the galactic evolution recipe.

JEFF MANGUM is an astronomer at National Radio Astronomy Observatory (NRAO) and Editor of the "Publications of the Astronomical Society of the Pacific" (PASP).
The Interstellar Visitor

`Oumuamua came from another star system to deliver a message.

By Ian O’Neill

This artist’s concept shows the interstellar asteroid, 1I/2017 U1. From its light-curve observations, this object is thought to be highly elongated.

[ESO/M. Kornmesser]
We look to the stars and ponder the alien worlds that orbit those distant points of light. As telescopes have become more powerful, our eyes have been opened to a stunning menagerie of worlds that orbit other stars, known as extra-solar planets—or, simply, exoplanets. Astronomers have even detected the tell-tale signs of comets and asteroids colliding in young and old star systems many light-years away, revealing an incredible diversity of how planetary systems evolve around other suns.

But to get a detailed look at these worlds and their building blocks, scientists say, we'll have to wait until we physically go there to observe these extra-solar locales up-close. That was, at least, until Oct. 19 when astronomers surveying the skies for errant space rocks serendipitously spied something different, something alien. Rather than waiting for humanity to build a starship, the universe did us a favor and delivered an object from another star. And this object is like nothing we've seen before.

`Oumuamua, the Messenger

Discovered by astronomers using the near-Earth object (NEO) hunting Pan-STARRS1 telescope in Hawaii, the faint, 20th-magnitude object was designated “C/2017 U1” as it was initially believed to be a comet. Travelling at a speed of 16 miles (26 kilometers) per second, it quickly became clear that C/2017 U1 was not gravitationally bound to the Sun. In fact, it had already been flung around the Sun in September and was on its way back out of the solar system. It had come from another star, that much was clear—it was the first confirmed interstellar comet.

Follow-up observations revealed something else about this interstellar interloper: It wasn't actually a comet. With no sign of dust and gas that typically surrounds a cometary nucleus after making a solar visit, the object revealed its true nature. It had come within 23,400,000 miles (37,600,000 kilometers) of the Sun on Sept. 9, a distance that would normally vaporize a small comet. It was therefore an asteroid and not the ancient icy mass that astronomers initially assumed. Its official designation was then changed to A/2017 U1 (as it's an asteroid), and then quickly modified to 1I/2017 U1—with an “I” to denote the object’s interstellar origins. The Pan-STARRS1 discovery team also decided on a moniker for the interstellar asteroid: “Oumuamua,” which means “a scout or messenger sent from the distant past to reach out to us” in Hawaiian.

As `Oumuamua was traveling so fast and rapidly becoming dimmer as it receded into the night, time was of the essence for astronomers to learn more about the speeding mass.

“We had to act quickly,” said Olivier Hainaut, of the European Southern Observatory (ESO) in Garching, Germany, in a statement.
“`Oumuamua had already passed its closest point to the Sun and was heading back into interstellar space.”

Like Nothing We’ve Ever Seen...
Using the incredibly powerful Very Large Telescope (VLT) at ESO’s Paranal Observatory high in the Atacama Desert in Chile, Hainaut and colleagues tracked `Oumuamua to add another layer of intrigue to the interstellar visitor. By combining precision observations of `Oumuamua’s with the VLT’s FORS instrument with other observatories, astronomers were able to gain precision measurements of the object’s color, brightness and trajectory. But on recording variations in the asteroid’s brightness, something truly bizarre was revealed: As it spun on its axis every 7.3 hours, the asteroid’s brightness varied by a factor of ten.

“This unusually large variation in brightness means that the object is highly elongated: about ten times as long as it is wide, with a complex, convoluted shape,” said Karen Meech, of the Institute for Astronomy, Hawaii, who led the study published in Nature on Nov. 20. “We also found that it has a dark red color, similar to objects in the outer solar system, and confirmed that it is completely inert, without the faintest hint of dust around it.”

...Yet Remarkably Unremarkable
Our solar system is no stranger to space rocks of abnormal shapes, but this estimated quarter-mile (400-meter) long asteroid—that had been reddened by hundreds of millions (or possibly billions) of years of being bombarded by cosmic rays as it traveled through the space between the stars—apparently looks like a giant cigar. And astronomers are at a loss to understand how such a weirdly-shaped asteroid could have formed.

Understanding the origins of 1I/2017 U1 will no doubt be a matter of debate for some time to come, but astronomers have been trying to build a picture as to where it came from and how it formed.

It was initially pointed out that `Oumuamua originated from the approximate direction of Vega, the brightest star in the constellation of Lyra, some 25 light-years away. Astronomers were quick to point out, however, that if `Oumuamua originated from Vega, it would have taken nearly 300,000 years for it to travel the interstellar distance. Of course, stars move, and Vega wasn’t at that position in the sky 300,000 years ago if we consider its motion through the Milky Way. It is more likely that `Oumuamua was ejected from its star system billions of years ago and has been drifting through interstellar space for several orbits of the galaxy.

Its star system birth place will likely forever remain a mystery, but what can the interstellar asteroid’s composition tell us about the environment it was ejected from?

In a study carried out by the WIYN telescope at Kitt Peak National Observatory in Arizona and the Nordic Optical Telescope in the Canary Islands, astronomers found the interstellar interloper was...
surprisingly familiar.

“[T]he most remarkable thing about U1 is that, except for its shape, how familiar and physically unremarkable it is,” said Jayadev Rajagopal, astronomer at the National Optical Astronomy Observatory (NOAO) and coauthor of the study, in a statement. In other words, its size, rotation and color weren’t uncharacteristic of asteroids in our own solar system—though its shape was, without a doubt, strange.

Might `Oumuamua be a contact binary, where two asteroids stick together and remain as one? Such asteroids are common in the solar system, but an asteroid with `Oumuamua’s comparatively rapid spin would likely cause such an elongated asteroid to break apart.

“One of our team wondered if, during a planetary system formation, if there was a large collision between bodies that had molten cores, some material could get ejected out and then freeze in an elongated shape,” Meech said in an interview with BBC News. “Another team member was wondering if there could be some process during the ejection—say if there was a nearby supernova explosion that could be responsible.”

SETI Implications

Though all evidence points to `Oumuamua’s origins being asteroidal in nature, there’s an extremely unlikely possibility that astronomers have also investigated: what if that highly elongated, tumbling object isn’t an asteroid at all, but instead an alien spacecraft?

After all, the discovery of U1 and speculation of its interstellar journey roughly mirrors the story line of “Rendezvous With Rama,” Arthur C. Clarke’s 1973 science fiction classic novel in which an interstellar object built by an extraterrestrial intelligence arrives in our solar system.

To investigate, the Breakthrough Listen project used the Green Bank Telescope in West Virginia to probe `Oumuamua for any artificial radio transmissions. No signals have yet to be detected, though observations are ongoing. Earlier observations by the SETI Institute’s Allen Telescope Array in California also drew a blank.

Speculation about `Oumuamua’s origins aside, one thing seems certain: Astronomers predict that interstellar asteroids like `Oumuamua fly through the solar system about once a year, and they always have. It’s only now, with the sensitive optics of survey telescopes, that we can detect these asteroid orphans.

“For decades we’ve theorized that such interstellar objects are out there, and now—for the first time—we have direct evidence they exist,” said Thomas Zurbuchen, associate administrator for NASA’s Science Mission Directorate in Washington, in a statement. “This history-making discovery is opening a new window to study formation of solar systems beyond our own.”

The hyperbolic trajectory of 1I/2017 U1 strongly suggests the object is interstellar [UH/IfA]
Clash of Tiny Titans Causes Small Space-Time Splash

The first gravitational wave signal was detected on Sept. 14, 2015, but in that short period it seems that observations of black hole mergers have (almost) become routine.

Most recently, two diminutive black holes careened into one another a billion light-years away to merge as one. Only a few months ago this would have been big news, but after the five detections that came before it, the detection of GW170608 was barely a blip in the science headlines—a sign of just how far we’ve come in a comparatively short time.

Detected by the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors in Washington and Louisiana, and the Virgo experiment near Pisa, Italy, on June 8, 2017, GW170608 has the distinction of being the most lightweight black hole smashup yet recorded.

With relatively peewee sizes of seven and 12 solar masses, these two objects spun into one another, creating a single black hole of 18 solar masses. But seven plus twelve doesn’t equal eighteen; why the arithmetical error? Well, one solar mass of black hole stuff was instantaneously converted into gravitational waves and it was those space-time ripples that washed through our planet on June 8, after traveling a billion light-years to get here.

The reason why the GW170608 signal was only announced in November is because physicists were busily trying to understand two highly significant gravitational wave signals that were detected on August 14 and 17: A precise LIGO-Virgo three-detector observation of a black hole merger (GW170814) and then the historic observation of a binary neutron star merger (GW170817), respectively. It’s interesting to note that gravitational wave astronomy has only just begun and already physicists are inundated with signals from deep space.

Read more about GW170608 in the LIGO Collaboration’s news release and for more on GW170817 and neutron star mergers, check out Mercury columnist Christopher Wanjek’s article on page 16.
The Megastructure That Never Was

Tabby’s Star, you may have heard of it. Otherwise known as KIC 8462852, the infamous star has spent a lot of time in the news for one key reason: aliens. But a recent study has found that the infamous star’s bizarre behavior is most likely down to dust and not some extraterrestrial intelligence building a Dyson sphere-like stellar energy collector.

This finding comes courtesy of astronomer (and Tabby’s Star’s namesake) Tabetha S. Boyajian who is leading a crowd-funded effort to get to grips with KIC 8462852’s inexplicable dimming events. First seen in data released to the Planet Hunters project—which examines transit data from NASA’s Kepler space telescope to citizen scientists to help seek out extra-solar planets orbit in front of their host stars—KIC 8462852’s brightness has a history of dipping dramatically. Historical observations of the star also show a long-term dimming trend.

Many natural phenomena have been put forward to explain this strange behavior, but one by one, they were each ruled out. Was it a comet swarm blocking the starlight? No. Could it be some as-yet unknown stellar cycle? Most likely not.

Then an unlikely, yet exciting, explanation came to the fore: could it be intelligent aliens—well on their way to becoming a Type II civilization—building a vast structure around its host star? Lacking evidence to the contrary, the “megastructure” hypothesis hogged the headlines until Boyajian’s team released their study’s findings on Jan. 3.

“The new data shows that different colors of light are being blocked at different intensities,” said Boyajian in a statement. “Therefore, whatever is passing between us and the star is not opaque, as would be expected from a planet or alien megastructure.” These latest findings agree with an October study that used observations from NASA’s Spitzer and Swift missions to detect this wavelength dependency of observed dimming.

Tabby’s Star is still an exciting astronomical object with an unprecedented transit signal, but it’s likely a complex dust structure surrounding the star causing the dimming events and not an extraterrestrial construction site. Shame.
astronomy in the news

A Star’s Portrait so Detailed You Can See Its Granules

Say “hello” to \( \pi^1 \) Gruis, a red giant that is fast approaching the end of its main sequence life. Located approximately 530 light-years from Earth, \( \pi^1 \) Gruis is part of a (likely) binary pair with its yellow main sequence partner, \( \pi^2 \) Gruis. The pair form a naked-eye double that can be found in the Southern Hemisphere constellation of Gruis (The Crane). Red giants are stars that have run out of hydrogen to burn in their cores and have begun burning heavier elements. As a result, they puff up hundreds of times larger than our Sun and violent stellar winds start to rip them to shreds, forming planetary nebulae.

So why are we getting to know this red giant? Well, this is the first time that astronomers have resolved the granular structure bubbling in a star’s photosphere beyond the solar system. This incredible feat was achieved by using the ESO’s Very Large Telescope (VLT) located at Paranal Observatory in Chile.

Granules are the patterns formed by convection currents that rise through the upper layers of a star. As the plasma expands and emerges at the star’s surface (the photosphere), a patchwork quilt-like pattern is created. The hot and bright centers of the cells are separated by the darker and cooler plasma around the edges. The Sun, for example, is covered with around two million cells, each 1,500 kilometers (930 miles) wide. But \( \pi^1 \) Gruis’ cells are much bigger, spanning about 120 million kilometers (75 million miles) across—about a quarter of the star’s diameter.

For more information on how astronomers were able to study \( \pi^1 \) Gruis’ granulation, see the ESO news release.
There’s a Super Blue Blood Moon on Jan. 31

Skywatchers are in for a special treat on Jan. 31. As the second Full Moon of the month, it is known as a “Blue Moon.” It will also be the second Supermoon of the month (following the Full Wolf Moon of Jan. 1) and therefore a “Super Blue Moon.”

But wait, there’s more.

Serendipitously, this particular Super Blue Moon will occur when the Moon passes into the Earth’s shadow. Yes, it will also be a lunar eclipse—or a “Blood Moon”—technically making this lunar rarity a “Super Blue Blood Moon”!

Supermoons happen when a Full Moon coincides with the Moon’s closest point (perigee) in its orbit around Earth. The technical term for a supermoon is “perigee syzygy” of the Earth-Moon-Sun system, when the Earth, Moon and Sun are aligned at the same time the Moon is at its closest point to Earth. “Supermoon” is a popularized term that refers to a brighter than normal Full Moon. Indeed, when this alignment occurs, Supermoons appear 14 percent larger and 30 percent brighter than a Full Moon at apogee (furthest point in its orbit).

For the next Supermoon, however, its brightness will be hindered by the Earth getting in the way. Full lunar eclipses are also known colloquially as “Blood Moons” as, although direct sunlight is blocked during a lunar eclipse, some sunlight is scattered by our planet’s atmosphere giving it a ruddy hue. Depending on atmospheric conditions, the Moon can appear distinctly reddish, hence the “blood” in Blood Moon.

For more information about how to observe this special lunar event, consult The Old Farmer’s Almanac.
reflections
By Ian O’Neill

A Hollywood Launch

While driving northbound on the Interstate 101 to an appointment in Thousand Oaks in Ventura County, Calif., (north of Los Angeles) on the evening of Dec. 22, my wife, father and I saw something in the sky. At first, while trying to concentrate on the road, I assumed it was an aircraft’s contrail and a particularly dazzling trick of the light—but then it became so much more. When people started to pull off the road during rush hour we knew it has to be something special. Realizing I was getting horribly distracted by the drama unfolding overhead, for our safety I also pulled off the freeway to watch a white plume erupt in the stratosphere and two objects emerge. I wracked my brain to work out what it was and, looking back, it’s funny how irrational thoughts ran through a checklist of increasingly unlikely possibilities: "Asteroid? Missile? ...UFO?" Only for commonsense to quickly kick in: "Wait... wasn't there a launch scheduled for tonight?" Yes, it was a launch, from Vandenberg Air Force Base. And it was a SpaceX Falcon 9 rocket carrying 10 Iridium communications satellites into orbit. We were very lucky to see the whole event, just after the rocket’s first stage had separated and was spinning away, with high-altitude ice crystals creating a light display that we will never forget.