Space News
IAN O'NEILL
A rundown of some of the most exciting developments in space and time.

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on the cover
Buzz Aldrin's boot print on the surface of the Moon. Fifty years ago, on July 20, Apollo 11 made history when Neil Armstrong and Aldrin became the first humans to step onto another world. Now NASA has plans to go back by 2024. [NASA]

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Time to Dump the “Habitable Zone”?

It’s one of my guilty pleasures to count how many people get bent out of shape when the media interprets a new “habitable zone” exoplanet discovery as “aliens live there!” Usually it’s an astronomer (or someone who’s scientifically minded or a stickler for accuracy), who will (rightly) point out that just because it’s in the habitable zone “doesn’t mean it’s inhabited.” Traditionally, I’ve been that person, calling out media misdeeds (usually by the tabloid press), but as the tally has now surpassed 4,000 confirmed worlds orbiting other stars, and the diversity of these worlds has surpassed our most outlandish imaginings, perhaps the scientific community needs to reconsider how we use certain vernacular to convey the complex topic of astrobiological possibilities in the public arena. Because, let’s face it, the topic of aliens gets pageviews; the mainstream press isn’t changing any time soon.

Take, for example, the recent discovery of GJ 357 c. It’s a “super-Earth” (another term that presumes a lot) orbiting its star within the habitable zone—the region surrounding any star that’s neither too hot or too cold for water to exist in a liquid state on its (hypothetical) surface. This planet is likely very unlike Earth (it’s three-times bigger, for a start), but it’s being called a “habitable world” solely on the basis that it orbits its star at the right distance—forgetting that we know little else. It may not have an atmosphere. It may not possess water. Does it even have a solid surface? Who knows.

Other commenters have pondered this dilemma (one of the best discussions on the topic was penned by astrophysicist Elizabeth Tasker in 2017, it’s well worth the read), and the consensus has been that while “habitable zone” is descriptive, it’s too general and hints that aliens (with biology like ours, no less) live there. We barely understand how life emerged on our world, let alone how life evolves—or even if it exists!—elsewhere.

So, when considering these special exoplanets in orbits where liquid water might persist, perhaps we should discuss “temperate zones”—a more scientifically accurate descriptor of the temperature potential of an orbit without making promises about its biological populous.

Dr. Ian O'Neill
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Dinosaurs, Astronomy, and Space Exploration

If humanity disappeared tomorrow, in 65 million years’ time very little evidence would be left of our nature to explore and understand the universe.

Imagine if all the humans on Earth suddenly disappeared. After 65 million years, what evidence would remain to prove we were here, did astronomy, launched rockets, and investigated the great mysteries of the cosmos?

According to one of my favorite books, “The World After Us,” future alien archaeologists might find bits of plastic, but nearly everything humanity had ever built would be gone. There would be nothing left suggesting we built computers, launched rockets into space, or observed the sky with massive telescopes.

During an ASP staff party—and after consuming a few glasses of wine—I posed a thought experiment I am still teased about. “If dinosaurs dominated the Earth for over 150 million years and became extinct 65 million years ago, how do we know dinosaurs didn’t do astronomy?” After all, Homo sapiens have been around for only 100,000 years and in that time we’ve accomplished a lot. T. Rex had lots more time on their tiny hands; what if dinosaurs did astronomy and explored the cosmos, but evidence of their accomplishments is long gone?

Human civilization arose only 5,000 years ago, but even within this short time frame most of the achievements of our ancestors have either been destroyed or buried under tons of vegetation and debris. We know only some of our early scientific accomplishments from written descriptions made by subsequent generations,
but then on rare occasions we discover a surprising artifact in an archaeological dig. A particularly jaw-dropping example comes from the Maya. Archaeologists decoded a 12th century pre-Columbian Mayan stone calendar and used it to predict the date of the total solar eclipse that passed through southern Mexico on July 11, 1991—a prediction off by a couple of days!

By making careful observations of the Moon and Sun, virtually every ancient civilization discovered that for a given solar eclipse, the Sun, Moon and Earth returns to the same relative positions in 6,585.3 days (18 years, 11 day, and 8 hours). This is the Saros Cycle and we can use it to predict when and where the geometry of the North American Eclipse of August 21, 2017 will repeat. The path and duration of totality for the 2017 eclipse will occur again on September 2, 2035. But because a Saros Cycle includes an additional 8 hours, this eclipse will pass across China, or a third of the way around the globe to our west.

In 1901, one of the most amazing scientific artifacts was discovered by sponge divers who were exploring an ancient shipwreck off the Greek Island of Antikythera. Along with large marble sculptures, bronze statues, pottery, coins, and jewelry, these divers recovered an odd lump of badly corroded metal and wood. The artifact was ignored for decades until CT imaging revealed something amazing—this unremarkable lump of bronze and wood was an ancient crank-driven analog computer, consisting of 37 metal gears, dials, and pointers.

This “computer” had been constructed around 150 BC. Given the name Antikythera, this intricate and complex gear mechanism tracked the date, accurately followed the motion of the Moon and Sun through the zodiacal constellations, displayed the current phase of the Moon, and used the Saros cycle to predicted lunar and solar eclipses. No one expected the ancient Greeks possessed the knowledge and skills needed to make a device like this—literally 1,200 years before these same calculators would appear in Europe.

Is the Antikythera mechanism an extremely lucky discovery of the only computer of its kind at the time, or are there many more examples of ancient technologies buried and long forgotten? How much did our ancestors in Mesopotamia, Asia, the Americas, Africa, or Polynesia accomplish in astronomy that we know nothing about? So, did the dinosaurs explore space? Did they do astronomy? Did they create their own version of the Antikythera? Of course they didn’t. They couldn’t because they never developed the intelligence required. Based on the ratios of their brain volume to physical size, most dinosaurs weren’t any smarter than possums. Even the Velociraptor—genius of the Jurassic Park movie franchise—was not quite as clever as your cat. Being around the planet a long time, even for hundreds of millions of years, doesn’t guarantee evolution will bestow a species with intelligence. After all, bacteria have been around for 4 billion years and there is no evidence they solved Fermat’s Last Theorem, or even cared.

It’s Homo sapiens that won the evolutionary jackpot, developing a highly intelligent and curious brain interested in asking and answering questions about the universe.

While we celebrate the anniversary of the Apollo missions over the next few months and marvel at the astonishing accomplishment of sending humans to the Moon and returning them safely to Earth, let’s take a moment to appreciate our unique and rare ability to question, explore, and invent—and hope we continue to use our unique brains wisely.

LINDA SHORE is the Chief Executive Officer of the Astronomical Society of the Pacific.
ASP 2019 Awards Announced!

The ASP recognizes individual achievements in astronomy research, technology, education, and public outreach each year. Recipients of our awards have included luminaries such as Edwin Hubble, Vera Rubin, Isaac Asimov, Margaret Burbidge, Carl Sagan, and Katherine Johnson.

Our most prestigious award, the Catherine Wolfe Bruce Gold Medal, was established in 1898 by Catherine Wolfe Bruce, an American philanthropist and patroness of astronomy. The Bruce has been awarded annually by the ASP to a professional astronomer in recognition of a lifetime of outstanding achievement and contributions to astrophysics research and is one of the most important awards in the field. Nominees are welcome from ASP Members and members of the astronomical community through March 1 of each year. The 2019 Awards Gala will be held at the DoubleTree by Hilton in Burlingame, Calif., on Nov. 9. Please sign up to our email list to be notified of when tickets are available.

Catherine Wolfe Bruce Gold Medal
The 2019 Catherine Wolfe Bruce Gold Medal is awarded to Dr. Martha P. Haynes, in recognition of her international leadership and pioneering work in radio studies of galaxies.

Dr. Haynes has made major contributions to our understanding of the composition, interactions, distribution, and evolution of galaxies in the universe throughout an impressive research career spanning over 40 years. Haynes is an internationally recognized leader and pioneer in radio studies of galaxies, specifically observations of the 21 cm wavelength of neutral hydrogen (HI).

Haynes has also been a leader and advocate for the development of state-of-the-art instruments to expand our ability to probe the radio universe. She provided oversight and vision to the improvements made to the Arecibo Radio Telescope in Puerto Rico, culminating with the ALFALFA HI Survey, which covered 1/6th of the sky and detected an astonishing 31,000 galaxies. Haynes and her students and colleagues have also studied large clumps and clusters of galaxies at immense scales of up to hundreds of megaparsecs. As one of her nominators stated, Haynes has “completely altered our view of the scale of inhomogeneities in the Universe, which is now recognized as a fundamental tenet of cosmology.” As Chair of its Board of Directors, Haynes currently spearheads the Cerro Chajnantor Atacama Telescope (CCAT) initiative to construct the high-altitude, CCAT-prime sub-millimeter radio telescope in northern Chile that will peer into the
early universe to investigate galaxy and star formation. She is also the scientific lead of the ALFALFA Undergraduate Team which promotes collaborative research by faculty and students at 23 academic institutions, most serving mainly undergraduates, from across the U.S. and Puerto Rico.

**Arthur B.C. Walker II Award**
The Arthur B.C. Walker II Award is presented to an outstanding African American (or member of the African Diaspora) who works in the areas of astronomy as a recognized leader in efforts to diversify the scientific community. The 2019 Arthur B.C. Walker II Award honors Dr. William M. Jackson, Jr., Distinguished Research and Emeritus Professor of Chemistry at the University of California, Davis, for outstanding achievement in astronomy and demonstrating a substantial commitment to promoting diversity and inclusion in STEM.

**Maria and Eric Muhlmann Award**
The Maria and Eric Muhlmann Award is given annually for recent significant observational results made possible by innovative advances in astronomical instrumentation, software, or observational infrastructure. The 2019 recipient of the Muhlmann Award is Dr. Mark J. Reid, Senior Radio Astronomer at the Smithsonian Astrophysical Observatory, a pioneer in the use of Very Long Baseline Interferometry (VLBI) and in the development of the Very Long Baseline Array (VLBA).

**Robert J. Trumpler Award**
The Robert J. Trumpler Award is given each year to a recent recipient of the PhD degree in North America whose research is considered unusually important to astronomy. The recipient of the 2019 Trumpler Award is Dr. Katheryn Decker French, who completed her PhD in Astronomy at the University of Arizona, Tucson (2017) with a focus on a radio survey of the gas clouds within galaxies that have recently ended the star-forming phase of their evolution.

**Klumpke-Roberts Award**
The ASP bestows the Klumpke-Roberts Award on those who have made outstanding contributions to the public understanding and appreciation of astronomy. Awardees include Carl Sagan, Isaac Asimov, Chesley Bonestell, Timothy Ferris, Walter Sullivan, Heidi Hammel, and the staffs of *Sky & Telescope* and *Astronomy* magazines. The 2019 recipient is Prof. Jay Pasachoff, Field Memorial Professor of Astronomy and Director, Hopkins Observatory, Williams College, MA.

**Las Cumbres Amateur Outreach Award**
The Las Cumbres Amateur Outreach Award, given for the first time in 2001, seeks to honor outstanding educational outreach by an amateur astronomer to K-12 children and the interested lay public. The 2019 recipient is Lynn Powers, President of the Southwest Montana Astronomical Society for her dedication in sharing her knowledge of and passion for astronomy.

**Richard H. Emmons Award**
Dr. Jeanne Bishop, a well-known astronomy educator, wished to honor her father, an astronomer with a lifelong dedication to astronomy education, by creating the Richard H. Emmons Award that, since 2006, recognizes and celebrates outstanding achievement in the teaching of college-level introductory astronomy for non-science majors. The 2019 recipient is Prof. Nick Schneider, Professor of Astrophysical and Planetary Sciences at the University of Colorado, Boulder, for his commitment to teaching and his innovative methods.
Teegarden b Crowned “Most Earth-Similar”

Move over TRAPPIST-1, there’s a new (potentially) habitable star system in town. In June, astronomers announced some rather exciting exoplanetary news. Only 12.5 light-years away, two alien worlds were discovered orbiting a diminutive red dwarf called Teegarden’s Star. One of those exoplanets, Teegarden b, is really special as it ranks as having the most attributes like Earth of all exoplanets discovered to date. While we have little idea whether or not it has an atmosphere, it’s been given an Earth Similarity Index (ESI) of 95 percent. It’s almost the same mass as Earth and orbits its star right in the middle of the habitable zone—meaning that if there’s water on its hypothetically rocky surface, it might be in a liquid state. As we are all intimately aware, on Earth, where there’s liquid water, there’s life.

As already discussed on page 3 of this issue of Mercury, however, while Teegarden b may sound like the perfect interstellar getaway, we know very little about its true habitability, so speculation about our new interstellar neighbors is premature.

Discovered by astronomers from the CARMENES project, which is tasked with seeking out exoplanets orbiting cool red dwarf stars, Teegarden b and its sibling Teegarden c have very quick orbits, zipping around their host star once every 5 and 11 days, respectively. Because the pint-sized star system is so compact, it’s likely the two worlds are tidally locked with their star. Tidally locked worlds will have one hemisphere perpetually facing the star, while the other hemisphere is in perpetual darkness. How habitable such worlds would be is anyone’s guess, when one half is always in daylight while the other is in deep freeze. Also, while the star may provide enough heat for liquid water to persist, the two exoplanets will be bathed in radiation generated by the star’s stellar winds. These factors would be a challenge for alien life (with biology like ours, in any case) to gain a foothold and evolve.

One interesting point is that if aliens have evolved in this star system, and if they’ve developed similar astronomical techniques as us, when observing our Sun from their vantage point, they would see the planets orbit in front of our star (events known as transits). So, it’s interesting to think that as we debate how habitable (or not) their planet is, they may be asking the same of that Teegarden b-like exoplanet orbiting a certain nearby yellow dwarf star.
**Ploonets: Moons That Go Rogue**

What do you call an orphaned moon with planetary ambitions? While this may sound odd, astronomers have identified a hypothetical type of object that could be hiding in exoplanetary data—and they suggest that we call these objects “ploonets.”

The ploonet hypothesis may appear, at first, to be a little outlandish, but the scenario is relatively straightforward. In a paper published in the journal *Monthly Notices of the Royal Astronomical Society* this month, researchers have taken a stab at understanding what might happen to an exomoon in orbit around its host exoplanet as a star system evolves.

After forming in the cool outer reaches of a star system, a large gas giant exoplanet may have a bunch of large moons in tow. Over time, as the system evolves, the exoplanet may migrate closer to its star. This inward motion would cause some gravitational perturbations between the planet and moons, in some cases causing them to be ejected. But what happens to them next? Well, after running their simulations, the researchers deduced that while 44 percent of the time the moons will smash into the planet, 48 percent of the time they will end up in orbit around their star sans planetary host (the remaining 6 percent will be eaten by the star and 2 percent will be slingshot into interstellar space). These newly independent ploonets try to live their best lives parading as planets and it’s possible that astronomers have already seen these objects. This could also explain why astronomers have yet to discover any exomoons—of all the exoplanets discovered to date, most are “hot Jupiters” (i.e. large gas giant exoplanets that orbit close to their stars) and this class of world is most likely to lose its moons via this mechanism.

As an interesting side note, in the distant future, our very own Moon might have plooney aspirations: “Earth’s tidal strength is gradually pushing the Moon away from us at a rate of about 3 centimeters a year,” astronomer and lead author Mario Sucerquia told *New Scientist*. “Therefore, the Moon is indeed a potential ploonet once it reaches an unstable orbit.”
Bombing an Asteroid to Reveal Its Secrets

After dropping a pair of hopping rovers onto asteroid Ryugu's surface in September (see the cover of the Fall 2018 issue of Mercury) and collecting its first dusty samples in February, Japan's Hayabusa2 was just getting started.

In April, the robotic satellite shot an explosive impactor (called the Small Carry-on Impactor, or SCI) at the boulder-strewn space rock, blasting a crater roughly 2 meters wide to expose pristine asteroid material under its surface. On July 11, the spacecraft returned to the scene of the bombing and gently touched down a second time to collect material from inside the fresh crater.

During the descent and touchdown, the mission's Small Monitor Cam (CAM-H) captured photos of the operation and the Japanese space agency (JAXA) stitched them together as an animation, allowing us to see the dramatic and otherworldly event unfold. Watch the video, it's spectacular—witnessing the floating debris get kicked up after touchdown is particularly enjoyable.

The whole operation took only 10 minutes to complete and now the samples, which are thought to date back to the dawn of our solar system's formation billions of years ago, are in sealed containers awaiting the return trip to Earth.

The highly successful mission is due to leave Ryugu in December, making a flyby of our planet a year later to drop off the samples, before the spacecraft continues its interplanetary voyage to rendezvous with another deep space target.
**ALMA Gets Intimate With a Black Hole’s Dinner**

The world's most powerful radio observatory has zoomed into the center of a massive galaxy to study the violent, swirling mess of cold interstellar gas that will eventually be slurped down by one of the most monstrous supermassive black holes known. The gargantuan black hole lurks in the center of elliptical galaxy NGC 3258, which is located about 100 light-years from Earth. Astronomers from Texas A&M University and the University of California, Irvine, used observations by the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to precisely measure the motion of gas surrounding the black hole to determine that it's packing a mass of an incredible 2.25 billion Suns!

While this is undoubtedly a very large black hole, from 100 million light-years away, it appears extremely small and ALMA alone cannot directly image the black hole's event horizon (although the observatory is a part of the global Event Horizon Telescope that released its first image in April; see the Spring 2019 issue of *Mercury*). By observing the motion of the disk, the researchers could measure the gravitational effects that black hole has on the surrounding material to indirectly determine its mass.

While there are several ways to “weigh” a black hole, in the last decade, ALMA has pioneered this new method to study supermassive black holes in elliptical galaxies. Approximately 10 percent of elliptical galaxies possess rotating disks of cold and dense gas in their cores which contain carbon monoxide (CO)—a molecule that can be detected by millimeter-wavelength radio telescopes. Whereas the Hubble Space Telescope can see the disk of gas and dust in the region, ALMA can determine the direction and speed of rotation (by measuring its Doppler shift), adding another layer of information that astronomers wouldn't otherwise have access to.
space news

InSight: Operation “Save the Mole”

NASA’s newest Mars resident, the InSight lander, measured its first “marsquake” on April 2, 128 days (or sols) after landing on Elysium Planitia (see page 11 of the Spring 2019 issue of Mercury). While the seismometer instrument is making great gains in helping us understand how seismically active the Red Planet is, another key instrument, the Heat and Physical Properties Package (HP³), a.k.a. “the mole,” has had a tougher time in getting started. While hammering its way underground on Feb. 28, the heat probe stopped burrowing and mission scientists have since been working to get the 40-centimeter (16-inch)-long probe back on track.

In June, InSight’s robotic arm was commanded to painstakingly lift the mole’s support structure out of the way so they could get a better look at the task in hand. What they saw was a partially chiselled pit with the mole’s rear end sticking in the air. The lander isn’t exactly designed to provide a mole breakdown service, but plans are in full swing to see what can be done with the tools the robot has at its disposal. And one tool might just be up to the task in hand: the small scoop on the end of InSight’s robotic arm.

The team has deduced that the probe hit something hard as it dug, whether that be a rock or unexpectedly hard soil. The result was that, as the mole continued to dig away, it carved out a little pit. In doing this, the mole lost traction and just bounced around without making progress. So, it’s hoped that by using the scoop to push down on the material surrounding it, the pit will collapse and the mole will gain some much needed traction so it can continue to burrow.

“We’ve completed the first step in our plan to save the mole,” said Troy Hudson of a scientist and engineer with the InSight mission at NASA’s Jet Propulsion Laboratory in Pasadena, Calif. “We’re not done yet. But for the moment, the entire team is elated because we’re that much closer to getting the mole moving again.”

The mole in the pit and InSight’s scoop as imaged on July 28. [NASA/JPL-Caltech]
A Cometary Surprise

Although the European Rosetta mission was commanded to crash into comet 67P/Churyumov-Gerasimenko on Sept. 30, 2016, ending a historic mission of intrigue and discovery, that doesn’t mean the discoveries have stopped coming.

A few months ago, astrophotographer Jacint Roger from Spain was studying archived images of the 2.5-mile (4 kilometer)-wide comet when he noticed an “unexpected companion” in orbit. The images (that Roger stitched together as a handy animation on Twitter) were captured by Rosetta in 2015 as the comet was a couple of months post-perihelion (closest point to the Sun of its 6.5 year orbit), so activity on the comet’s nucleus was still very active—the ices were sublimating via heating by sunlight, ejecting gas, dust and other debris into its extended coma. It appears that a sizable chunk of “other debris” broke off and became a four-meter (13-feet)-wide mini-moon, a satellite that mission scientists are now studying to understand its origin and whether or not it remained in orbit. By modelling the object’s path around 67P, mission scientists have been able to deduce that it remained in orbit for at least 12 hours, and later observations (after the object had passed behind the comet) suggest it was still there as of Oct. 25, 2015.

Dubbed a “Churymoon,” the object was imaged by Rosetta’s (Optical, Spectroscopic and Infrared Remote Imaging System) instrument, which had a knack for imaging the small pieces of debris that the comet was blasting out into space, often revealing a blizzard of particles when the comet underwent peak heating at perihelion. Sometimes the quantity of debris in Rosetta’s orbit was so dense that the spacecraft’s starfinder system would become confused, sometimes triggering the spacecraft’s safe mode.
Total eclipses of the Moon are regarded now as mere spectacle, but there was one such eclipse that witnessed a turning point in astronomical history.

Before dawn on October 18, 1092, a monk named Walcher was observing the sky from Malvern, a town 120 miles northwest of London. Walcher was not just the second prior of the monastery at Malvern, but an astronomer. On that morning he used an astrolabe to determine the mid-point of the lunar eclipse.

If you are familiar with Arab astronomy, this was not exactly a momentous event—the astrolabe had been in use for centuries, allowing people to measure the time of day (or night) based on the Sun’s altitude or, at night, the Moon’s altitude. But its very first use as an astronomical measuring instrument in Western Europe was on that morning in 1092.

While living in Italy the year before, Walcher had observed a lunar eclipse, but he was only able to record seeing it in the west before dawn. Returning to England, he met another monk who had seen the same eclipse in the east, before midnight. Scholar Dorothee Metilski writes that the discussion they had about the difference in eclipse time was “of the greatest significance in the introduction of Arabian science into Europe.” The ‘eclipse method’ of calculating time (and thus finding latitude and longitude), which Walcher pioneered in England with an astrolabe, was in use for the next 500 years.
Walcher went on to create a set of tables for 76 years, from 1036 to 1111. He used 940 conjunction times to improve the existing method of tracking the path of the Moon and Sun through the zodiacal signs. In his study of the Moon, Walcher calculated its daily motion in both zodiacal parts and in terms of hourly motion. He wrote in a treatise in the year 1112 that his inspiration was “the change in the Moon’s waxing and waning” that affected the human body. Many people even today relate their mood, or even the prevalence of crime, to the phases of the Moon. Walcher hoped his work would have medical applications.

But his tables contained inherent errors; he noted even as early as the September 23, 1093 solar eclipse that his predicted times were in error by several hours. By 1108 his lunar eclipse prediction was off by 16 hours. It was not until 1120, when Walcher met Petrus Alfonsi, that he learned how to create more accurate tables. Alfonsi’s knowledge of astronomy and medicine derived from the Islamic parts of Spain. Taught by this Hebrew scholar, Walcher “became the first medieval Latin author to properly expound the notion that the Moon’s orbital nodes performed their own motion along the zodiac in a direction contrary to that of the Sun and Moon.” I quote here from a new book, Scandalous Error, by Nothaft, who identifies the encounter between Walcher and Alfonsi “as a key moment in the history of European astronomy.” It resulted in a tract entitled De dracone, attractively penned in green, red and black ink by Walcher in 1120 with the express purpose of disseminating the knowledge he had gained from Alfonsi. One major change between his 1112 tract and this one is that the former used awkward Roman numerals and fractions; the Arabic numerals we use now appear in his 1120 work.

Alfonsi wrote his own astronomical tables while in England, dated to 1116. The manuscript, now in Oxford, is based on Arabic tables compiled two centuries earlier by al-Khwarizmi, a Persian astronomer. Thus at least some elements of the great astronomical tradition of the Islamic world finally reached England; another great scholar, Abraham bar Hiyya, performed the same service for southern France as his translations from Arabic were concentrated in Toulouse.

As for the astrolabe he acquired in England, we know Walcher’s was based on a design from Toledo, Spain, and likely was made there. In his account of the 1092 observation, he made mention of three of the instrument’s points, using their Arabic names. Three centuries later, around 1390, Chaucer wrote an influential treatise on the astrolabe, the oldest work in English about a scientific instrument.

Walcher died in 1135; his tombstone describes him as “a good astronomer.”

DR. CLIFFORD CUNNINGHAM was recently seen chatting with Mr. Spock (Zachary Quinto) in Austin, and Capt. Kirk (William Shatner) in Pensacola.
How to Celebrate Apollo 11? Teach Its Science

There’s a huge collection of online resources to learn about the Moon and all things Apollo.

On July 20, 1969, Apollo 11 landed on the Moon. The legacy of the Apollo missions continues to transcend time and data collected by the Apollo missions still yields new discoveries, from lunar rock samples to instruments left on the lunar surface. If you want to capitalize on the excitement of the 50th Moon landing anniversary in your classroom this fall, there are several online resources to consider.

You and your students can experience the excitement of the Apollo 11 lunar landing. “First Men on the Moon” includes video footage from the lunar lander module as it descends toward the Moon’s surface. The experience also includes audio from both the astronauts and flight control. The audio is accompanied by text transcripts and thumbnail images of each speaker. You even hear Buzz Aldrin’s iconic phrase “The Eagle has landed” as you near the end of the 18-minute landing process!

Likewise, you can “live stream” Apollo 17, the final mission to the moon, in December 1972. “The Last Mission to the Moon” even allows you to experience the excitement of the launch. This site contains actual control room video footage during launch and as well as a transcript of the dialog. Now, this site includes the entire mission: from rocket launch to lunar landing and back to Earth on a collection of over 300 hours of video! You can select portions of the mission by scrolling down a pane on the right-hand side. During the lunar mission, you see both video and image stills captured by the astronauts. With so much on this site, you are limited only by your imagination!

Getting to the Moon was an incredible endeavor involving science, engineering, computer coding, and politics. You can explore...
the full scope of this endeavor at the Smithsonian National Air and Space Museum website. “Apollo to the Moon” includes topics such as getting to the Moon and astronaut life as well as details about all Apollo missions. Computer buffs in your class might be interested in the software for the Apollo mission. 
If so, the original code is on GitHub. Meanwhile, those more interested in the Apollo Guidance Computer itself can check out virtual simulations.

What about images and informational videos? NASA has a web-site dedicated to the Apollo missions. The left hand menu provides an informative collection of topics. Choose “About the Apollo Missions” and you can explore individual Apollo missions or learn about Saturn rockets. “Apollo 11” celebrates the mission that first took men to the lunar surface. You can also browse images of the Apollo landing sites by choosing “Apollo Sites Revisited.” The Lunar and Planetary Institute has a cool set of Apollo lunar panoramas and Arizona State University’s “Apollo Image Archive” consists of a large collection of images scanned from original NASA films. The latter site has a whole page devoted to the method of digitizing images from old photographic film: you could use this to discuss how students in disciplines like film studies and video production might find careers preserving archival scientific data! Kipp Teague’s “The Project Apollo Archive” has loads of NASA images and videos, an interactive “Lunar Lander Simulator”, and Apollo memorabilia. (Take a look at the Ronald McDonald official Rand McNally Map of the Moon!)

If you want to dig a bit deeper, the “Virtual Microscope” has an extensive collection of rocks from all six lunar landing Apollo missions. Each sample includes a fact sheet and microscope slides. Now, you might be thinking “Darn it, Jen, I’m an astrophysicist not a geologist!”—no worries, I’ve got you covered! The Teaching Resources page directs you to resources on petrology and the study of rocks using a microscope. And if, like me, you are not a lunar expert, you might want to start your lecture preparations by watching a few videos from the Lunar and Planetary Institute’s “Moon 101 Lecture Series.”

DR. JENNIFER BIRRIEL is a stellar astrophysicist and Professor of Physics at Morehead State University in the newly formed Department of Physics, Earth Science, and Space Systems Engineering. She was born in 1969 — a few months after the Apollo 11 landing. (And, yes, she is a fan of the original “Star Trek” series!)
Voids Fill in the Voids About Universal Expansion

In cosmology, Buddha strikes again.

All is possible when emptiness is possible.” So said Nagarjuna, among the most revered Buddhist philosophers, some 18 centuries ago.

It seems that Nagarjuna was on to something. The answer to one of the most profound questions in cosmology—how fast is the universe expanding, or, more to the point, where is this crazy thing headed—may lie in emptiness, those lonely stretches of space called cosmic voids with nearly no stars or gas.

A paper published in July in the journal Physical Review D further matures this exciting new field of void cosmology and the measurement of the expansion rate of the universe, the cosmological constant (or, the vacuum energy of space), and dark energy, the hypothesized force thought to be accelerating the expansion of the universe.

In this regard, the darkest parts of the universe may be the most illuminating.

Astronomers describe the universe as a cosmic web with bright galaxies strung along filaments of matter separated by dark voids. These voids were chiseled out by gravity—or lack thereof. When the dust settled after the Big Bang some 13.8 billion years ago, matter began to coalesce under the attractive force of gravity. Regions slightly more dense pulled in matter from regions slightly less dense.

In short, the rich got richer and the poor got poorer. Within a few hundred million years, brilliant galaxies formed, glowing like jewels along these filaments of matter, leaving the voids bereft of any matter to form many stars, let alone whole galaxies. Fast-forward 13 billion years or so. Astronomers now see revelatory information...
in the distorted shape of these voids and how they change over time, as their shape is a product of cosmic expansion.

Our primary understanding of cosmic expansion comes from studying the redshift of so-called standard candles, such as Type Ia supernovae, thought to glow at a uniform rate; and thus their distance can be determined by how dim they appear to us. Data from the first detectable light in the universe, the cosmic microwave background (CMB), also establishes important parameters, such as the amount of matter and energy in the universe.

Nevertheless, studying voids as a cosmological tool dates back several decades. One important paper in the field was published in 2016, in Physical Review letters, succinctly titled “Constraints on Cosmology and Gravity from the Dynamics of Voids” by Nico Hamaus, Alice Pisani, Paul M. Sutter and others.

Tapping into data from the Sloan Digital Sky Survey (SDSS), the team analyzed the spatial distributions of galaxies near cosmic voids. What little matter that does remain in the voids pines for the edges, where the dense matter is; and meanwhile, the vacuum energy in the void pushes the boundaries farther and farther apart. The team’s analysis revealed a four-times improvement in precision in the modeling of matter density and the growth of cosmological structure.

The latest work, led by Seshadri Nadathur of the University of Portsmouth, builds on this SDSS analysis by incorporating a new theoretical modelling of distortions in voids that Nadathur says is more accurate and has been tested using simulations.

His group looked at numerous voids at an average distance of 5.5 billion light years, an era when dark energy appears to have kicked into action to accelerate cosmic expansion. They also applied a measurement technique called “velocity field reconstruction” and combined this with data from galaxy clustering (a cosmology mainstay) and baryon acoustic oscillations (a relic imprint from sound wave in the hot plasma of the early universe). This combined effort lowered the uncertainty of these cosmological measurements by a factor of two, Nadathur said.

“Void studies have been a little on the periphery of the field of cosmology,” Nadathur said. “We think our new result will bring it front and center and make voids one of the standard tools of future studies.”

Much more needs to be understood in this type of modeling, however, to be sure astronomers aren’t making predictions based on false assumptions. As Nagarjuna also said, “Emptiness wrongly grasped is like picking up a poisonous snake by the wrong end.”

CHRISTOPHER WANJEA is a Baltimore-based science writer. His book Spacefarers: How Humans Will Settle the Moon, Mars, and Beyond will be published by Harvard University Press the spring of 2020.
Why Do Galaxies in Large Clusters Age Prematurely?

When humans age, environmental factors can play a huge role in our health—the same is apparently true for galaxies.

Let's visualize together for a moment. We live on Earth—the third planet from the Sun. The Sun is a pretty average star, not very large, and living its best middle-aged life. Though it's special to us, our solar system isn't so unique either; there are about 300 billion other stars in the Milky Way galaxy, most of which also have planets.

If we zoom out a little more, we can see that the Milky Way is dancing with roughly 50 other galaxies … which also have hundreds of billions of stars with planets. This little collection of galaxies is known as the Local Group, and even that's not very exceptional. That's because some galaxies are in huge groups with hundreds to thousands of other galaxies, all gravitationally bound to one another. These structures are called galaxy clusters, and they are the most massive objects in the Universe. Let me repeat that: the MOST massive.

If we were in one of these clusters, our night sky would look very different. For one thing, it would be brighter, as our neighborhood would be quite crowded. The stars in our own galaxy would appear red or yellow instead of blue, as blue colors signify youth in a galaxy, emitting from areas where new stars are born—but our galaxy would likely never birth a new star again. In fact, almost every galaxy in our neighborhood would look like a dim, orange blob of light because nearly all galaxies in clusters are no longer forming stars—a conundrum that really bugs astronomers.

How do we figure out what killed galaxies in clusters if we can only take pictures of their carcasses?

Let me paint a picture for you: if we think of galaxies as our grandparents, galaxies in cluster environments would be the ones you know lived a hard life just by looking at them. They're always tired; maybe they had too many kids all at once, or they just partied a
little too hard in their youth, and now they live in a home with other senior citizens who went through something similar.

However, galaxies living in small groups or isolation, like our Milky Way, would be those grandparents that still go salsa dancing once a week and can do more pushups than you can. Really, they will probably outlive us all.

These two types of galaxies were born at the exact same time. But the less crowded ones are still gently forming stars and hanging onto that blue-colored youth, essentially the equivalent of enjoying a really slow retirement.

So, what exactly happened to cluster galaxies that caused them to age so rapidly? To get to the bottom of this, astronomers have created simulations to understand the possible births and lives of cluster galaxies based on data from hundreds of real senior galaxy clusters nearby. This is essentially the equivalent of taking thousands of photos of senior citizens and using physics to model what these citizens might have looked like when they were babies.

As you can imagine, a lot of assumptions and theories go into these models, so we need pictures of middle-aged, teenage, and baby clusters to really test our theories. Thankfully, in the last decade, we’ve started filling in our evolutionary photo album with more middle-aged and teenage pictures ... but we’re seriously lacking baby photos.

Galaxy cluster “babies,” also known as protoclusters, can be difficult to identify because they don’t have the same qualities as their descendants. The galaxies inside a protocluster are likely blue, instead of red, as they are still growing and forming stars. They are also more spread out across the sky as they are still traveling across vast distances to eventually fall into the final cluster formation. And they are hard to see because they live in earlier times in the Universe and are therefore farther away from us.

Due to these difficulties, we must seize the opportunity to study a protocluster deeply whenever we do find one. In the past two years, international teams working with the Subaru Telescope and archival data from the Herschel Space Observatory have identified some very big, very distant protocluster candidates. One of those protoclusters is already proving important to filling in our evolutionary photo album.

The Distant Red Core (DRC) is a massive galaxy protocluster caught in the act of formation in the early Universe. Our current measurements show that every galaxy in this cluster is simultaneously forming stars at extreme rates—I’m talking thousands...
of times faster than the Milky Way galaxy. These galaxies are also violently merging with their neighboring galaxies, a mechanism that’s believed to trigger extreme bursts of star formation as huge reservoirs of gas collide. According to detailed simulations, these processes are believed to accelerate galaxy evolution, bringing the senior lifestyle to the cluster galaxies at a much more rapid pace than their isolated peers.

Soon, we will determine exactly how many galaxies are expected to collapse into this protocluster—is it tens or is it hundreds? Then, we will predict what the cluster might look like today after evolving for 11 billion years.

Over the next decade, new powerful telescopes will help us discover and characterize more infant galaxy clusters so we can get a more complete story. Even more enticing, since galaxy clusters are likely some of the first objects to form in the Universe, we will be able to use these protocluster studies to map out the fingerprint leftover from the Universe’s own birth—the Big Bang.

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Are Supermassive Black Holes Galactic Regulators?

*Feedback from active galactic nuclei may influence a galaxy’s ability to form stars.*

At the core of every massive galaxy resides a supermassive black hole (SMBH). The majority of these black holes, including the one at the heart of our own Milky Way galaxy, called Sagittarius A*, are relatively dormant cosmic entities. However, some of these objects have voracious appetites. For these select few, which are known as active galactic nuclei (AGN), an abundant supply of gas, dust, and interstellar matter rapidly funnel onto their central cores. As this accreting matter swirls around the heart of the host galaxy, powerful electromagnetic radiation is generated, which may appear as brilliant jets emanating perpendicular to the galaxy’s plane of rotation.

There are outstanding questions regarding the physics of AGN and astronomers are trying to understand how this energetic accretion disk, and its associated outflow of radiation, influence the overall properties of a host galaxy. To tackle this unresolved phenomenon, Robert Maiolino at the Kavli Institute for Cosmology (UK) and Giovanni Cresci at The National Institute for Astrophysics (Italy) considered both theoretical and observational results to elucidate the dynamics of AGN and galactic co-evolution.

They report on X-ray observations which directly map outflows on parsec-scales near the accreting SMBH. Outflows confirmed in this region fiercely emerge from the galaxy’s central engine at velocities near 10 percent the speed of light! Comparatively, as the outflows propagate out to kiloparsec-scales, their presence is inferred through interactions with neighboring matter. For example, massive, high velocity outflows may strike nearby gas and strip them of some of their electrons. These highly ionized species of gas can then be measured in the spectra of galaxies that host an AGN.

AGN models consider the dynamics of these energetic environments and attempt to predict how star formation is affected by this radiation. Several recent models yield results that suggest these
outflows can halt star formation, whereby galactic matter necessary to form stars is heated and ultimately removed in the path of the outflows.

However, the statistical observational evidence to support these results is unfortunately sparse. In response, astronomers consider a relatively new technology—Integrall Field Unit (IFU) spectroscopy. This technology operates by utilizing a bundle of optical fibers that are assembled into a precise array to conduct observations. These observations can then generate spatially resolved spectra across an entire galaxy. In fact, many observatories, such as the Apache Point Observatory in Sunspot, New Mexico, rely on IFU spectroscopy to determine the local impacts of AGN outflows across a galaxy.

Utilizing this method, astronomers conducted near-infrared observations of a sample of AGN between a redshift range of $z \sim 1-3$, and determined a spatial anti-correlation between fast outflowing gas (traced by OIII emission) and the presence of star formation (traced by Hα emission) in the central regions of the galaxies in the survey, supporting the results presented in the simulations.

The findings also suggest that the outflows do not necessarily cause a galaxy-wide shutdown of star formation, and that the local suppression of star formation may not occur simultaneously with the outflows. Rather, the researchers propose that the presence of outflows and subsequent suppression of star formation may occur after a delay, on the timescale of a billion years. They reason that the energetic outflows heat the nearby gas to such an extent that the cooling necessary for star formation becomes inhibited as the galaxy evolves. This mechanism is known as “negative feedback” and operates to limit the total mass of a galaxy.

In contrast, some theorists pose a “positive feedback” mechanism, whereby fast AGN outflows may actually stimulate star formation through the compression of molecular clouds (as traced by CO observations at millimeter wavelengths) in the galactic disk, or even directly in the outflows! The basis of this assertion stems from the observed correlation between AGN luminosity, which traces AGN activity, and nuclear star formation rate, which is measured by the density of molecular gas in the central region of a galaxy. While evidence has been proposed for this relation in a $z \sim 1.6$ quasar and a local AGN (NGC 5643), there is still a lack of statistically robust observational data to support the process.

Ultimately, higher spectral and spatial resolution observations, more accurate models, and a richer sample of AGN at a uniform redshift are required to determine the true nature of AGN feedback—either positive, negative, or a combination of the two. Researchers are eager to uncover this cosmic mystery and the topic continues to be the subject of much debate in the astronomical community!

JAMES NEGUS is currently pursuing his Ph.D. in astrophysics at the University of Colorado Boulder, and also serves as the ASP’s Junior Board Fellow. He analyzes Active Galactic Nuclei and their role in galactic evolution utilizing the Sloan Digital Sky Survey. Find out more about James on his website.
Bridging the Learning Divide

Formal and informal learning have their pros and cons, but the ASP is at the intersection working to get the best out of both.

Learning is a remarkable attribute. With little apparent effort, almost everyone adds to their knowledge and skills on a regular basis. The majority of learning takes place outside of a formal classroom environment, however, which may suggest the time spent in classrooms is an aberration (or at least a departure from the norm), but it remains the venue that we most closely identify with “learning.” It may not be so surprising, then, to find out that many of whom who find the classroom environment challenging revel in the opportunities offered by the informal realm. This seems particularly true for science related venues. The eagerness seen in visitors to museums, festivals, and even public star gazing events speaks to the desire humans have to increase their understanding of the natural world, and in particular the universe beyond our home planet.

A formal science classroom environment, at least these days, places an emphasis on inquiry-based pedagogy with students investigating natural phenomena, collecting and reasoning about evidence. This is possible due to the prolonged contact teachers have with learners throughout the course of a year. Informal environments don’t generally have the luxury of time with which to develop concepts, or to allow learners to undertake long-term projects. Many, such as The Exploratorium, have exhibits that are interactive in nature, where visitors have the opportunity to interact directly with a variety of phenomena. These, in turn, frequently influence classroom practice.

The Astronomical Society of the Pacific has long involved itself with developing programs and resources useful in a variety of environments, frequently bridging the gap between the formal and informal. Project ASTRO, for example, is a program where volunteer astronomers are partnered one-to-one with individual classroom teachers. It is one of the first programs to work with scientists to help them better connect with their audience. An essential element of
Project ASTRO is bringing the teams together for professional development and planning time to ensure the experience is more than a lecture. The astronomer then visits “their” classroom at least four times during the school year.

One of the challenges for a program such as Project ASTRO is the way in which the volunteer astronomers learned themselves. The majority of them were in school prior to the emphasis on inquiry-based investigations and, as with many with a scientific mind, thrive in a lecture and demonstration-rich environment. At times it can be difficult to imagine someone learning in a different way than how we learned, and making an adjustment can take time as a different perspective takes hold.

Other programs at the ASP have addressed this need to make available resources and professional development to help astronomers make the necessary shifts so as to best actively engage their audiences and visitors to their events. The Night Sky Network works with amateur astronomy clubs around the country to provide them with materials and techniques to use in their local outreach events. The AAS Astronomy Ambassadors program, and now the NSF-funded On The Spot programs work with early career scientists to give them tools and techniques to better understand where their audience is at, and to make adjustments to their presentations in real time.

For much of the general public, a visit to a planetarium is a great introduction to the realms of the cosmos. This is true for many classrooms as well with most planetaria offering programming for classroom field trips. While they may have a scripted live show with a tour of the night sky, and a set recorded program, many times the experience is little more than playing a video on an overhead dome. While most attendees may find this an uplifting experience, it’s a passive one without an active educational component. The ASP’s second NSF-funded program seeks to correct this.

Project PLANET is working with 1st and 3rd grade teachers to develop an instructional sequence to include a storybook, and a planetarium experience. Drawing on the books Moonbear’s Shadow, and Breakfast Moon, and activities developed for My Sky Tonight, the project is developing an active learning environment for investigating shadows and lunar phases. The planetarium experience will directly support classroom practices in an interactive format. Project PLANET aims to create a collaborative environment for learning across venues and preliminary results indicate students participating in the project benefited from exposure to its three-pronged approach.

The common element in all of these programs is the bridging between the formal and informal educational realms. Drawing on the strengths of both, the educational opportunities for people with different learning styles will continue to find inspiration as they add to their understanding of the universe of which they are a part.

BRIAN KRUSE manages the formal education programs at the ASP.
Just the Facts

To avoid the eighth-circle-of-hell tedium of grading, lean on your students’ collaborative creativity and have some fun.

Astronomy is a big field. Possibly the biggest (to paraphrase Douglas Adams). Every day, astronomers add volumes to the encyclopedia of the universe while revising others. As much as I would like to, there is literally no way I can keep up with everything going on.

Unfortunately, students come to ASTRO101 seemingly expecting that their professor not only knows every factoid about the universe, but will also teach it.

In 15 weeks.

With a mere 37.5 contact hours (plus labs), I can’t possibly detail every single Uranian moon, no matter how cool their names are. I do, however, want my students to get a feel for how they can discover and convey astronomical information, so I set them all loose on teaching the factoids that they are clamoring to learn in a fashion that does not involve eighth-circle-of-hell tedium to grade: humorous videos.

My first—and largely unsuccessful—round of video assignments was assigned back in the dark ages 2005, when I attempted to get student groups to create shows about constellations for our small planetarium. “This will be cool,” I told myself. “We could show school-children neat things about this season’s sky!” So, over the course of several weeks, I gave the lab groups prompts about the mythology, prominent stars, deep sky objects, and best viewing times for their constellations. Unfortunately, every show wound up being an illustrated, narrated homework assignment. “In Greek mythology, [constellation] was [constellation’s backstory]. The brightest star in [constellation] is [name]. There are [x] galaxies and [y] nebulae in [constellation].” And, as it was the culminating project for the lab,
everyone saw all the video projects on the last day of class at the “Astronomy Film Festival.”

Most wound up being as dry as dust. Worse still, it was a pedagogical nightmare, as there was no way for students to learn from the mistakes of others or to showcase their own creativity. I abandoned the whole video project idea for a few years, and then inspiration smacked me in the face like the supersonic punch of a mantis shrimp.

It was Ze Frank’s “True Facts about the Mantis Shrimp,” an irreverent—but fascinating—exploration of the mantis shrimp narrated in the impersonated voice of Morgan Freeman. Rated PG-13, each True Facts video showcases a different—often unusual—animal. The series began in 2012, and it soon picked up sponsorship from BBC’s Earth Unplugged. If you have never seen a “True Facts” video, stop what you are doing right now and go watch the one about the mantis shrimp.

Now imagine what “True Facts about the Moons of Uranus” would look like. Or “True Facts about the TRAPPIST-1 star system.” Or binary pulsars. Or any one of thousands of topics that you don’t necessarily want to test your students over, but that you would like them to be aware of. Imagine the digital natives in your class mashing up videos, images, memes, and even original animations and music as they create their own story line to convey their research.

This is no longer a circle of hell at all.

To figure out the topics for each semester, I skim the press releases that have come out of astronomy for the previous year or two, leaning heavily toward more obscure objects and missions. Then, during the first class meeting, a representative from each of the fifteen groups in my 100-person class draws their group’s topic from a paper bag. It’s often something they have never heard about, but this novelty gives them a great way to start.

“What is ten?” a confused group once asked. It was actually Io, and I was delighted when their video began with an epic voice narrating, “True Facts about ten. I mean…True Facts about Io.”

One thing I did not want to repeat from my previously unsuccessful video assignment was the sense of overload that comes with having everyone present on the same day of class. Instead, the due dates are staggered. Each group has at least a month to craft their final product, and for five class meetings, three videos are presented. Students (and I) can easily sit through and assess twelve minutes of videos. They make quite an agreeable intermission in a 75-minute class period, in fact.

Obviously, creating a four-minute video on an astronomical topic when you have had zero exposure to astronomy requires more than just a video about the mantis shrimp. I show them one of the more
superlative productions from a previous semester with the challenge, “Here’s the bar that’s been set for you. Try to raise it.” I also provide each group with a starter kit of references (typically including a recent press release related to the topic), timelines, suggestions for scheduling collaborations outside of class, and the rubrics by which they will eventually be graded. They have about fifteen minutes during the first class meeting to set up appointments with their team members, and from there, I leave it up to them unless they specifically reach out for help.

At first there is a bit of pushback from students who have been bitten by previous group projects, but they soon realize that there is no reward for freeloading. If they pull more than their weight, they get more credit. If their group agrees that they didn’t do their share, they get less credit. Group members who contribute nothing get nothing in return. The only way that someone can be a freeloader is if the group collectively chooses to give that person credit, and most groups seem more than willing to hang moochers out to dry. One group even put their absent member in the video’s credits as “Water Boy,” which was a harsh move, to be sure, but except for stipulating that the videos be PG-13 at worst, I do not police their content or presentation. If their style resonates with their classmates, their video will get high marks during our in-class screening.

I have additional advice for them. “Keep up with everything you contribute,” I tell them during that first class meeting. “Someone might not like your ideas or your tone of voice or some other random thing, and so they might be tempted to give you less credit than you deserve. Lay out what you’ve done, how much time it took you do those things… everything. Be able to justify your value to the final production just in case.” I go one further. I tell them that this is precisely the thinking they will need to do when they face job performance evaluations wherever they wind up working. It’s not just about a grade in their astronomy class.

The balance between having a basic template and enjoying creative freedom seems to work. I don’t run into the hyper-scripted problem of “In Greek mythology, this constellation was…The brightest stars are…” Even groups with the earliest due date produce quality videos. Moreover, there are few similarities in style and production. Students have created original raps, hand-drawn...
whiteboard animations (a la “Minute Physics”), and short films with characters and plotlines. Several videos have done such a good job explaining material we later encounter in class that I have used them as resources.

Some videos, though… well.
They need help.

Sometimes the content is grossly inaccurate (spotting this is my job), and sometimes the presentation is cringe worthy (fellow students are brutally honest with their video evaluations). Sometimes both.

Because the last in-class screenings happen around midterm, there is plenty of time for groups to edit and resubmit if they want a better grade. I summarize the content and production issues for them, tell them what grade they will earn if they choose to do nothing, and let them decide. Many groups make the changes to raise their grades, and although I don’t show the edited videos in class, I do make the links available for anyone who wants to watch them.

It’s the rare group that is completely dysfunctional. Sometimes they split into two factions, and sometimes one member feels completely ostracized. I try to help them work things out, but in the event that the differences seem irreconcilable, I allow for secession. While working as a member of a team is a good life skill—and one that my university explicitly requires of the ASTRO101 courses—some teams are toxic. I would argue that it’s a good life skill to learn to recognize these situations and exit them.

Having now screened well over 100 group-produced videos over the past few years, I am thrilled to report that this is an area where students chronically exceed expectations. ASTRO101 students are incredibly creative, and this project provides a bridge between their own personalities and the universe they are researching. As an added bonus, they see that the professor’s role is not to rattle off random facts. They can take care of that themselves. Instead, my job is to help students understand the patterns in the universe so that when new discoveries are made, they have a better chance of seeing where they fit into the bigger picture.

Have you created an assignment for your students that gives them a way to explore astronomy creatively (and that doesn’t involve eighth-circle-of-hell grading)? I’d love to hear about it… and possibly steal it.

DR. C. RENEE JAMES is a science writer and professor of physics at Sam Houston State University, where she has taught introductory astronomy 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.
On July 2, 2019, the Moon passed directly between Earth and the Sun in what was the first total solar eclipse since the Great American Eclipse, on August 21, 2017. The shadow of the Moon crossed the southern Pacific Ocean and was visible to viewers in parts of Chile and Argentina, many of whom traveled far to witness the event. The eclipse was also observed from Earth orbit by NOAA's GOES satellites—and, thanks to some well-timed observation commands by MingChuan Wei of China’s Harbin Institute of Technology and the student-built camera and radio transceiver on the DSLWP-B/Longjiang-2 satellite, from beyond the Moon itself.

The image seen here is one of a series captured by the Inory Eye camera aboard DSLWP-B, a microsatellite that has been orbiting the Moon since June 2018. It has been re-oriented from the original so the horizon of the Moon runs along the bottom (north on Earth is aimed to the upper left) and color-adjusted to approximate natural color. The dark spot on Earth is the Moon’s shadow over the Pacific off the western coast of Chile, captured at around 19:00 UTC on July 2.

The commands to image the eclipse were uploaded to the spacecraft by German amateur radio astronomer Reinhard Kühn, and received by the amateur-operated Dwingeloo Telescope in The Netherlands. Since the camera is incapable of movement, the only way to frame the view is by accurate timing and pointing of the satellite itself.

These are the first such images of their kind, showing the Moon and its shadow cast onto Earth captured in single-frame pictures. While the satellite has imaged the Earth from the Moon before, this is its first eclipse. Find out more about DSLWP-B on the project website.

Thanks to Tammo Jan Dijkema for the information on Inory Eye and the radio telescope process.

[MingChuan Wei (Harbin Institute of Technology, BG2BHC/BY2HIT), CAMRAS Dwingeloo Radio Telescope, Reinhard Kühn DK5LA. Image edit by Jason Major]
Einstein’s Cross Is a Relativistic Wonder

The four bright spots in this image are actually all the same thing: the bright X-ray glow of the accretion disk surrounding an active supermassive black hole—a quasar—located over 9 billion light-years away in the constellation Pegasus. Between it and us lies an entire galaxy, “only” about 400 million light-years away, and the warping of space by its gravity is acting as a lens to bend the light from the distant quasar into a quadruple apparition known as Einstein’s Cross (Q2237+0305).

Recent observations by NASA’s Chandra X-ray Observatory of this (as well as four other lensed quasars) have been used to measure the size of the magnified X-ray-emitting region surrounding the distant black hole, estimated to contain the mass of 500 million Suns. Using a technique called microlensing, which uses individual stars in the intervening galaxy to increase magnification, a team of researchers has determined that the black hole responsible for Einstein’s Cross is spinning incredibly, mind-blowingly fast—over 70 percent of the speed of light. That’s about 470 million miles (756 million kilometers) per hour!

These findings indicate that over billions of years of accumulating material into rapidly spinning, multimillion-degree disks—especially when aligned with their own rotation—supermassive black holes like the one in Einstein’s Cross can keep accelerating until they achieve near-relativistic velocities.

This year marks the 20th anniversary of the Chandra X-ray Observatory, one of NASA’s four “Great Observatories” investigating our universe in specific wavelengths of light from space. Operated by the Smithsonian’s Astrophysical Observatory in Cambridge, MA, Chandra launched aboard Space Shuttle Columbia (STS-93) on July 23, 1999 and is positioned in a highly elliptical orbit, taking it as far as 83,591 miles (134,527 kilometers) from Earth. Watch the video by Steer Films about Chandra’s amazing journey from development to launch and how it has opened our eyes to the X-ray universe. ★

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.
On the FAST Track

A giant radio telescope in China displaced thousands of people during its construction. But now it’s complete, and it could change our view of the cosmos forever.

By Steve Murray

The Five-hundred-meter Aperture Spherical Telescope (FAST).
[National Astronomical Observatories, Chinese Academy of Sciences]
Tianyan (“the eye of heaven”) is open and astronomers are excited about what it’s seeing. The Five-hundred-meter Aperture Spherical Telescope (FAST)—the world’s biggest radio astronomy dish—is demonstrating its enormous potential, even while its commissioning tests are still underway.

FAST astronomers reported some of their initial results earlier this year in *Science China Physics, Mechanics & Astronomy* and *Research in Astronomy and Astrophysics*. Their studies include analyses of abnormal emission shift events, frequency-specific pulse profiles, a study of rotating radio transients and the status of a large-scale sky survey of neutral hydrogen (HI).

Chinese scientists have big plans for the instrument, including support to pulsar timing arrays and to the search for exoplanets. The first FAST pulsar discovery occurred in August 2017, only ten years after project funding was first awarded and, as of July 2019 its pulsar discovery count was up to 85. Astronomers around the world are watching its progress closely. “They’re getting some amazing results for such an early-stage telescope,” says George Hobbs, lead for the Parkes Pulsar Timing Array project at the Australia Telescope National Facility. “FAST is already getting involved in millisecond pulsar timing, and their instrumentation and setup and science cases are all thought out.”

The FAST concept began taking shape in 1994 when attendees at the General Assembly of the International Union of Radio Science began discussing ideas for a next-generation radio telescope. Those plans later evolved into the *Square Kilometre Array*, an approach that didn’t include China’s technical concepts. The country nevertheless decided to press on with their own world-class instrument. Funding for FAST was awarded in 2007 and telescope construction began in 2011.

Scientists chose a site for the telescope about 1,100 miles (1,700 kilometers) from Beijing. A limestone depression among the karst hills of southwest China’s Guizhou Province, known locally as Dawodang, offered natural topography that would reduce construction costs. Its remoteness and sparse population also promised to minimize electromagnetic emissions that could interfere with radio astronomy work. “Sparse” didn’t mean “empty,” however, and 65 villagers living near Dawodang were moved about 9 miles (15 kilometers) away in 2009. Later, nearly 10,000 residents living within 3 miles (5 km) of the site were also moved to ensure a radio quiet zone around FAST. The resettlement costs of $269 million far exceeded the $180 million spent on actual telescope construction.

Although the 1,000-foot (305-meter) diameter antenna at Puerto Rico’s Arecibo Observatory had reigned as the world’s biggest single-dish radio telescope since 1963, that baton was passed in 2016...
when FAST construction was completed. With almost twice the illuminated dish area, astronomers expect that FAST will achieve twice the sky coverage at three times the scan speed of Arecibo, all with greater sensitivity. First light for FAST occurred in September 2016 during its official opening when the telescope observed its first radio source. A two-year commissioning program then began to verify the telescope’s physical systems and software performance.

**Under the Hood**

FAST looks a lot like Arecibo and many of its features are described in comparison to its famous predecessor. The similarities aren’t a coincidence. “A few Chinese astronomers, came out and had a look at Arecibo during the design stage of FAST,” notes Robert Minchin a former Group Lead for Radio Astronomy at Arecibo Observatory. Minchin, now a Senior Scientist with the SOFIA Science Center (USRA), adds that “other astronomers from among the Arecibo user community have also been heavily involved with FAST development.” Although Arecibo lessons may be reflected in some of the FAST design, novel differences give the new instrument some cutting-edge performance advantages.

The dishes of both telescopes, for example, are made of aluminum panels connected via a network of flexible cables, although FAST components are bigger and heavier: 4,450 FAST panels are used to cover more than twice the surface area spanned by 39,000 panels at Arecibo. The cabling system needed to support the more than 2,000 tons of FAST panels weighs another 1,300 tons.

Because both FAST and Arecibo antennas are installed in karst depressions, tracking requires operators to move the telescope receiver. This means that neither FAST or Arecibo can make full use of their dish areas. The illuminated area of FAST has an effective diameter of 984 feet (300 meters) while Arecibo has an effective diameter of 755 feet (230 meters).

Both FAST and Arecibo antennas have a spherical curvature, but while the Arecibo dish shape is fixed, FAST can reshape part of its dish as a paraboloid in real time. A fixed spherical dish focuses reflected energy along a line, requiring receiver position adjustments to collect it accurately. A paraboloid focuses reflected energy to a point, where smaller adjustments can achieve the same goal.

A system of 2,226 mechanical actuators is attached by cables to points along the FAST panel network to create its paraboloid shape. Each actuator can independently vary the length of its connecting cable by about 18 ½ inches (47 centimeters) and the shape can be adjusted continuously to a tolerance of 0.04 inches (1 millimeters) to maintain accurate tracking. An accurate antenna shape is critical because it sets an upper limit to observing performance. And even
with this level of precision, FAST will have operating limits. “The quality of the dish surface—how perfect the parabola has to be—is directly related to the wavelength of light you’re looking at,” says Scott Ransom. Ransom is a staff astronomer at the National Radio Astronomy Observatory (NRAO) and works with the Green Bank Telescope in West Virginia. “The reflecting surface can’t have any bumps bigger than about roughly 1/50th or 1/100th of that wavelength. If you’re going to make a really big dish, it’s easier to get the shape right if you’re only looking at longer wavelengths. It’s difficult and expensive to build to that standard at higher frequencies, which is why FAST will never work much above about 2 GHz.”

Both FAST and Arecibo position a feed cabin at their focal points to house the receivers that collect radio energy. The FAST feed cabin is about 43 feet (13 meters) in diameter and weighs 30 tons—a “lightweight” compared to Arecibo’s 900-ton feed cabin. Three pairs of opposing cables, anchored by six towers spaced around the rim, suspend the cabin 460 feet (140 meters) over the dish, and can be adjusted to position the cabin to within 4 inches (100 millimeters) across a focal plane diameter of 676 feet (206 meters). The cables can also adjust cabin tilt to accommodate the curvature of the dish surface and a 6 degree-of-freedom Stewart platform—where the receivers are mounted—increases pointing accuracy and compensates for wind-induced vibration.

Cabin positioning and dish curvature for FAST are monitored by a laser system. Over 2,000 prisms are installed across the telescope as laser light targets. The position signals they register furnish real time feedback information to control the telescope and to alert operators to any safety limits during its operation.

The FAST team has used two generations of receivers for the telescope. A low frequency ultra-wideband system was installed in 2016 and has been used primarily for commissioning tests and early

A pulsar is a rapidly-spinning neutron star with a powerful magnetic field. As shown in this diagram, beams of radio waves (yellow) are emitted from the pulsar’s north and south magnetic poles, which are offset from the spin axis (red). As it spins, radio waves sweep through our field of view, allowing radio observatories on Earth to register each spin as a flash. [B. Saxton, NRAO/AUI/NSF]
observations between 270 and 1620 MHz. A narrowband receiver was installed in 2018 and processes beams from 19 individual targets over a frequency range of 1.05 to 1.45 GHz. The new system was designed and built by Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO) and Hobbs especially proud of their contribution. “We were quite famous for building multibeam receivers,” he says, “so when FAST said they wanted a survey receiver, they knew it was technology that worked. In fact, they’re very happy with it.”

Growing Pains
During early tests, concerns cropped up with the accuracy of the hydraulic actuators used to control the dish shape and with greater-than-expected wear in these devices as a result of continuously adjusting the panels. Issues like these influenced early decisions to conduct the first major scan of the visible sky by FAST, the Commensal Radio Astronomy Fast Survey (CRAFTS). A comprehensive survey could use the extraordinary sensitivity of FAST to generate an enormous volume of new data while engineering control problems were addressed and other commissioning work continued. CRAFTS takes advantage of the wideband 19-beam receiver to make observations for multiple astronomy objectives—such as the search for galactic and extra-galactic hydrogen, pulsars, and fast radio bursts (FRBs)—all at the same time (i.e., commensally).

CRAFTS is being executed in a “drift scan” mode, using a fixed dish shape and allowing the sky to rotate over the site. The zenith of the receiver is shifted periodically to view a new strip of space, a process that requires about 220 days to complete a single survey, the FAST team plans on performing two such surveys before CRAFTS concludes. Ue-Li Pen is a professor at the University of Toronto and a FAST Fellow—a consultant to telescope staff on a range of science issues. He’s also an astronomer with Canada’s CHIME (Canadian Hydrogen Intensity Mapping Experiment) Telescope, an instrument that operates exclusively in a drift scan mode, so he appreciates the challenges of completing comprehensive surveys like this. “These telescopes both have unique strengths,” he says, “but CHIME has a very wide field of view and sees a lot of sky at once. FAST takes a very long time to survey the sky, but when it does, it’s much more sensitive than CHIME.”

While many of the early technical problems have since been resolved, as of March 2019, engineers at FAST report that considerable pointing calibration work still needs to be done.

A Bright Future . . . and a Quiet One?
Size matters in radio astronomy. “There are two ways to get a lot of signal,” says Patrick Weltevrede. “One is to use a very big telescope, and the other is to stare at the same object for a long time.” And FAST is a really big telescope. Weltevrede, who collaborated in a recent pulsar discovery at FAST, is a Lecturer in pulsar physics at the University of Manchester, United Kingdom and has worked with both the Lovell and Parkes telescopes. Scientists anticipate that FAST may discover over 4,000 new pulsars; about 300 of these are expected to have millisecond periods and about 10 percent of them should be stable enough for use in pulsar timing arrays. Observations of the 21 cm (the 1.4 GHz neutral hydrogen, or HI) line—another big goal for FAST—will offer new insights about the formation of the early universe. Currently, the most distant neutral hydrogen detections have been made at a redshift of about z = 0.2. Early evolution of galaxies, however, are better examined at a redshift of z = 0.3 or larger. Astronomers at FAST are looking to reach out to z = 0.35.

If FAST is a boon for world astronomy, however, it’s also becom-
ing a boon for the local economy. Although Guizhou Province was not a wealthy part of China when FAST began, people were quick to see a regional business opportunity in the new telescope. Pingtang Astronomy Town, has blossomed with breathtaking speed about 10 miles (16 kilometers) from the FAST facility, with businesses, hotels, restaurants and (yes) telescope tours.

The draw is irresistible. Says Hobbs, “Everyone in China knows about FAST and wants to see it.” And scientists at FAST are trying to manage the effects of this popularity. Visitors to the telescope site are capped at 3,000 per day, with strict rules about the use of electronics closer than 3 miles (5 kilometers). But with as many as 10 million visitors a year to the town (based on 2017 tourism estimates), the problem of cell phones, Wi-Fi and other electronic noise may be impossible to control and may become a part of working life for FAST astronomers.

**Pulsar Discoveries Await**

Although FAST is a new, cutting-edge instrument, with time it will find its place as part of a larger astronomy landscape among other radio telescope and other astronomy science agendas. “It’s a very sensitive telescope that can clearly compete with Arecibo in terms of sensitivity,” says Weltevrede, “but other instruments around the world will always have important roles to play. The Parkes Telescope, for example, is located further south, and can cover part of the sky that just isn’t visible to FAST. Some telescopes can observe higher frequencies, too, where the shape of your dish needs to be very accurate. The Effelsberg Telescope [in Germany], for instance, can observe at much higher frequencies than FAST.”

And a lot of radio astronomy research requires those higher frequencies. “FAST has a really big advantage in a huge chunk of pulsar science,” says Ransom, “because it’s sensitive at the frequencies where pulsars emit most of the energy we can see. But there is a whole bunch of science you can get outside of that range such as looking at pulsars toward the galactic center, where you have to go to high observing frequencies to get through the interstellar medium effects. You can’t do that with FAST. As a matter of fact, FAST can’t see the center of our galaxy.”

Still, FAST represents a big leap in capability, and that means that a big leap is coming in our understanding of the radio universe. “If they continue to improve,” adds Ransom, “then FAST will be one of the absolute best pulsar telescopes in the world within the next couple of years. If that happens, the majority of pulsars we know about in say, 5 to 10 years, will have been discovered by FAST. They’re going to do some really amazing pulsar science.”

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The Moon: Earth’s ‘Eighth Continent’?

As economic interest overtakes political competition, a global collaboration has been formed to ensure the lunar surface is explored in an open, peaceful and sustainable way.

By Tracy Staedter

Astronaut Jack Schmitt makes his way to the Apollo 17 mission’s Moon buggy during the last human mission to the lunar surface in 1972. [NASA/Gene Cernan]
It’s been 50 years since Neil Armstrong took a giant leap and became the first person to set foot on the Moon. Massive efforts to advance technology fueled by tensions with Russia created a race for the lunar surface that captivated the world. An estimated 650 million people tuned in to the televised event on July 20, 1969, according to NASA. America won, but the joy was short-lived. In just three short years, manned missions to the Moon would end with Apollo 17. No boot has kicked up lunar dust since.

That’s about to change. NASA has been charged to return to the Moon by 2024 and they’ll have company. Governments from China, India, Europe, Israel, and Russia as well as private space companies, such as SpaceX, Blue Origin, Astrobiotic, and more have all set their sights on Earth’s satellite. Although geopolitical motivations are there, the drive is primarily economic—many see the potential for tourism, mining, and turning the Moon into a waystation to asteroids, Mars, and beyond. How, though, with so many stakeholders jumping onto the lunar bandwagon, will pushing not come to shove? How will countries with no Moon program participate in the excitement? How will individual citizens feel represented?

Answer: the Moon Village Association, a new international, non-governmental organization (NGO) composed of private industry, universities, research centers, government representatives, individual experts, and members of the public interested in exploring the Moon in a sustainable, open, and peaceful way. To date, 250 people have joined from 39 countries, all with the expressed goal of fostering cooperation around what some people call Earth’s “eighth continent.”

The association was co-founded by Giuseppe Reibaldi, formerly a senior executive at the European Space Agency, where he worked for 35 years in many different positions to develop new technologies, engineer the heaviest Earth observation satellite, and manage complex payloads for the International Space Station’s European Columbus Laboratory. An exuberant, self-proclaimed optimist, Reibaldi says he started the Moon Village to help ensure that all people of the world would benefit from lunar explorations and to help define an international code of conduct that regulates the use of space resources.

“The logical place for this is the United Nations, but it’s a complex organization and it’s difficult to achieve results in the short term. That’s why I pushed for the creation of this,” Reibaldi tells Mercury magazine.

It Takes a Village

Reibaldi said the concept for establishing the Moon Village Association arose from a research paper he wrote with Max Grimard, former head of business and strategy at Airbus Defense and Space. The paper, presented at the 2015 meeting of the International Astronautical Federation, analyzed the role that non-governmental
organizations played in rallying public support for global activities. Some successful groups include World Wildlife Fund, the largest independent conservation organization, Amnesty International, which conducts research and promotes action to prevent and end human rights abuses, and Oxfam, which finds solutions to poverty and injustices.

When Reibaldi and Grimard looked at organizations that focused on space, they found that many were based in the United States and concentrated their efforts on lobbying for US-centric programs. Of the international NGOs, such as the International Academy of Astronautics, the International Astronautical Federation, Space Generation Advisory Council, or the Students for the Exploration and Development of Space, none directed their messages to a wide community. “They usually address a minority population of space professionals, or space fans, who do not need to be convinced,” Reibaldi and Grimard wrote in their paper.

Around the same time, Reibaldi set up a reflection group made of space experts from all the world to discuss how private citizens could become more engaged in exploration activities beyond Earth. The team quickly concluded that the Moon was humanity’s next destination and engaging the public early would be important. The Moon Village Association took shape. Unlike the name might imply, the Moon Village is not aiming to build a geographically contained community on the Moon, but rather a virtual community made of individuals and institutional members spread throughout the world.

Reibaldi drew from his career-long network of space experts and began recruiting volunteers to help build a coalition. In addition to Reibaldi, eight other experts make up the core board of directors, including John Mankins, former Chief Technologist for Human Exploration and Development of Space at NASA, Jan Kolar, founder and director of the Czech Space Office, and Tai Sik Lee, a professor at Hanyang University and founder and CEO of the International Space Exploration Research Institute, to name a few. Another nine make up the advisory council. In November 2017, they registered in Vienna as China’s Chang’e 4 mission is one of the 2019 Moon Village Association Mission Prize winners, for achieving a landing on the lunar far side and deployment of the rover Yutu 2. (CNSA)
an NGO and that same month held the first international workshop at the International Space University (ISU) in Strasbourg.

**Synergistic Cooperation**

From the beginning, Reibaldi said he wanted results. He wasn’t joking. Within a year, group members had formulated nine non-binding principles that represented a general consensus of how Moon missions and Moon-related activities should be conducted within the Moon Village. Reibaldi and other members of the Moon Village believe that implementing the association’s tenets could not only bring the world closer together, but enhance knowledge, progress and world peace. To encourage adherence to the principles, they established the Moon Village Association Mission Prize. The 2019 recipients are NASA, for their Lunar Reconnaissance Orbiter, and the China National Space Administration, for the Chang’e 4 lander.

Michael Simpson, the pro bono managing director of the International Institute of Space Commerce and vice chair of the Hague International Space Resources Governance Working Group, says he’s been impressed with the collaborative, conversational dialogues held between Moon Village members. Simpson, who is part of the Moon Village’s advisory council, says he’s seen his fair share of committee meetings. Most of them might be described as briefings, he says, not inquiries. But Moon Village workshops are different. Members, who Simpson says are “not used to sitting on their tails in the face of an interesting idea,” spend a significant amount of time listening carefully, collegially pushing back, and thoughtfully reacting to comments. When it comes to making important decisions, they come from the bottom up. He points to how the Moon Village produced the nine principles. Instead of publishing them first and then responding to reactions from members, the association vetted them to be sure everyone was on the same page. The result were principles that resonated with a significant portion of members, who are not all from the same cultures or disciplines. The process also demonstrates fundamentally how the association works.

“To some extent it’s trying to model the kind of synergistic planning, thinking, and community building that one would hope could emerge among human settlements on the Moon. It’s fairly refreshing to see that kind of approach,” says Simpson.

These synergies are going to be crucially important as different entities explore and settle the Moon, says Simpson. Because so many different places on the Moon will fascinate different people, either because of their scientific, commercial, or geographic uniqueness, various groups will find themselves scattered across the lunar surface. Each will face unknown challenges in a harsh environment that will daily threaten their lives. It would behoove them to work together. “In space, for the current time, you have to be careful who
you offend, hurt, or eliminate, because they may be the very people that your own existence depends upon,” he says.

Perhaps the biggest benefit of the Moon Village, says Simpson, is its ability to “get the conversation out of the scientific-technical-space-geek silo.” They want their message to be heard by a broader public.

Reibaldi repeatedly underscored his commitment to engaging the general public. To get the word out, representatives from the Moon Village will attend events centered on the anniversary of the Moon landing, including the 70th International Astronautical Congress in Washington, D.C., this October. “I am obviously an idealist,” Reibaldi says. But, “We live in a world full of hatred and violence and the young people need to have an example. We need something positive to inspire them.”

**Moon Village Association Principles**

**Principle 1:** Adhere to applicable international rules and agreements dealing with human activities in space, such as the Outer Space Treaty of 1967 and others, and conduct peaceful activities with thoughtful consideration and respect for the cultural heritage of humanity on the Moon.

**Principle 2:** Improve knowledge of the lunar environment and its use for scientific research.

**Principle 3:** Reduce the cost and risk of transport to and from Earth and the Moon, and within cis-Lunar space.

**Principle 4:** Support the economic development of the lunar community.

**Principle 5:** Employ or establish and document open-source engineering standards of broad applicability and/or usefulness.

**Principle 6:** Develop and build elements / systems that provide critical services for lunar missions and activities, such as navigation, communications, power, and resources.

**Principle 7:** Develop and demonstrate technology enabling cost-effective, reliable and safe robotic and human operations on the Moon’s surface and surroundings.

**Principle 8:** Make available sufficient information to allow global cooperation and engagement involving the general public in the expansion of human activities to, and eventual settlement of the Moon.

**Principle 9:** Contribute ethically to human society in terms of culture, the arts, education or other fundamentals.

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That’s No Lightsaber. It’s a Galaxy.

I’m a sucker for Star Wars references in space imagery, so there was no way that I was going to pass on the opportunity to feature this intriguing Spitzer space telescope observation!

As rightly pointed out by NASA, this image certainly isn’t a lightsaber (it’s not a blaster bolt, either), it’s a bit bigger than that. It’s a galaxy called NGC 5866, located 44 million light-years away, that’s almost exactly edge-on from our perspective. As Spitzer views the universe in infrared light, the red line represents heat being emitted by the interstellar dust that fills the galactic disk. As the edge-on disk is so defined, astronomers can deduce that the galaxy has a very flat ring (or disk) of cool dust encircling its outermost regions. The diffuse blue light surrounding the main disk is generated mainly by stars.

NGC 5866 has a diameter of roughly 60,000 light-years, making it half the size of our galaxy and, because of its orientation, we have little idea about its other attributes. Is it a spiral galaxy? We might assume so, but we’ll never be sure. However, we may be able to learn a little about its history.

When galaxies collide and merge, their dusty disks become warped and messy. As this example is very neat and defined, it’s possible that NGC 5866 has had a very peaceful evolution, free from violent merging events in its recent past.
The NASA/ESA Hubble Space Telescope captured its most recent view of Jupiter on June 27, 2019, revealing a stunning array of color and detail in the planet's roiling clouds. As revealed in previous observations of the massive gas giant, Jupiter's Great Red Spot continues to shrink, a phenomenon that planetary scientists have yet to understand. [NASA, ESA, A. Simon (Goddard Space Flight Center), and M.H. Wong (University of California, Berkeley)]