Announcing ASP’s first fully-illustrated skywatching manual!

We are pleased and proud to announce the release of The Total Skywatcher’s Manual, a fully illustrated, family-friendly guide for astronomy enthusiasts of all ages and backgrounds.

Written by ASP staff (Linda Shore, David Prosper, and Vivian White), this quintessential guide will help you choose the best telescope, identify constellations and objects in the night sky, search for extraterrestrial phenomena, plan star parties, capture beautiful space imagery, and much more.

For more information and to order, visit: astrosociety.org/skywatchers

63 SPOT A LLAMA IN THE INCA MILKY WAY

64 LEARN HOW THE ABORIGINALS SEE THE MILKY WAY

63 SPOT A LLAMA IN THE INCA MILKY WAY

In the Andes, the Inca saw shapes in both the stars and the darkness. They believed that the dark patches inside the Milky Way were various unseen drinking animals that they called the “sky river.” They imagined Urcuchillay, the llama-shaped mother, with her baby on her back, walking through the sky river. Further to the southern skies, the naked and young llama named the Milky Way. The Inca also saw a fox, partridge, toad, and serpent in the Milky Way’s darkness.

LEARN HOW THE ABORIGINALS SEE THE MILKY WAY

The indigenous of Australia have observed the sky for 40,000 years, making extremely careful observations of the night sky and passing them down through generations. They are experts in the southern hemisphere skies, where the Milky Way is very easy to see and utterly spectacular. In fact, skies are so clear that you can easily see dark clouds of gas and dust that obscure distant stars. Some aboriginal groups imagine the Milky Way as a river containing fish (bright stars) and water lily bulbs (dim stars). A legend from the Yirrkala community says the two dark patches near Sagittarius (often called the Coalsack today) represent the bodies of brothers who drowned while fishing. To several other clans, the Coalsack is part of a much larger dark feature of the Milky Way that represents a gigantic emu in the sky.
Coloring the Universe
TRAVIS RECTOR, KIMBERLY KOWAL ARCAND AND MEGAN WATZKE
This customized excerpt is from a new book that offers an insider’s look at how spectacular images of deep space are made.

The 2016 Transit of Mercury
FRED ESPENAK WITH PAUL DEANS
What it’s all about, when and where to look, and how to safely view the transit, particularly as a test run for observing the solar eclipse in 2017.

Extrasolar Planets: The Saga Continues
PAUL DEANS
An occasional account of our ongoing discoveries of planets beyond the solar system, including a look into the birthplaces of exoplanets.

Astronomy in the News
Changes in Jupiter’s Great Red Spot, a possible new (ninth) planet in our solar system, and a supernova caught in the act. These are some of the discoveries that recently made news in the astronomical community.
Rippling green curtains fringed with red rolled across the horizon, expanded, brightened, and filled the sky. Overhead, green and purple strands of light poured out of the zenith. There was no Moon present, but the ocean and surrounding mountains were gently lit by this amazing display of the aurora borealis, the northern lights.

Last October I was fortunate to be leading an aurora tour in Norway. We lucked out with the perfect combination of clear skies and a solar blast. For four nights, as we sailed the Norwegian coast, we were spoiled by the best aurora display I think I have ever seen.

The Sun is still active enough that aurora sightings are occasionally made even in the northern US states. But almost-permanent aurora activity occurs under the “aurora oval,” a region stretching from northern Canada to Alaska, northern Russia, northern Norway, and Iceland. Weather permitting, you’re likely to see a display above these areas, which is why companies offering northern lights tours (including an annual Alaska visit by MWT Associates, one of the ASP’s supporters) head to these regions.

But be warned. The appearance of these celestial lights (not to mention the state of the regional weather) is impossible to predict months in advance. So if you book an aurora tour, keep in mind an old saying: you pays your money and you takes your chances. I really did luck out...and I know it.
Back to the Future with the ASP Catalog

*With the return of the ASP catalog comes a variety of new products.*

July 15, 2015. The end of an era. That’s the day the legendary F.A.O. Schwarz flagship store in Manhattan — located in the ground floors of the General Motors Building at Fifth Avenue and 58th Street — closed its doors for good.

This iconic toy palace first opened its doors in New York City under the name *Schwarz Toy Bazaar* in 1870, and by 1896 it was known throughout New York City as the “Original Santa Claus Headquarters.” Most people know this F.A.O. Schwarz store even if they never had the chance to visit. Tom Hanks made it famous in the movie *Big* when he played “Chopsticks” on the store’s “Piano Dance Mat,” a gigantic keyboard played by stepping on it (right).

I first visited this F.A.O. Schwarz store in 1987. I was a 27-year-old science education doctoral student studying in Boston out traveling with a girlfriend. She had grown up in New York City and just had to make her annual pilgrimage to the store. Clutched in her hands was the store’s annual holiday catalog, first published in 1876.

It was hard not to be impressed by the store’s main entrance. Twinkling above your head were 80,000 LED lights, and you were surrounded by fantastic displays of toys of every kind. But stuffed animals, dolls, and trains were not my cup of tea. I was an astronomy nerd, and my favorite “toy catalog” was waiting in my mailbox back in Boston. It was the one published by the Astronomical Society of the Pacific’s “Astronomy Shop.”

If you were an ASP member between roughly 1980 and 2000, you have the same fond memories of the Society’s catalog. When it was established in 1978, there weren’t a lot of other ways to purchase astronomy-related items and gifts — and even fewer places to find education resources and materials to help you teach astronomy more effectively. I was just like one of those kids at F.A.O. Schwarz whenever the ASP released a new slide set. And then there were those goofy bumper stickers such as “Astronomy is Looking Up,” “Astronomers Do It In The Dark,” “Black Holes Are Out Of Sight,” and my personal favorite — “If The Universe Is Expanding, Why Can’t I Find A Parking Space?”

I was crushed when the ASP stopped publishing its catalog of goodies in 2008, and perhaps you felt the same way. The F.A.O. Schwarz of astronomy had closed its doors.

What happened to the Society’s catalog is completely under-
standable. The cost of producing and mailing a full-color catalog became prohibitively expensive and a tremendous financial burden to the ASP, particularly with the emergence of the Internet and online retailers such as Amazon.

Of course, the ASP Store never actually went away. Even today we still sell astronomy education resources, lunar calendars, planispheres, activity kits, and past volumes of the ASP Conference Series. But the ASP Store is currently a modest operation.

When I arrived at the ASP to serve as its Executive Director, many members told me how much they missed the ASP Store Catalog. Many said the catalog — along with the 10% discount — was an important membership benefit and the primary reason they became an ASP member in the first place. You have been heard.

It is with great excitement and pleasure that I announce the return of the ASP Catalog and the introduction of new products!

While the ASP will not be mailing out a full-color paper catalog, we will be creating a modest digital publication and e-mailing it directly to ASP members each year. You will still be able to purchase ASP products on the website (https://www.astrosociety.org/astroshop/), and you will receive a 10% membership discount.

Proceeds from the ASP Store directly fund the Society’s astronomy education initiatives, including programs providing assistance to science teachers, museum educators, park rangers, amateur astronomers, and out-of-school STEM programs for children. Re-establishing the ASP Catalog not only helps sustain our astronomy education programs, but it also allows us to support your passion for astronomy and help you share what you learn with others.

The F.A.O. Schwarz of astronomy welcomes you back. Please look around the store!

LINDA SHORE is the Executive Director of the Astronomical Society of the Pacific.

What’s In Store

You may already have purchased some of the new items we released for the 2015 holiday season. These new products are still available and include:

• The Total Skywatcher’s Manual, the ASP’s first stargazing book in its 126-year history.
• ASP Star Quest Fundana, a bandana featuring a northern hemisphere constellation map.
• ASP Glass Mug, the first of a line of collectable coffee mugs depicting all 88 constellations, this one features the nebulae, star clusters, and other objects found within Orion, the Hunter.
• ASP Stainless Steel Travel Mug, featuring a list of the major meteor showers of the northern and southern hemisphere.
• ASP Skywatcher’s Kit, everything a beginning stargazer needs to get started.

You can find these products on our ASP Astronomy Gifts page.
This year marks the 300th anniversary of two events relating to the transits of Venus in 1761 and 1769. First, it was in 1716 that Edmond Halley published an important paper linked to future transits. Even though he did not live to see the Venus transits, his work laid the foundation for the great international effort to observe them.

In 1716 Halley wrote “Venus’s transit over the sun’s disk, whose parallax, being almost 4 times greater than that of the sun, will cause very sensible differences between the times in which Venus shall seem to pass over the sun’s disk in different parts of our earth. From these differences, duly observed, the sun’s parallax may be determined, even to a small part of a second of time…”

What was so important about measuring this parallax? Quite simply it would give astronomers their first way to definitively measure distances to the planets. Nothing less than our fundamental understanding of the size of the solar system was at stake. Based on Halley’s paper, European nations mounted major international expeditions to observe both transits.

The transit of Venus in 1769 brought forth the greatest outpouring of research papers the science of astronomy had ever seen for a single event. It is estimated 400 papers were sent to the various scientific societies of Europe. One of these was by William Ludlam. He is the focus of the second event this column is commemorating, for it was 300 years ago, in 1716, that Ludlam was born.

Ludlam scarcely rates a footnote, even in astronomy books written about the transits. He is not mentioned at all in the 2004 book *The Transits of Venus* by William Sheehan and John Westfall, though his name is listed in a table of observers in Andre Wulf’s 2012 book *Chasing Venus*.

So who was this obscure astronomer? Like many men of the time, his income derived from being a vicar, while he did most of his real work in the sciences. In 1765, by the age of 49, his reputation was such that he was appointed as one of the three men skilled in mechanics who reported to the Board of Longitude on the merits of John Harrison’s watch. It was Harrison’s technical skills that solved the age-old problem of determining longitude at sea, a critical issue for astronomical observations and nautical navigation.

Two years later, William Ludlam became the director of St. John’s Observatory in Cambridge. Archival records at Cambridge show that from 1767 to 1768, he made 1,300 stellar transit timings on 240 nights of observing. The clock he used for these timings is now at the National Maritime Museum in Greenwich.

But St. John’s is not where he observed the Venus transit! In his paper about the transit in the *Philosophical Transactions of the Royal Society*, Ludlam says, “the telescope, used for viewing the planet, was made by Mr. Dollond, with a triple object glass of 33 1/3-inches...
Defining a Planet

It turns out that this is no easy task, and it really isn’t a new problem either.

In August 2006, the International Astronomical Union (IAU) issued Resolution B5 defining a “planet.” In order to qualify as a planet, the object (a) must orbit the Sun, (b) be sufficiently massive so as to be (nearly) round in shape, and (c) must have cleared the neighborhood around its orbit. This resolution is prefaced by a statement that this applies to planets and other bodies in the solar system, except satellites. The resolution actually defines three classes of objects: planets, dwarf planets, and “small solar system bodies.” The subsequent resolution (B6) defines Pluto as a dwarf planet.

The resolution sparked a very public scientific debate. Many in the general public decried the perceived demotion of Pluto. A class of third-grade students in California wrote a book entitled Poor Pluto published by Scholastic in 2007. Meanwhile, educators examined the implications of the new definition for astronomy students, and informal discussions regarding the definition of a planet flooded the Internet.

In a 2009 paper, Giovanni Valsecchi contended that the IAU definition invokes an unnecessary and confusing mix of conditions, with criterion (a) being a dynamical condition, criterion (b) being a physical condition, and criterion (c) being an evolutionary condition.
He proposed that a planet be defined as a celestial object that does not fuse hydrogen and meets three purely dynamical criteria for most of its existence:

1. **It moves about the Sun (or a star) along a path that does not let it approach another planet to within a distance of a thousand times larger than its physical radius;**

2. **It alters, within its gravitational attraction, the motion of nearby planets and/or the star about which it orbits, by a small yet detectable amount;**

3. **All other bodies that can come close to, or cross, its path have masses at least a thousand times smaller than the mass of the planet itself.**

By this definition, the eight largest objects in the solar system are planets. Unlike the IAU’s, this description also encompasses exoplanets.

It turns out that the definition of what counts as a planet has a long and interesting history. Valsecchi noted that the Moon was considered a planet when the geocentric model held sway. When Ceres was discovered in 1801, it too was considered a planet. After the subsequent discoveries of Pallas and Vesta, Ceres was reclassified as an asteroid.

As the New Horizons spacecraft approached Pluto, the planet debate resurfaced. In late 2015, Jean-Luc Margot proposed a way to quantify the third criterion of the IAU definition. Like Valsecchi, Margot invokes dynamical arguments for his definition. He developed a mathematical expression for the minimum mass that an object must have in order to clear its orbital region, which he sets as the volume of space defined by 3.5 times the radius of the Hill sphere, within a timescale on the order of the host star’s main sequence lifetime. Margot’s expression for the clearing time depends only on the mass of the object, the mass of the host star, and the orbital radius of the object around the host star. For an earth-mass planet orbiting a one-solar-mass star at a distance of one astronomical unit, the clearing time is only one million years or so.

Margot’s definition provides a clear quantitative distinction between the eight planets of the solar system and the dwarf planets. It also makes the second criterion of the IAU definition redundant since any object large enough to clear its orbit will automatically be massive enough to be round or nearly round. Finally, it improves on the IAU definition by being applicable to exoplanets.

But this latest definition is already sparking debate: it appears to leave open the possibility that the Moon might be considered a planet! Perhaps the IAU needs to define the criteria for an object to be a “satellite.”

JENNIFER BIRRIEL is Professor of Physics in the Department of Mathematics & Physics at Morehead State University in KY. She notes that the italicized text in this piece are direct (or nearly direct) quotes from the sources cited.
How to Acquire an Image of Titan

The Cassini spacecraft is not a simple “point and shoot” image-taking platform.

In late 2015 you might have seen a new image of Titan from NASA’s Cassini mission (right). It’s composed of several images from the Visible & Infrared Mapping Spectrometer (VIMS). I’m a member of the VIMS Operations Team, the group that design the instructions that VIMS carries out as Cassini orbits Saturn. I wanted to describe one of my jobs — and also explain where that image came from.

The series of events that led to the picture began about a year ago, with negotiations among the different groups of scientists who work on Cassini. Every part of each of Cassini’s orbits is divided between studies of the rings, different moons, Saturn itself, and more.

No part of Cassini can move independently, and the instruments are distributed around the body (or bus) of the spacecraft. This means that the orbit segments have to be further divided among the 12 instrument teams, with each allocated time for specific observations lasting between a few minutes and a couple of days. The “prime” instrument for each observation gets to decide which direction the orbiter actually points, and the other instruments are “riders” who do what they can from their positions on the bus.

For each of the prime observations the scientist in charge informs the Operations team what they want to image, when, and for how long. Cassini runs on a 10-week cycle called a sequence, so we’re usually designing about 15 prime observations across a handful of orbits at a time.

At this point it’s about six months before the observations “fly” or are executed by Cassini, and the fun part (for me) begins. My job is to figure out how to make those observations happen. Cassini is an 18-year-old spaceship about the size of a freight container, full of delicate mechanics and electronics that we want to keep working for another two years until mission end. So there are numerous “flight rules” we can’t violate — from how fast we can turn without breaking our reaction wheels to how close we can point to the Sun without blinding our optics. VIMS has a special restriction because it is a cryogenic instrument; our nominal operating temperature is 60K. If it gets much warmer than that, usually because we’re angled too close to the Sun or Saturn itself, our data quality suffers.

With all this in mind, I write a file that describes the motion, timing, and orientation of the spacecraft, and run it through PDT (Pointing Design Tool) software. PDT checks for flight rule violations; in response I tweak the input file. I’ve done as many as 60 iterations for one observation in order to accommodate the flight rules and get as
much time as possible looking at what the scientist wants to look at. After we’re done with the designs, we send them to both the scientists and Spacecraft Operations at NASA’s Jet Propulsion Laboratory. JPL combines our designs with those from the other instruments to complete the sequence and run their own checks for flight rule violations. Usually a few issues will come up in the merged sequence, which will be corrected and rechecked in greater and greater detail over the next several months.

About a month before flight, we have an internal meeting of the VIMS team for the scientists to finalize the details of each observation. Together they decide the specifics of the instrument’s exposure time, mode, and number of images taken for each pointing. Finally, the sequence is coded in binary and uploaded, via a Deep Space Network (DSN) antenna, 746 million miles to Cassini.

During the next 10 weeks the sequence is executed. Every day or so we have another pass on the DSN, where we receive binary transmissions from the spacecraft. Those data are converted into more useable file types and distributed to the instrument teams. The images comprising that shot of Titan were captured on November 13, and the next day I received an email saying the data had arrived. After that, one of our Titan team members processed and combined the data into the mosaic you see on the previous page.

In that one picture is the work of dozens of people, across the world, for nearly a year. I’m lucky enough to be one of them, and being part of that amazing process is the best part of my job.

EMILY JOSEPH is a Research Assistant (with an emphasis on Mars studies) at the Planetary Science Institute and is part-time on the Cassini VIMS operations team. You can find her on Twitter @EmExAstris.

Most Earth-Like Worlds Have Yet to Be Born

Our planet came early to the Earth-like planet-forming party in the evolving universe.

Astronomers are conducting extensive observations to estimate how many planets in our Milky Way galaxy might be potential abodes for life. These are called “Earth-like” — in other words, Earth-sized worlds that are at the right distances from their stars for moderate temperatures to nurture the origin of life. The search for extraterrestrial intelligent life in the universe (SETI) is based on the hypothesis that some fraction of worlds, where life originates, go on to evolve intelligent technological civilizations.

Until we ever find such evidence, Earth is the only known abode of life in the universe. But the universe is not only vastly big, it has a vast future. There is so much leftover gas from galaxy evolution available that the universe will keep cooking up stars and planets for a very long time to come.

Earth came early to the party in the evolving universe. According to a new theoretical study, when our solar system was born 4.6 billion years ago only eight percent of the potentially habitable planets
that will ever form in the universe existed. And, the party won't be over when the Sun burns out in another six billion years. The bulk of those planets — 92% — have yet to be born.

“Our main motivation was understanding the Earth’s place in the context of the rest of the universe,” said study author Peter Behroozi of the Space Telescope Science Institute (STScI) in Baltimore, Maryland, “Compared to all the planets that will ever form in the universe, the Earth is actually quite early.”

Looking far away and far back in time, Hubble has given astronomers a “family album” of galaxy observations that chronicle the universe’s star formation history as galaxies grew. The data show that the universe was making stars at a fast rate 10 billion years ago, but the fraction of the universe’s hydrogen and helium gas that was involved was very low. Today, star birth is happening at a much slower rate than long ago, but there is so much leftover gas available that the universe will keep cooking up stars and planets for a very long time to come.

“There is enough remaining material [after the big bang] to produce even more planets in the future, in the Milky Way and beyond,” added co-investigator Molly Peeples of STScI.

Kepler’s planet survey indicates that Earth-sized planets in a star’s habitable zone, the perfect distance that could allow water to pool on the surface, are ubiquitous in our galaxy. Based on the survey, scientists predict that there should be one billion Earth-sized worlds in the Milky Way galaxy at present, a good portion of them presumed to be rocky. That estimate skyrockets when you include the other 100 billion galaxies in the observable universe.

This leaves plenty of opportunity for untold more Earth-sized planets in the habitable zone to arise in the future. The last star isn’t expected to burn out until 100 trillion years from now. That’s plenty of time for literally anything to happen on the planet landscape.

The researchers say that future Earths are more likely to appear inside giant galaxy clusters and also in dwarf galaxies, which have yet to use up all their gas for building stars and accompanying planetary systems. By contrast, our Milky Way galaxy has used up much more of the gas available for future star formation.

A big advantage to our civilization arising early in the evolution of the universe is our being able to use powerful telescopes like Hubble to trace our lineage from the big bang through the early evolution of galaxies. The observational evidence for the big bang and cosmic evolution, encoded in light and other electromagnetic radiation, will be all but erased one trillion years from now due to the runaway expansion of space. Any far-future civilizations that might arise will be largely clueless as to how or if the universe began and evolved.
A Gamma-Ray Powerhouse in a Galaxy Next Door

One pulsar is producing half of the gamma rays in the Large Magellanic Cloud.

It took 75 months of observational data, but scientists have identified the most luminous gamma-ray pulsar to date, the first such pulsar discovered outside the Milky Way galaxy.

The pulsar, called PSR J0540-6919, is in the Tarantula Nebula of the Large Magellanic Cloud (LMC), known since the 1980s as an emitter of radio waves and X-rays. Its gamma-ray pulses are 20 times more intense than those from the previous record holder, the mighty Crab pulsar. Moreover, this single source is behind about half of the gamma rays in the entire LMC.

The pulsar’s dominance in the region has astronomers rethinking the origin of gamma rays (and cosmic rays!) from star-forming regions, thought to have been more diffuse. A team led by Pierrick Martin of the Institute for Research in Astrophysics and Planetology, France, announced these results in November 2015 at the annual International Fermi Symposium near Washington, D.C.

The LMC is “large” only in comparison to the Small Magellanic Cloud — both dwarf galaxies are less than 1/100th the mass of the Milky Way and visible from the Southern Hemisphere. Although more than 150,000 light-years from Earth and farther than any object in our own galaxy, the LMC lies away from the dusty galactic plane where we reside and thus provides astronomers with a clear view of phenomenon such as star formation, Martin said.

In the heart of the LMC is the Tarantula Nebula, a star-forming region more active than anything found in ours or other neighboring galaxies. Indeed, if it were as close as the Orion Nebula (1,300 light-years), the Tarantula Nebula would cast a shadow on the ground, according to calculations from astronomers at the National Optical Astronomy Observatory.

So, clearly big things happen in the tiny LMC. All that rapid star formation results in massive stars that burn fast and die young, releasing their contents in supernova explosions. The explosions produce shock waves, which accelerate particles to high speeds and high energies, creating cosmic rays. These cosmic rays can collide to produce gamma rays.

Astronomers have thought that most of the gamma rays in the Tarantula Nebula and other nebulae come as a result from this diffuse production of star stuff. Ah, but not so fast. PSR J0540-6919 throws a wrench in this comfortable theory.

As with all pulsars, PSR J0540-6919 is the rapidly spinning core remains of a once-massive star that has gone supernova. And as
with all gamma-ray pulsars, this is quite young, perhaps only about a thousand years old. Compared to older pulsars, young pulsars tend to have stronger magnetic fields, faster spins, and steeper spin-down rates, all resulting in the release of a lot of energy. Only about 5% of pulsars emit gamma rays, the most energetic form of light.

Stacking up data from NASA’s Fermi Gamma-ray Space Telescope during the last six years, and matching this with old data from the now-defunct Rossi X-Ray Timing Explorer, Martin’s team was able to distinguish among gamma-ray sources. In short, they found only two sources in the Tarantula Nebula: PSR J0540-6919 and another pulsar called PSR J0537-6910.

This other pulsar doesn’t pulse much in gamma rays, but that’s a mystery for another day. The bigger surprise, said Paul Ray, an astrophysicist at the Naval Research Laboratory, was that it’s the pulsar, not the whole nebula, that’s producing the bulk of the gamma rays, even though the Tarantula Nebula is the most turbulent star-forming region, by far, among nearby galaxies. “That’s really exciting,” said Ray, who wasn’t part of the observation. Ray added that PSR J0537-6910 has “a huge gap in luminosity…and varies dramatically” in the pulsing pattern compared to the Crab. And why two young gamma-ray pulsars can be so different is yet another mystery.

Gamma rays reaching Earth from extragalactic sources are relatively rare, Martin said. So for now, to solve these mysteries, all astronomers can do is hold up their light buckets long enough to collect as many photons as possible. Fermi has discovered 160 of the 165 known gamma-ray pulsars, which ain’t too shabby.

CHRISTOPHER WANJEK is a communications director at the National Institutes of Health.

Probing for Understanding

Misconceptions are everywhere, even with something as simple as the phases of the Moon.

“Be very, very careful what you put into that head, because you will never, ever get it out.” Attributed to Cardinal Thomas Wolsey (1473-1530). As with most quotes, the one above is surely taken out of context. Educators like it because it speaks to them of the importance of conveying accurate content to learners during a course of instruction, lest erroneous prior conceptions get reinforced, or new ones formed.

The short film A Private Universe debuted in 1987, and immediately became a critical resource to help educators understand the importance of learner engagement in hands-on activities to forestall, and correct, misconceptions they hold related to natural, particularly astronomical, phenomena. The film starts with the now-famous scene at a Harvard University commencement where new graduates and faculty members are asked to explain the understanding of the reasons for the seasons, and the causes of the phases of the Moon. A Private Universe showed how even the most highly educated can
have enduring misconceptions, and how traditional science instruction does little to replace them.

Educators at every level have a pretty good idea of what prior conceptions learners bring with them, important knowledge when designing educational experiences. In a formal classroom environment, the educator has the added benefit of having more time to probe learners’ ideas and use what they glean to make adjustments to their instructional plan. One of the easiest strategies in the classroom involves the use of a “formative assessment probe,” where learners are presented with a description of a phenomenon and a set of responses from which they have to select the one they agree with the most. Learners are also asked to provide a reasoned explanation for why they agree with their selected response.

Probes such as these are useful when working with both pre- and in-service teachers during a professional development workshop. Not only do they engage the teachers in educational best practices, it also allows us to have a better understanding of the misconceptions they have about astronomical concepts and phenomena. During a recent visit to a science methods class for pre-service teachers in an elementary credential program, the following probe was used.

Much as the Harvard graduates had misconceptions about the causes of the phases of the Moon, many of the prospective teachers in the workshop had their own. This particular probe — from the book *Uncovering Student Ideas in Astronomy* by Page Keeley and Cary Sneider, 2012, NSTA Press — was selected to discover their mental model of how much of the Moon is lit at any time, and what it would look like if we are unable to see the fully lit side from Earth. The probe shows an illustration of a crescent Moon in the night sky and asks how much of the entire lunar surface is actually lit by the Sun. Answer options included one quarter or less, half of the Moon, three quarters, or the entire Moon. Students are then prompted to explain their thinking and provide an explanation for their answer.

Elementary teachers, let alone prospective elementary teachers, seldom have an extensive background in science, so it was not surprising to discover most of the students had uncertainty about how much of the Moon is lit at any time. A couple of the students had the misconception that the dark part of the lunar surface was due to the Moon passing into Earth’s shadow. One student asked why we could not see stars through the transparent darkened portion of the Moon.

Following the probe, students were given white polystyrene balls, with only a single light bulb for illumination, and were asked to test their ideas. They were able to model how much of their “moon” was illuminated at any time, and to observe how it would look at different positions as the ball orbited their heads.

The results were amazing! The formative assessment probe to determine the learners’ current mental models, combined with a modeling activity, produced a significant conceptual shift that eventually provided fertile ground for an accurate understanding of
A Moon phase activity as part of a workshop at the 2010 ASP conference. [Paul Deans]

phenomena including phases of the Moon and solar and lunar eclipses. When asked if their understanding depended on the hands-on modeling experience, the response was a unanimous YES!

And, they became more likely to affect a change in student understanding once they have classrooms of their own.

At the end of the sessions, these university students reflected on their experience:

- I used to think… the Moon just turned dark; but now I know… that it is its own shadow.
- I used to think… the shadow on the Moon was the Earth; but now I know… it’s the Moon’s own shadow.
- I used to think… that the part showing on the Moon was the only part lit by the Sun; but now I know… that half is always lit and it’s all about perspective.

BRIAN KRUSE manages the formal education programs at the Astronomical Society of the Pacific. He and Page Keeley will be co-presenting at the 2016 NSTA conference in Nashville (March 31–April 3) and will be focusing on the use of probes to support eclipse modeling activities.

AAS Nova: Astronomy Research Results for Everyone

Read summaries of current astrophysics research from a variety of AAS publications.

The American Astronomical Society’s latest online publication is AAS Nova, which highlights results published in the AAS’s peer-reviewed journals. It provides a curation service to inform astronomy researchers and enthusiasts about breakthroughs and discoveries they might otherwise overlook.

Highlights feature research articles that are selected because they are of particular importance or are of potential interest to a broad community. Highlights are brief, single-page summaries of the research and results, presented within the context of the field. Additional selected research articles are featured in the Journals Digest, accompanied by single-sentence summaries of their results or impact.

AAS Nova also occasionally publishes Featured Images (especially interesting figures or images from recent papers, accompanied by brief descriptions) and AAS Publishing News articles (updates on new initiatives or changes from the AAS journals, ebooks, and other publishing endeavors).

AAS Nova is a public service, and anyone — from professors and researchers to elementary school teachers and other educators — can access it or subscribe to the mailing list. You can also like the AAS Nova page on Facebook or follow @AASNova on Twitter if you prefer to get the latest posts that way.

One important note. While the Highlights are always free to access, the original articles on which they are based, published in the AAS journals, are typically behind a paywall. However, those that are highlighted on AAS Nova are made free to read for the first 30 days after they are highlighted (click on the citation).

The editor of AAS Nova is Susanna Kohler. She received her BS in physics from University of California at Santa Barbara in 2008 and her PhD in astrophysics from University of Colorado Boulder in 2014. Susanna is an administrator and former author for astrobites.com and a founding organizer of ComSciCon, a science communication workshop series for graduate students. She has pursued outreach in astronomy and physics for more than a decade, both as a public speaker and as a freelance writer whose pieces have appeared in a variety of online publications.

The following is a Highlights sample from a recent AAS Nova release. To sign up for this service, visit the AAS Nova home page.

A Gap in TW Hydrae’s Disk

Located a mere 176 light-years away, TW Hydrae is an 8-million-year-old star surrounded by a nearly face-on disk of gas and dust. Recent observations have confirmed the existence of a gap within that disk — a particularly intriguing find, since gaps can sometimes signal the presence of a planet.

Gaps and Planets

Numerical simulations have shown that newly-formed planets orbiting within dusty disks can clear the gas and dust out of their paths. This process results in pressure gradients that can be seen in the density structure of the disk, in the form of visible gaps, rings, or spirals.

For this reason, finding a gap in a protoplanetary disk can be an exciting discovery. Previous observations of the disk around TW Hydrae had indicated that there might be a gap present, but they were limited in their resolution; despite TW Hydrae’s relative nearness, attempting to observe the dim light scattered off dust particles in a disk surrounding a distant, bright star is difficult!

Image of TW Hydrae’s disk from GPI (right) and a simulated scattered-light image (left) from a model of a ~0.2 Jupiter-mass planet orbiting in the disk at ~21 AU in the J band. [Adapted from Rapson et al. 2015]
But a team led by Valerie Rapson (Rochester Institute of Technology, Dudley Observatory) recently set out to follow up on this discovery using a powerful tool: the Gemini Planet Imager (GPI).

**New Observations**

GPI is an instrument on the Gemini South Telescope in Chile. Its near-infrared imagers, equipped with extreme adaptive optics, allowed it to probe the disk from ~80 AU all the way in to ~10 AU from the central star, with an unprecedented resolution of ~1.5 AU.

These observations from GPI allowed Rapson and collaborators to unambiguously confirm the presence of a gap in TW Hydrae’s disk. The gap lies at a distance of ~23 AU from the central star (roughly the same distance as Uranus to the Sun), and it’s ~5 AU wide.

**Modeled Possibilities**

There are a number of other potential explanations for this gap — for instance, the inner disk could be casting a shadow on the outer disk, or the gap could be a natural consequence of how grains fragment and evolve within the disk.

Nevertheless, an orbiting planet embedded in the disk may well be the cause. When Rapson and collaborators ran numerical simulations of a planet orbiting within a disk like TW Hydrae's, they found that a planet of 0.16 Jupiter masses, orbiting at a distance of 21 AU, reproduces the observations well.

With any luck, we’ll be able to learn more with additional observations in the future. Deeper images may reveal additional features that point to a planet shaping the disk structure. And if the planet is actively accreting gas in the disk, we may even be able to directly image the planet!

**Citation:** Valerie A. Rapson et al 2015 ApJ 815 L26.

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**LEGACY GIVING**

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— Plato

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Coloring the Universe

This customized excerpt is from a new book that offers an insider's look at how spectacular images of deep space are made.

By Travis Rector, Kimberly Kowal Arcand, and Megan Watzke

Formally known as IC 1396A, this dark nebula is more commonly known as the Elephant Trunk Nebula. [T. A. Rector (University of Alaska Anchorage) and H. Schweiker (WIYN and NOAO/AURA/NSF).]
If you’re reading this article, you probably love astronomy images. When looking at an image of, say, a galaxy, have you ever wondered “Is this real?” or maybe “Is this what it really looks like?”

The first question is easy to answer. Yes, everything you are seeing is real. Unless it is “space art,” these images are of real objects in outer space. They aren’t creations of a graphic artist’s imagination. But answering the second question is not as simple. How a telescope “sees” is radically different than how our eyes see. Telescopes give us super-human vision. In most cases they literally make the invisible visible.

An Iconic Image
Here’s an example. For many space aficionados, the picture (below left) is iconic. It captures the famous Horsehead Nebula. The image was taken with an advanced digital camera on a telescope at the Kitt Peak National Observatory (KPNO) in southern Arizona. This is what the telescope and its camera can see. But let’s pretend you have the ability to board a spaceship and fly to the Horsehead Nebula — what would you see? After a journey of more than a thousand light-years, you look out of the window of your spaceship at this same scene. But you’re now at a distance one hundred times closer than before, when you were standing on the Earth. Here’s your view now (right).

Left: The iconic Horsehead Nebula is part of a dense cloud of gas in front of an active star-forming region known as IC 434. [T.A. Rector (NOAO/AURA/NSF) and the Hubble Heritage Team (STScI/AURA/NASA).]
Right: The same area of the sky but shown as you would see it with your naked eye. [T.A. Rector (NOAO/AURA/NSF).]
You'd see some of the brighter stars but none of the dust and gas in the nebula, including the horsehead shape. Why?

**What a Telescope Does**

To better understand what’s going on, it helps to know what a telescope does. Just as a pair of binoculars can make the upper-level seats in an arena almost as good as courtside, a telescope can make a distant object appear much closer. But a telescope does more than this. It doesn’t just magnify an object; it also amplifies it. It makes something faint appear much brighter.

Some people might think that the reason why a telescope can see objects our eyes can’t is because it magnifies something that is too small for us to see. And this is often true. But the Horsehead Nebula is actually not that small. The fields of view of those images of the Horsehead are about twice the size of the full Moon in the sky. You can’t see it because it is too faint, not because it is too small.

So why couldn't you see the Horsehead Nebula even if you were much closer? For an object that appears to be larger than a point of light (galaxies and nebulae, but not stars), how bright it appears has nothing to do with how far away it is. Moving closer to it will make it bigger, but not brighter. This may seem counterintuitive, but you can try it at home. Walk toward a wall. As you approach you’ll notice that the wall is getting bigger but otherwise is the same brightness. The same is true of the Horsehead Nebula. If you can’t see it with your eyes while on Earth, you still won’t see it from your spaceship.

Why then can a telescope see it? A telescope offers several advantages over our eyes. As marvelous as the human eye is, it’s not that well suited for nighttime observing. First, our eyes are tiny. The opening that allows light to enter, known as the pupil (the black area at the center of the eye), is only about one-quarter of an inch wide when fully open.

In comparison, the mirror that collects light for the Gemini North telescope, at one of the professional observatories atop Mauna Kea in Hawai‘i, is about 8 meters (27 feet) across. What this means is that, at any given moment, this mirror is collecting more than a million times more light than your eye. The more light you can collect, the fainter an object you can see.

Human eyes also don’t collect light for long. Our eyes function like a video camera, taking images about 30 times every second. So the exposure time for each image captured by the human eye is only 1/30th of a second. With digital cameras attached to the telescope we can collect light for as long as we like. The longer the exposure, the more light the telescope collects.

Typically, a single exposure is not more than 10 to 20 minutes, but multiple exposures can be added together to make a single image.
with an exposure time that is, in effect, much longer. To create the most sensitive image ever made, astronomers collected more than 50 days worth of observation time with the Hubble Space Telescope of a single portion of the sky. Known as the Hubble eXtreme Deep Field (XDF), this image represents a cumulative exposure time of about two million seconds.

The human eye is complex. It isn’t sensitive to faint light, and it only detects amounts that are above a certain threshold. In comparison, modern electronics detect nearly all of the light that enters a telescope’s camera, even if it takes hours to collect the light. All of these factors enable telescopes to go far beyond the limits of human vision. The faintest objects in the XDF are about 10 billion times fainter than what the human eye can see.

Finally, the universe and the amazing objects in it glow in other types of light — from radio waves to gamma rays — that are impossible for our eyes to see. It’s taken scientists and engineers many decades to develop our abilities to capture the views of the universe that we enjoy today. Without these technical tools, many phenomena and objects would simply be invisible to us entirely.

It’s no exaggeration to say that telescopes give us superhuman vision. Nearly every astronomical image contains objects too small and/or too faint for us to see. And these images often show us kinds of light our eyes can’t detect. So how do astronomers take what the telescope sees and convert it into something we can see? Are these images showing us what the universe really looks like?

How Telescopes and Cameras Work
When a news story reports something like, “Astronomers have taken a picture of a new galaxy,” it’s easy to imagine scientists pointing a camera toward outer space, pressing a button (“click!”), and the image appears on the back of the camera. Perhaps even a flash goes off (it is nighttime after all). In reality, taking an image of a cosmic source is not the same as taking a picture with your phone.

A telescope is essentially a giant telephoto lens. It is a device that collects light from a distant object. The camera on the telescope then uses that light to make an image. For this reason, telescopes are often referred to as “light buckets.”

The purpose of the camera is to capture that light and assemble an image from it. The digital cameras on a telescope are, at the most fundamental level, essentially the same as the digital cameras you own. In fact, the technology in everyday digital cameras was first developed and used on telescopes. At the heart of any digital camera — on a telescope or not — is its detector, the piece of hardware that actually captures and stores light.

How We Use Color
Digital cameras are remarkable tools for detecting faint light from stars, nebulae, and galaxies. But there’s one problem. Measuring the
electricity in a pixel tells you the intensity of the light but not the color. In other words, digital cameras can only see in black and white (or, more precisely, gray scale). How then do we get a color image?

First off, what is color anyway? When you take visible light and spread it out into a spectrum (using a prism, for example, or looking at a rainbow), the colors correspond to the energy of the light. Red light is the lowest energy kind of light we can see. Next up in energy is orange, then yellow, green, blue, indigo, and finally violet. Violet is the highest energy form of light we can see. You may have learned “ROY G. BIV” in school to remember this.

The way we see color is somewhat complex. In some cases, a star may look red simply because it is emitting more red light than the other colors. Some colors, however, can be created in more than one way. For example, there are two ways to see yellow light. You could either have an object that emits just yellow light (like the low-pressure sodium lamps often seen in parking lots). Or, you could have an object that emits a range of light that includes red and green but not much blue. Red and green light, when added together, combine to produce yellow. When all of the colors are added together in equal amounts you see white.

Making Color in Photography
Historically, making a color image hasn’t been easy. Black-and-white photography was first developed at the start of the 19th century. The first successful color photographs came about 50 years later, with a technique first proposed by Scottish physicist James Clerk Maxwell (who also is famous for coming up with the theory that tied electricity, magnetism, and light together). Known as the three-color process, it is (in one form or another) the basis for all modern color photography. The technique consists of taking black-and-white images through blue, green, and red filters. These are then combined to produce the color image. Remarkably, by mixing the “primary” colors of red, green, and blue in different amounts, we can create all the colors we can see. (Again, we can make yellow by adding red and green light in roughly equal amounts with little to no blue.)

This is the process used with digital cameras on professional astronomical telescopes. Astronomers take one or more pictures of the same field of view through each filter. The images are then combined to form a color image.

But it is important to know that astronomers use more than just red, green, and blue filters. The telescopes at KPNO have more than 100 filters that are used for a wide range of purposes. The choice of filters is primarily dependent on the science to be done. For example, by measuring the brightness of a faraway galaxy through different filters, astronomers can estimate its distance from us. Also, they don’t always use three filters. Sometimes they use only one. And sometimes they use many more than three. Some astronomical images have been made using as many as 13 filters!

In a nutshell, the process for making a color astronomical image works like this:

• Take images of an astronomical object through multiple filters.
• Assign a color to each image (“colorize” it).
• Combine them to make the final color image.

It sounds simple but in practice it is not. Astronomers use a wide range of filters to look at many different kinds of objects for a variety of reasons. So there’s no simple rule for how to choose colors for each filter. It depends on the filters used, the object studied, what’s interesting about it, and the person who is putting the image together.

There are many examples of how astronomers do this, but first let’s start with a common scenario.
**Broadband Filters**

Astronomers often use what are known as “broadband” filters, so named because they allow a wider range of the electromagnetic spectrum to pass through. Sometimes astronomers will use red, green, and blue filters similar to those used on your camera. In this case, the image would not be too far from what you’d see if your digital camera were mounted to the telescope (and if it were much more sensitive). Once the black-and-white images captured through the different filters are available, assembling the color image is then usually straightforward: the image taken through the red filter is colored red, the image taken through the green filter is colored green, and the blue filter is colored blue.

Most often, astronomical images are made with broadband filters other than simple red, green, and blue. There are filters of other colors as well. In general, when assigning colors to each image we give the image the color that the filter appears to have when held up to a bright, white light. In some cases, however, the filters used in visible telescopes are of energies of light just beyond what the human eye can see. For example, the “U” filter (for “ultraviolet”) in the widely used Johnson-Cousins UBVRI filter set shows the energy range just above what the eye can see. And the “I” filter (for “infrared”) captures the energy just below what we can see. Since they are close to those colors, they are often colored violet and red respectively.

This technique of combining colorized layers can be used for any type of light the cosmos gives off — such as microwaves or X-rays. When using broadband filters, astronomers almost always choose to use chromatic ordering. By that, we mean that the lowest-energy light is assigned red, the middle-energy light is green, and the

![Three images showing portions of the B, V, and I images used to make an image of the Pleiades cluster.](image)

The three images (above) show a portion of the B, V, and I images used to make an image of the Pleiades cluster. They have been “colorized” to be blue, green, and red. These three images are then combined to produce the three-color image at right. [T.A. Rector (University of Alaska Anchorage), Richard Cool (University of Arizona), and WIYN.]
highest-energy light is blue. Objects that emit relatively more low-energy light will be redder, whereas objects that emit relatively more high-energy light will be bluer.

**Narrowband Filters**

Luckily for those who study the cosmos, each type of gas glows with different, distinct colors. This enables astronomers to identify and map out the distribution of various types of gases in space by just looking at those colors. It’s a powerful tool. It allows us to know what’s inside a nebula without actually flying out to it, collecting, and analyzing the gas directly (a trip that would be impossible anyway because of the enormous distances to these cosmic objects).

To see these specific colors astronomers use what are called *narrowband filters*. The most commonly used such filter is called the hydrogen alpha filter (also known as “H-alpha”). It allows only a specific color of red light produced by hydrogen gas to pass through. H-alpha is therefore a handy tool for detecting warm hydrogen gas. Because the narrowband filter blocks out other kinds of light, it allows astronomers to better see the location and distribution of this gas in whatever object they observe.

Astronomers use many different kinds of narrowband filters to learn not only where gas is in outer space but also what kinds of gas are present. We can also use these filters to determine important physical characteristics such as the temperature and density of the gas. Somewhat ironically, by using narrowband filters to exclude light we can sometimes learn more. Or, as the French composer Claude Debussy once said, “Music is the space between the notes.”

**The Spaces Between the Notes**

Broadband filters allow relatively large portions of the light spectrum to pass through them. Some of these filters (for example, the Harris B, V, and R filters) roughly match up to the range of colors seen by the short-, medium-, and long-wavelength (S, M, and L) cones in our eyes. So, in a sense, these filters can be used to roughly mimic what our eyes could see (that is, if our eyes were a million or so times more sensitive than they are now).

Narrowband filters, by design, allow only a sliver of light to pass through. Each filter lets through a specific color of light produced by a certain type of atom inside the warm gas. All of the other colors are blocked out. We can then study only the light these elements make. For this reason, narrowband filters “see” light differently than your eyes do.

When making images with narrowband filters, astronomers use color in a different way. Color can be used to show detail in the object that would not normally be visible. The selection of colors can also help distinguish different physical processes in the nebula or galaxy in question. Astronomers can look at these images and deduce great stories invisible to the untrained eye. So how do astronomers use narrowband filters? And how are color images made with them?

Let’s look at an example that illustrates the challenges of making a color image using data from narrowband filters. Three of the most commonly selected are [OII], [NII], and [SII], which show specific colors of red light produced by oxygen, nitrogen, and sulfur atoms respectively. These colors of red light are similar to hydrogen alpha. In fact, they so closely resemble each other that our eyes cannot tell the difference. Fortunately, with the use of narrowband filters, our cameras can.

A good question to ask then is: What colors should be used for each filter? If all of these filters — hydrogen alpha, [OII], [NII], and [SII] — were shown as red then we’d lose valuable information. If we are to use colors other than red, which ones? There is no single answer.
for this question. Instead, it depends on the filters used, the object observed, the science to be illustrated, and the aesthetic goals.

Astronomers often look at nebulae with three particular narrow-band filters: h-alpha, [OIII], and [SII]. The “intrinsic” colors of these filters are red, green, and red — the colors of Christmas. What’s the best way then to assign color to these filters so we may see the most detail? Almost by accident, astronomers started using the color scheme of [OIII] (blue), hydrogen alpha (green), and [SII] (red). This is in chromatic order and is the color scheme used for the Pillars of Creation image of M16 (right). Amateur astronomers often refer to using these three filters with this color scheme as the “Hubble palette,” although in reality only a small fraction of images from Hubble use this scheme.

Scientific and Beautiful
In this article we’ve talked about some of the steps in the complex process of converting what the telescope can see into something we humans can see. It’s a fundamental challenge because our telescopes observe objects that, with a few exceptions, are invisible to our eyes. That is of course the reason why we build telescopes. There would be no point in building machines like Gemini, Hubble, and Chandra if they didn’t expand our vision.

These images illustrate the science that is being done with these telescopes. The reputations of the observatories, and the scientists who use them, are tied to the truth of what’s in the image. No self-respecting scientist would intentionally do something to create a misleading image from his or her data. Think of a doctor who has taken an X-ray of an ailing patient. He or she may use techniques to enhance the picture so that more detail can be seen, but he or she would never add or remove a fracture in a bone. The same is true here.

There is an artistry to making these images, but ultimately the goal is a scientific one: to share with people the discoveries astronomers are making with these fantastic machines of exploration. With advances in telescopes, cameras, and image-processing software, we continuously improve our ability to see planets, stars, and galaxies. Although each image is a representation, it offers a real view into our real and fascinating universe.

To learn more about how astronomers make images we invite you to read our new book, also titled Coloring the Universe. The book has more than 300 images, and each image has its own story as to how it was created, what it shows, and what scientists learn from it. We hope that, by reading the book, people will better understand and appreciate these beautiful images. Coloring the Universe is available from the University of Chicago Press as well as from several major online book sellers.

TRAVIS A. RECTOR is professor of physics and astronomy at the University of Alaska Anchorage. He has created more than 200 images with the giant telescopes at Gemini Observatory, Kitt Peak National Observatory, the National Radio Astronomy Observatory, and others. KIMBERLY KOWAL ARCAND directs visualization efforts for NASA’s Chandra X-ray Observatory at the Chandra X-ray Center (CXC) located in Cambridge, Massachusetts. MEGAN WATZKE is the public affairs officer for the Chandra X-ray Observatory.
The 2016 Transit of Mercury

What it’s all about, when and where to look, and how to safely view the transit as a test run for observing the solar eclipse in 2017.

By Fred Espenak with Paul Deans
The transit or passage of a planet across the disk of the Sun may be thought of as a special kind of eclipse. On Monday, May 9, 2016, Mercury will transit the Sun for the first time since 2006. The movement of a planet across the face of the Sun is a relatively rare occurrence. As seen from Earth, only transits of Mercury and Venus are possible. There are approximately 13 transits of Mercury each century. In comparison, transits of Venus occur in pairs with more than a century separating each pair.

The Basics
The principal events occurring during a transit are conveniently characterized by contacts, analogous to the contacts of an annular solar eclipse. The transit begins with contact I, which is the instant when the planet’s disk first touches the solar disk. Shortly thereafter, the planet can be seen as a small notch along the solar limb. The entire disk of the planet is first visible on the Sun’s face at contact II. During the next several hours, silhouetted Mercury slowly traverses the brilliant solar disk. Contact III occurs when the planet’s limb again touches the edge of the Sun. Finally, the transit ends at contact IV when Mercury’s disk no longer touches the solar disk.

Contacts I and II define the phase called ingress while contacts III and IV are known as egress. Position angles for Mercury at each contact are measured counterclockwise from the north point on the Sun’s disk.

Where and When
The table below gives the times of major events during the May 9th transit in Universal Time (UT) as well as Eastern and Pacific Daylight time. Greatest transit is the instant when Mercury passes closest to the Sun’s center (i.e., minimum separation). The position angle is the direction of Mercury with respect to the center of the Sun’s disk as measured counterclockwise from the celestial north point on the Sun. Since the contact times are geocentric they are only correct for a theoretical observer stationed at Earth’s center. The actual contact times for any given location may differ from the geocentric times by up to a minute either way.

<table>
<thead>
<tr>
<th>Event</th>
<th>Position</th>
<th>Universal</th>
<th>Eastern</th>
<th>Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact I</td>
<td>83°</td>
<td>11:12</td>
<td>07:12</td>
<td>pre-sunrise</td>
</tr>
<tr>
<td>Contact II</td>
<td>84°</td>
<td>11:15</td>
<td>07:15</td>
<td>pre-sunrise</td>
</tr>
<tr>
<td>Greatest Transit</td>
<td>154°</td>
<td>14:57</td>
<td>10:57</td>
<td>07:57</td>
</tr>
<tr>
<td>Contact III</td>
<td>224°</td>
<td>18:39</td>
<td>14:39</td>
<td>11:39</td>
</tr>
<tr>
<td>Contact IV</td>
<td>224°</td>
<td>18:42</td>
<td>14:42</td>
<td>11:42</td>
</tr>
</tbody>
</table>

The transit will be widely visible from most of Earth including the Americas, the Atlantic and Pacific Oceans, Europe, Africa, and...
much of Asia, as shown in the illustration (above right). The transit begins before sunrise for observers in western North America. The transit ends after sunset for eastern Europe, Asia, and most of Africa. Regions where the entire transit is visible include eastern North and South America, the Atlantic Ocean, and Western Europe. None of the transit will be visible from eastern Asia, Japan, Indonesia, Australia, and New Zealand.

For North American observers, I have created PDFs containing predicted contact times and the corresponding altitude of the Sun for a number of cities in the US and Canada. In addition, Xavier Jubier has an interactive transit map and a local circumstances calculator on his website.

Recurrence of Transits
During the present era, transits of Mercury fall within several days of May 8 and November 10. Since Mercury’s orbit is inclined seven degrees to Earth’s, it intersects the ecliptic at two points or nodes, which cross the Sun each year on those dates. If Mercury passes through inferior conjunction (between Earth and Sun) at that time, a transit will occur. During November transits, Mercury is near perihe- lion and exhibits an apparent disk only 10 arc-seconds in diameter. By comparison, the planet is near aphelion during May transits and appears 12 arc-seconds across.

However, the probability of a May transit is smaller by a factor of almost two. Mercury’s slower orbital motion at aphelion makes
it less likely to cross the node during the critical period. November transits recur at intervals of 7, 13, or 33 years while May transits recur only over the latter two intervals. The next Mercury transit occurs November 11, 2019, followed by a gap of 13 years.

For those interested in more details, two catalogs listing dates and details for transits of Mercury (from 1600 to 2300) and Venus (from 3000 BCE to 3000 CE) can be accessed via my Transits of Mercury and Venus webpage.

FRED ESPENAK is a retired NASA astrophysicist and was the agency’s expert on eclipses. Known as “Mr. Eclipse,” he is the author of numerous books including Totality - Eclipses of the Sun and Eclipse Bulletin: Total Solar Eclipse of 2017 August 21 (with Jay Anderson). This article was adapted, with permission, from one published in the Observer’s Handbook 2016, Royal Astronomical Society of Canada.

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**Observing the Transit of Mercury — Safety First**

*by Paul Deans*

If you’re thinking of organizing an outreach activity for the August 2017 solar eclipse, consider the May 9, 2016, transit of Mercury as a test run for your solar observing techniques. But don’t overhype the transit. Unlike the Moon, which will obscure a substantial part of the solar disk during the eclipse (or all of it if you’re in the path of totality), Mercury is tiny, tiny, tiny. It’s only 1/150th or so the apparent diameter of the Sun, which means you’re not going to see it without optical aid. Look at the pair of images (right) taken two hours apart by the SOHO spacecraft during the 2003 transit of Mercury. How easily can you spot that tiny world? Were it not for Mercury’s motion across the top of the image during the two hours, it would not be particularly obvious.

Think of the transit of Mercury as an extremely miniature annular solar eclipse. This means the safety rules for observing an annular or partial eclipse of the Sun also apply to observing the Mercury transit. And the number one rule is: *Never look directly at the Sun without using a safe solar filter.* (A list of solar filter suppliers is on page 32.)

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**Danger in the Sky**

According to Ralph Chou, Professor Emeritus (Optometry and Vision Science) at the University of Waterloo, Canada, unsafe filters include all color film, black-and-white film that contains no silver, film negatives with images on them (x-rays and snapshots), smoked glass, sunglasses (single or multiple pairs), photographic neutral density filters, and polarizing filters. Looking at the Sun through a telescope, binoculars, or a camera with a telephoto lens without proper eye protection can result in “eclipse blindness”
(or in this case, “transit blindness”), a serious injury in which the eye’s retina is damaged by solar radiation. And because there are no pain sensors in the eye, you don’t feel the damage taking place and notice nothing until the visual effects appear hours later. (This NASA article explains what can happen.)

Hence your telescopes and binoculars require solar filters before pointing them toward the Sun and Mercury. The filters will protect your optics and ensure you don’t accidentally glimpse the Sun through an unfiltered scope. The solar filter must be attached to the front of your optics (the Sun-facing side). If your telescope has a finderscope, be sure to attach a filter to it, too, or cover it with tape.

Because Mercury is so small, two safe-viewing options usually employed during a solar eclipse are not useful here. One is the use of eclipse glasses. They’re excellent for observing a partial solar eclipse with the naked eye, but as mentioned earlier, Mercury won’t be visible against the Sun without optical aid. Another eclipse-viewing technique is making a pinhole projector or camera. The problem is the image is dim, and only sunspots (if any) much larger than Mercury will be visible using this method.

**Viewing the Transit**

So what filtered optics do you need to follow the transit? Obviously a telescope will do the job nicely (don’t forget to filter the finderscope as well as the main instrument). Even a small scope that magnifies 50 to 100 times should be enough for you to spot Mercury — though don’t expect to see anything more than a tiny dot.

You can also use binoculars (with solar filters attached to the front of each lens). But not just any pair will do. You need decent magnification, which is the first of the two numbers inscribed somewhere on the binoculars. That number should be 10 or higher, as in 10x30 or 12x50. Even so, Mercury will be hard to spot; mounting the binoculars on a tripod to keep them steady will help.

If you’re planning an outreach program for the transit, it’s preferable to be able to show a group what’s happening, instead of having only one person at a time look through a telescope or binoculars. A way to do this is via eyepiece projection. A refracting telescope is best for this. If you use a reflecting telescope, be sure to “stop it down” — that is, place a piece of cardboard over the front end of the scope with a small (one- to two-inch) hole cut into it off to one side. This lets in a limited amount of sunlight, thereby reducing the chance that concentrated sunlight might damage the reflector’s secondary-mirror holder.

Eyepiece projection doesn’t require a solar filter over the front of the scope. Instead, the unfiltered image passes through the telescope and is projected, via an eyepiece, onto a screen. One of the

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Left: A homemade solar filter over a telescope’s front lens, with the finderscope taped to block sunlight. Right: Purchased solar filters at the front end of binoculars. [Paul Deans x2]
simplest ways to do this is to build a Sun funnel (above). Whatever you do, set up and try everything before May 9th. Hopefully there will be a sunspot or two to observe (as a test subject) in the days leading up to the transit. A sunspot on the 9th will be even better, because watching Mercury pass by this solar storm will make the planet’s motion much more obvious.

Even if you’re not using this transit of Mercury as a test run for 2017, make sure you get out and observe it. The next one is 3.5 years away, after which it doesn’t happen again until November 2032 (and that one won’t be visible from North America).

PAUL DEANS has seen numerous solar eclipses as well as transits of both Venus and Mercury.

Solar Filter Suppliers

- **Astro-Physics, Inc.**: Solar-filter material.
- **Kendrick Astro Instruments** (Canada): Filters for telescopes and binoculars and solar-filter material.
- **Orion Telescopes & Binoculars**: Solar filters for telescopes.
- **Rainbow Symphony**: Solar filters.
- **Scope City**: Filters for telescopes and solar-filter material.
- **Thousand Oaks Optical**: Filters for telescopes and binoculars, threaded camera filters, and solar-filter material.

(Inclusion in this list does not imply endorsement by the Astronomical Society of the Pacific.)
Extrasolar Planets: The Saga Continues

An occasional account of our ongoing discoveries of planets beyond the solar system, including a look into the birthplaces of exoplanets.

By Paul Deans

Artist’s impression of the Kepler 453 system showing the recently discovered planet on the right and the eclipsing binary stars on the left. See page 39 for details. Illustration copyright Mark Garlick.
We’ve found planets beyond the solar system. Lots of them, in fact — currently more than 5,600 candidates and approaching 2,000 confirmed. Most have been discovered by the Kepler spacecraft, but many other telescopes and teams are now in the game.

It’s a little disconcerting to think that we may have become a bit blasé about exoplanet discoveries. I can’t help but think this might be the case since we’ve started naming some of these new worlds. I also find it interesting that the organization spearheading the NameExoWorlds contest is the one that created the controversial definition of a planet within our solar system (see page 8) — and doesn’t seem to have a firm definition for an extra-solar planet.

Moving on past the simple realm of discoveries, what are we learning about these worlds beyond? Well, astronomers are getting a better handle on how exoplanets are born. They’re able to peer into the disks of gas and dust that surround certain stars to discern telltale structures produced by protoplanets. They’re also imaging protoplanetary systems and finding what appear to be planet-size bodies caught in the act of accreting.

With a wealth of exoplanets to observe, astronomers are looking at their atmospheres and solving mysteries that, a few years ago, nobody knew were mysteries because nobody knew what questions to ask. And exoplanetologists (is there such a field?) have started studying exoplanets on a long-term basis, looking for (and finding) changes in exoplanetary atmospheres.

To learn more about exoplanets, all you need do is Google the topic, but here are a few good sites you may find interesting. The NASA/JPL PlanetQuest site goes beyond the numbers and features stories about some of these distant worlds the bring them to life. (For example, in early December they published a Star Wars planets story.) If you’re looking for numbers and background data, the NASA Extrasolar Planets Encyclopedia could be what you’re looking for.

Exoplanet Archive might be useful. But if you want “just the facts,” the Extrasolar Planets Encyclopedia could be what you’re looking for.

Shortly after the flyby of Pluto in July 2015, comments were made that the solar system portion of textbooks would need to be rewritten. In the case of exoplanets, the discoveries are coming so fast that a printed textbook on this subject would be out of date even before it could be published. And there are no signs that this deluge of data will slow any time soon.
Giant Planets Carving Paths around Four Young Stars
National Radio Astronomy Observatory

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have found the clearest evidence yet that giant planets have recently formed around four young stars. These new worlds, each presumably several times more massive than Jupiter, were inferred by the telltale structures they produced in the disks of gas and dust that surround the stars.

Though planets appear remarkably plentiful in our galaxy, astronomers still don’t fully understand how and under what conditions they form. To help answer these questions, scientists study the structure and composition of the planet-forming disks of dust and gas around young stars.

Certain disks, called transitional disks, have a surprising absence of dust at their centers, in the region around the star. Two main ideas have been put forward to explain these mysterious cavities. First, the strong stellar winds and intense radiation from the star could have blown away or simply destroyed the encircling gas and dust. Alternatively, massive young planets in the process of formation could have cleared the material as they orbit the star. Previous observations lacked the sensitivity and resolution to determine the most likely explanation.

With ALMA, however, the team of astronomers, led by Nienke van der Marel of Leiden Observatory, the Netherlands, was able to map the distribution of gas and dust in four of these transitional disks better than ever before.

The new ALMA images confirm that the dust-free zones of these disks are not empty, but instead contain significant amounts of gas. These gas-filled regions, the researchers discovered, also contain cavities that are up to three times smaller than the gaps observed in the dust. Such structures are best explained by the scenario in which newly formed massive planets have cleared the gas as they traveled around their orbits.

“Previous observations already hinted at the presence of gas inside the dust cavities,” explains Nienke van der Marel. “But as ALMA can image the material in the entire disk with much greater sharpness and depth than other facilities, we could rule out the alternative scenario. The deep gap points clearly to the presence of planets with several times the mass of Jupiter, creating these caverns as they sweep through the disk.” Further studies are now needed to determine whether more transitional disks also point toward this planet-clearing scenario, though ALMA’s observations have, in the meantime, provided astronomers with a valuable new insight into
the complex process of planetary formation.

“We can now take these exquisite ALMA data and better understand the step-by-step process of planet formation in these disks of gas and dust,” says team member Sean Andrews with the Harvard-Smithsonian Center for Astrophysics. “I and other astronomers are excited to take an even better look at these regions with the full power of ALMA.”

The formal names of the specific stars studied by ALMA are: SR 21, HD 135344B (SAO206462), DoAr 44, and Oph IRS 48. Their research paper is available as a PDF.

Astronomers Spy a Nursery of Baby Exoplanets

*Gemini Observatory*

In early December (2015) at the Extreme Solar Systems conference in Waikoloa, Hawai‘i, astronomers announced the discovery of at least one, probably two, baby Jupiter-like planets still actively forming and surrounded by their natal clouds of gas and dust. The Gemini Planet Imager, at the Gemini South telescope in Chile, provided the key data for this discovery. The system resembles an infant version of the first directly imaged planetary system, discovered using the Gemini North telescope on Maunakea.

Astronomers report that this system, surrounding a star known as HD 100546, is giving us a glimpse back in time to see what other, more developed exoplanet systems looked like in their adolescence. The star is remarkably similar to HR 8799, the first multiple planet system directly imaged and discovered in 2008, but HR 8799’s planets are fully formed. “Now, seven years later, we can for the first time see what this planetary system may have looked like while the planets were just coming into existence,” said principal investigator Thayne Currie, astronomer at the Subaru Observatory.

The team expects many more discoveries as they probe the environs of HD 100546 more deeply. According to University of Toronto graduate student Ryan Cloutier, systems like this one, containing multiple forming giant planets, have extensive spiral arms in their disks. “For HD 100546, its spiral arms may suggest the presence of additional planets,” says Cloutier. “In fact, one of the observed protoplanets might instead be a hotspot within the disk or a signpost of an unseen protoplanet.”

The unique set of data for this research, including high-contrast direct imaging, integral-field spectroscopy, and polarimetry, “really brought this system into focus — it’s remarkably powerful,” said co-investigator Carol Grady from NASA’s Goddard Space Flight Center.

The preprint of the Currie et al. paper can be found here.

Image of HD 100546 obtained with the Gemini Planet Imager at near-infrared wavelengths. The cross shows the position of the star, and the green hatched lines show the region interior to which GPI’s coronagraph blocks our view of the system. HD 100546 b appears as a bright point source sitting on a finger of disk emission. [Gemini Observatory]
Hubble Reveals Diversity of Exoplanet Atmospheres

*Hubble/European Space Agency*

To date, astronomers have discovered nearly 2,000 planets orbiting other stars. Some of these planets are known as hot Jupiters — hot, gaseous planets with characteristics similar to those of Jupiter. They orbit very close to their stars, making their surface hot, and the planets tricky to study in detail without being overwhelmed by bright starlight.

Due to this difficulty, Hubble has only explored a handful of hot Jupiters in the past, across a limited wavelength range. These initial studies have found several planets to hold less water than expected.

Now, an international team of astronomers has tackled the problem by making the largest ever study of hot Jupiters, exploring and comparing ten such planets in a bid to understand their atmospheres. Only three of these planetary atmospheres had previously been studied in detail; this new sample forms the largest ever spectroscopic catalogue of exoplanet atmospheres.

The team used multiple observations from both the NASA/ESA Hubble Space Telescope and NASA’s Spitzer Space Telescope. Using the power of both telescopes allowed the team to study the planets, which are of various masses, sizes, and temperatures, across an unprecedented range of wavelengths.

“I’m really excited to finally ‘see’ this wide group of planets together, as this is the first time we’ve had sufficient wavelength coverage to be able to compare multiple features from one planet to another,” says David Sing of the University of Exeter, UK, lead author of the new paper. “We found the planetary atmospheres to be much more diverse than we expected.”

All of the planets have a favorable orbit that brings them between their parent star and Earth. As the exoplanet passes in front of its host star, as seen from Earth, some of this starlight travels through the planet’s outer atmosphere. “The atmosphere leaves its unique fingerprint on the starlight, which we can study when the light reaches us,” explains co-author Hannah Wakeford, now at NASA Goddard.

These fingerprints allowed the team to extract the signatures from various elements and molecules — including water — and to distinguish between cloudy and cloud-free exoplanets, a property that could explain the missing water mystery.

The team’s models revealed that, while apparently cloud-free exoplanets showed strong signs of water, the atmospheres of those hot Jupiters with faint water signals also contained clouds and haze — both of which are known to hide water from view. Mystery solved!
“The alternative to this is that planets form in an environment deprived of water — but this would require us to completely rethink our current theories of how planets are born,” explained co-author Jonathan Fortney of the University of California, Santa Cruz, USA. “Our results have ruled out the dry scenario, and strongly suggest that it’s simply clouds hiding the water from prying eyes.”

**Astronomers Find First Evidence of Changing Conditions on a Super Earth**

*University of Cambridge, UK*

For the first time, researchers led by the University of Cambridge have detected atmospheric variability on a rocky planet outside the solar system, and observed a nearly threefold change in temperature over a two-year period. Although the researchers are quick to point out that the cause of the variability is still under investigation, they believe the readings could be due to massive amounts of volcanic activity on the surface. The ability to peek into the atmospheres of rocky ‘super Earths’ and observe conditions on their surfaces marks an important milestone towards identifying habitable planets outside the solar system.

Using NASA’s Spitzer Space Telescope, the researchers observed thermal emissions coming from the planet, called 55 Cancri e — orbiting a sun-like star 40 light-years away — and for the first time found rapidly changing conditions, with temperatures on the hot ‘day’ side of the planet swinging between 1000 ° and 2700 ° Celsius.

“This is the first time we've seen such drastic changes in light emitted from an exoplanet, which is particularly remarkable for a super Earth,” said Dr Nikku Madhusudhan of Cambridge’s Institute of Astronomy, a co-author on the new study. “No signature of thermal emission or surface activity has ever been detected for any other super Earth to date.” A PDF of the paper is available [here](#).

Although the interpretations of the new data are still preliminary, the researchers believe the variability in temperature could be due to huge plumes of gas and dust which occasionally blanket the surface, which may be partially molten. The plumes could be caused by exceptionally high rates of volcanic activity, higher than what has been observed on Io, one of Jupiter’s moons and the most geologically active body in the solar system.

“We saw a 300 percent change in the signal coming from this planet, which is the first time we’ve seen such a huge level of variability in an exoplanet,” said Dr Brice-Olivier Demory of the University’s Cavendish Laboratory, lead author of the new study. “While we can't be entirely sure, we think a likely explanation for this variability is large-scale surface activity, possibly volcanism, on the surface is spewing out massive volumes of gas and dust, which sometimes blanket the thermal emission from the planet so it is not seen from Earth.”
55 Cancri e is a ‘super Earth’: a rocky exoplanet about twice the size and eight times the mass of Earth. It is one of five planets orbiting a sun-like star in the Cancer constellation, and resides so close to its parent star that a year lasts just 18 hours. The planet is also tidally locked, meaning that it doesn’t rotate like the Earth does — instead there is a permanent ‘day’ side and a ‘night’ side. Since it is the nearest super Earth whose atmosphere can be studied, 55 Cancri e is among the best candidates for detailed observations of surface and atmospheric conditions on rocky exoplanets.

Most of the early research on exoplanets has been on gas giants similar to Jupiter and Saturn, since their enormous size makes them easier to find. In recent years, astronomers have been able to map the conditions on many of these gas giants, but it is much more difficult to do so for super Earths: exoplanets with masses between one and ten times the mass of Earth.

Earlier observations of 55 Cancri e pointed to an abundance of carbon, suggesting that the planet was composed of diamond. However, these new results have muddied those earlier observations considerably and opened up new questions.

“When we first identified this planet, the measurements supported a carbon-rich model,” said Madhusudhan, who along with Demory is a member of the Cambridge Exoplanet Research Centre. “But now we’re finding that those measurements are changing in time. The planet could still be carbon rich, but now we’re not so sure — earlier studies of this planet have even suggested that it could be a water world. The present variability is something we’ve never seen anywhere else, so there’s no robust conventional explanation. But that’s the fun in science — clues can come from unexpected quarters. The present observations open a new chapter in our ability to study the conditions on rocky exoplanets using current and upcoming large telescopes.”

**Discovery of Tenth Tatooine-like Circumbinary Planet**

*Institute for Astronomy, University of Hawaii*

Reminiscent of the fictional planet Tatooine in “Star Wars,” circumbinary planets orbit two stars and have two “suns” in their skies. The [newly discovered] planet, known as Kepler 453 b, takes 240 days to orbit its parent stars (an artist’s concept is on page 33); the discovery preprint is available here.

Kepler 453 b resides in the habitable zone of its host pair of stars, a surprisingly common occurrence for the circumbinary planets discovered by the Kepler Space Telescope. But because Kepler-453 b is larger than Neptune, it cannot be habitable.

However, because it is a giant gas planet, it may, like the giant gas planets in our solar system, have large moons, and those moons could be habitable. According to University of Hawaii astronomer Nader Haghighipour, the orbit of Kepler 453 b will remain stable for tens of millions of years, increasing the possibility of life forming on its moons.

Circumbinary planets form the same way planets form around single stars, but at greater distances from their host binaries. They then migrate to their more permanent orbits. This migration can be a result of the planets’ interaction with a disk of material around the entire binary system, or their interaction with other planets in the system. “In the case of Kepler-453 b, we believe that both of these mechanisms could have occurred,” Haghighipour said.

The stars themselves orbit each other every 27 days. The larger star is similar to the Sun, and has 94 percent of the Sun’s mass, while the smaller star contains only 20 percent as much mass and is far cooler and fainter, emitting less than one percent of the energy of the larger star. The discovery comes only four years after the first transiting circumbinary, Kepler 16 b, was detected.
Corrected Sunspot History Suggests Climate Change Since the Industrial Revolution Not Due to Natural Solar Trends

International Astronomical Union

The sunspot number, the longest scientific experiment still ongoing, is a crucial tool used to study the solar dynamo, space weather and climate change. It has now been recalibrated and shows a consistent history of solar activity over the past few centuries. The new record has no significant long-term upward trend in solar activity since 1700, as was previously indicated. This suggests that rising global temperatures since the industrial revolution cannot be attributed to increased solar activity.

The Maunder Minimum, between 1645 and 1715, when sunspots were scarce and the winters harsh, strongly suggests a link between solar activity and climate change. Until now there was a general consensus that solar activity has been trending upwards over the past 300 years (since the end of the Maunder Minimum), peaking in the late 20th century — called the Modern Grand Maximum by some. This trend has led some to conclude that the Sun has played a significant role in modern climate change. However, a discrepancy between two parallel series of sunspot number counts has been a contentious issue among scientists for some time.

The two methods of counting the sunspot number — the Wolf Sunspot Number and the Group Sunspot Number — indicated significantly different levels of solar activity before about 1885 and also around 1945. With these discrepancies now eliminated, there is no longer any substantial difference between the two historical records.

The new correction of the sunspot number, called the Sunspot Number Version 2.0, led by Frédéric Clette (Director of the World Data Centre [WDC]–SILSO), Ed Cliver (National Solar Observatory) and Leif Svalgaard (Stanford University, California, USA), nullifies the claim that there has been a Modern Grand Maximum.

The results, presented at the IAU XXIX General Assembly in Honolulu, Hawai’i, last August, make it difficult to explain the observed changes in the climate that started in the 18th century and extended through the industrial revolution to the 20th century as being significantly influenced by natural solar trends.

MORE INFORMATION

The newly calibrated sunspot group number during the last 400 years.

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MORE INFORMATION
New Clues to Ceres’ Bright Spots and Origins
NASA/Jet Propulsion Laboratory

Ceres reveals some of its well-kept secrets in two new studies in the journal *Nature*, thanks to data from NASA’s Dawn spacecraft. In one study, scientists identify the bright material as a kind of salt. The second study suggests the detection of ammonia-rich clays, raising questions about how Ceres formed.

Ceres has more than 130 bright areas, and most of them are associated with impact craters. Study authors, led by Andreas Nathues at Max Planck Institute for Solar System Research, Göttingen, Germany, write that the bright material is consistent with a type of magnesium sulfate called hexahydrite. A different type of magnesium sulfate is familiar on Earth as Epsom salt.

Nathues and colleagues, using images from Dawn’s framing camera, suggest that these salt-rich areas were left behind when water-ice sublimated in the past. Impacts from asteroids would have unearthed the mixture of ice and salt, they say. “The global nature of Ceres’ bright spots suggests that this world has a subsurface layer that contains briny water-ice,” Nathues said.

The surface of Ceres, whose average diameter is 584 miles (940 kilometers), is generally dark — similar in brightness to fresh asphalt — study authors wrote. The bright patches that pepper the surface represent a large range of brightness, with the brightest areas reflecting about 50 percent of sunlight shining on the area. But there has not been unambiguous detection of water ice on Ceres; higher-resolution data are needed to settle this question.

With its sharp rim and walls, and abundant terraces and landslide deposits, Occator appears to be among the youngest features on Ceres. Dawn scientists estimate it to be about 78 million years old.

Study authors write that some views of Occator appear to show a diffuse haze near the surface that fills the floor of the crater.
Hubble’s Planetary Portrait Captures New Changes in Jupiter’s Great Red Spot

*NASA/Goddard Spaceflight Center*

Scientists using NASA’s Hubble Space Telescope have produced new maps of Jupiter – the first in a series of annual portraits of the solar system’s outer planets.

Collecting these yearly images — essentially the planetary version of annual school picture days for children — will help current and future scientists see how these giant worlds change over time. The observations are designed to capture a broad range of features, including winds, clouds, storms and atmospheric chemistry.

Already, the Jupiter images have revealed a rare wave just north of the planet’s equator and a unique filamentary feature in the core of the Great Red Spot not seen previously.

“Every time we look at Jupiter, we get tantalizing hints that something really exciting is going on,” said Amy Simon, a planetary scientist at NASA’s Goddard Space Flight Center in Greenbelt, Maryland. “This time is no exception.”

Simon and her colleagues produced two global maps of Jupiter from observations made using Hubble’s high-performance Wide Field Camera 3. The two maps represent nearly back-to-back rotations of the planet, making it possible to determine the speeds of Jupiter’s winds.

The new images confirm that the Great Red Spot continues to shrink and become more circular, as it has been doing for years.

The long axis of this characteristic storm is about 150 miles (240 kilometers) shorter now than it was in 2014. Recently, the storm had been shrinking at a faster-than-usual rate, but the latest change is consistent with the long-term trend.

The Great Red Spot remains more orange than red these days, and its core, which typically has more intense color, is less distinct than it used to be.

In Jupiter’s North Equatorial Belt, the researchers found an elusive wave that had been spotted on the planet only once before, decades earlier, by Voyager 2. Similar waves — called baroclinic waves — sometimes appear in Earth’s atmosphere where cyclones are forming.
Researchers Find Evidence of a Real Ninth Planet

*California Institute of Technology*

Caltech researchers have found evidence of a giant planet tracing a bizarre, highly elongated orbit in the outer solar system. The object, which the researchers have nicknamed Planet Nine, has a mass about 10 times that of Earth and orbits about 20 times farther from the Sun on average than does Neptune. In fact, it would take this new planet between 10,000 and 20,000 years to make just one full orbit around the sun.

The researchers, Konstantin Batygin and Mike Brown, discovered the planet’s existence through mathematical modeling and computer simulations but have not yet observed the object directly. “This would be a real ninth planet,” says Brown, the Richard and Barbara Rosenberg Professor of Planetary Astronomy. “There have only been two true planets discovered since ancient times, and this would be a third. It’s a pretty substantial chunk of our solar system that’s still out there to be found, which is pretty exciting.”

“Although we were initially quite skeptical that this planet could exist, as we continued to investigate its orbit and what it would mean for the outer solar system, we become increasingly convinced that it is out there,” says Batygin, an assistant professor of planetary science. “For the first time in over 150 years, there is solid evidence that the solar system’s planetary census is incomplete.”

The road to the theoretical discovery was not straightforward. In 2014, a former postdoc of Brown’s, Chad Trujillo, and his colleague Scott Sheppard published a paper noting that 13 of the most distant objects in the Kuiper Belt are similar with respect to an obscure orbital feature. To explain that similarity, they suggested the possible presence of a small planet. Brown thought the planet solution was unlikely, but his interest was piqued.

He took the problem down the hall to Batygin, and the two started what became a year-and-a-half-long collaboration to investigate the distant objects.
Astronomers have discovered what appears to be a tiny star with a giant, cloudy storm, using data from NASA’s Spitzer and Kepler space telescopes. The dark storm is akin to Jupiter’s Great Red Spot: a persistent, raging storm larger than Earth.

“The star is the size of Jupiter, and its storm is the size of Jupiter’s Great Red Spot,” said John Gizis of the University of Delaware, Newark. “We know this newfound storm has lasted at least two years, and probably longer.”

While planets have been known to have cloudy storms, this is the best evidence yet for a star that has one. The star, referred to as W1906+40, belongs to a thermally cool class of objects called L-dwarfs. Some L-dwarfs are considered stars because they fuse atoms and generate light, as our Sun does, while others, called brown dwarfs, are known as “failed stars” for their lack of atomic fusion.

The L-dwarf in the study, W1906+40, is thought to be a star based on estimates of its age (the older the L-dwarf, the more likely it is a star). Its temperature is about 3,500 degrees Fahrenheit (2,200 Kelvin). That may sound scorching hot, but as far as stars go, it is relatively cool. Cool enough, in fact, for clouds to form in its atmosphere.

“The L-dwarf’s clouds are made of tiny minerals,” said Gizis.

Spitzer has observed other cloudy brown dwarfs before, finding evidence for short-lived storms lasting hours and perhaps days.

In the new study, the astronomers were able to study changes in the atmosphere of W1906+40 for two years. The L-dwarf had initially been discovered by NASA’s Wide-field Infrared Survey Explorer in 2011. Later, Gizis and his team realized that this object happened to be located in the same area of the sky where NASA’s Kepler mission had been staring at stars for years to hunt for planets.
Final Kiss of Two Stars Heading for Catastrophe

*European Southern Observatory*

Using ESO’s Very Large Telescope, an international team of astronomers have found the hottest and most massive double star with components so close that they touch each other. The two stars in the extreme system VFTS 352 could be heading for a dramatic end, during which the two stars either coalesce to create a single giant star, or form a binary black hole.

The double star system VFTS 352 is located about 160,000 light-years away in the Tarantula Nebula. This remarkable region is the most active nursery of new stars in the nearby universe and new observations from ESO’s VLT have revealed that this pair of young stars is among the most extreme and strangest yet found.

VFTS 352 is composed of two very hot, bright, and massive stars that orbit each other in little more than a day. The centers of the stars are separated by just 12 million kilometers. In fact, the stars are so close that their surfaces overlap and a bridge has formed between them. VFTS 352 is not only the most massive known in this tiny class of “overcontact binaries” — it has a combined mass of about 57 times that of the Sun — but it also contains the hottest components — with surface temperatures above 40,000° Celsius.

Extreme stars, like the two components of VFTS 352, play a key role in the evolution of galaxies and are thought to be the main producers of elements such as oxygen. Such double stars are also linked to exotic behavior such as that shown by “vampire stars,” where a smaller companion star sucks matter from the surface of its larger neighbor.

In the case of VFTS 352, however, both stars in the system are of almost identical size. Material is, therefore, not sucked from one to another, but instead may be shared.
NASA’s Chandra Finds Supermassive Black Hole Burping Nearby

Chandra X-ray Observatory

Astronomers have used NASA’s Chandra X-ray Observatory to discover one of the nearest supermassive black holes to Earth that is currently undergoing powerful outbursts. This galactic burping was found in the Messier 51 galaxy, which is located about 26 million light-years from Earth and contains a large spiral galaxy NGC 5194 (also known by its nickname of the “Whirlpool”) merging with a smaller companion galaxy NGC 5195.

This main panel of this graphic shows M51 in visible light data from the Hubble Space Telescope (red, green, and blue). The box at the top of the image outlines the field of view by Chandra in the latest study, which focuses on the smaller component of M51, NGC 5195.

The inset to the right shows the details of the Chandra data (blue) of this region. Researchers found a pair of arcs in X-ray emission close to the center of the galaxy, which they interpret as two outbursts from the galaxy’s supermassive black hole. The authors estimate that it took about one to three million years for the inner arc to reach its current position, and three to six million years for the outer arc.

Just outside the outer X-ray arc is a slender region of hydrogen emission detected in an optical image. This suggests that the X-ray emitting gas has “snow-plowed” or swept-up the hydrogen gas from the center of the galaxy. This is a clear case where a supermassive black hole is affecting its host galaxy, in a phenomenon that astronomers called “feedback.”
Caught in the Act

*ESA/Hubble Space Telescope*

Many stars end their lives with a bang, but only a few of these stellar explosions have been caught in the act. When they are, spotting them successfully has been down to pure luck — until now. On December 11, 2015, astronomers not only imaged a supernova in action, but saw it when and where they had predicted it would be.

The supernova, nicknamed Refsdal, has been spotted in the galaxy cluster MACS J1149.5+2223. While the light from the cluster has taken about five billion years to reach us, the supernova itself exploded much earlier, nearly 10 billion years ago.

Refsdal’s story began in November 2014 when scientists spotted four separate images of the supernova in a rare arrangement known as an Einstein Cross around a galaxy within MACS J1149.5+2223 (heic1505). The cosmic optical illusion was due to the mass of a single galaxy within the cluster warping and magnifying the light from the distant stellar explosion in a process known as gravitational lensing.

“While studying the supernova, we realized that the galaxy in which it exploded is already known to be a galaxy that is being lensed by the cluster,” explains Steve Rodney, co-author, from the University of South Carolina. “The supernova’s host galaxy appears to us in at least three distinct images caused by the warping mass of the galaxy cluster.”

These multiple images of the galaxy presented a rare opportunity. As the matter in the cluster — both dark and visible — is distributed unevenly, the light creating each of these images takes a different path with a different length. Therefore the images of the host galaxy of the supernova are visible at different times.
NASA’s Great Observatories Weigh Massive Young Galaxy Cluster

Astronomers used data from three of NASA’s Great Observatories to make the most detailed study yet of an extremely massive young galaxy cluster. This rare cluster, which is located 10 billion light-years from Earth, weighs as much as 500 trillion suns. This object has important implications for understanding how these megastructures formed and evolved early in the universe.

The galaxy cluster, called IDCS J1426.5+3508 (IDCS 1426 for short), is so far away that the light detected is from when the universe was roughly a quarter of its current age. It is the most massive galaxy cluster detected at such an early age.

First discovered by the Spitzer Space Telescope in 2012, IDCS 1426 was observed using the Hubble Space Telescope and the Keck Observatory on Mauna Kea, Hawaii, to determine its distance. Observations from the Combined Array for Millimeter Wave Astronomy indicated it was extremely massive. New data from the Chandra X-ray Observatory confirm the galaxy cluster’s mass and show that about 90 percent of the mass of the cluster is in the form of dark matter, a mysterious substance detected so far only through its gravitational pull on normal matter composed of atoms.

“We are really pushing the boundaries with this discovery,” said Mark Brodwin of the University of Missouri at Kansas City, who led the study. “As one of the earliest massive structures to form in the universe, this cluster sets a high bar for theories that attempt to explain how clusters and galaxies evolve.”

Galaxy clusters are the largest objects in the universe bound together by gravity. Because of their sheer size, scientists think it should take several billion years for them to form. The distance of IDCS 1426 means astronomers are observing it when the universe was only 3.8 billion years old, implying that the cluster is seen at a very young age.

The data from Chandra reveal a bright knot of X-rays near the middle of the cluster, but not exactly at its center. This overdense core has been dislodged from the cluster center, possibly by a merger with another developing cluster 500 million years prior.

MORE INFORMATION

This multi-wavelength image shows this galaxy cluster, called IDCS 1426, in X-rays recorded by the Chandra X-ray Observatory in blue, visible light observed by the Hubble Space Telescope in green, and infrared light detected by the Spitzer Space Telescope in red. (NASA/CXC/Univ of Missouri/M. Brodwin et al; NASA/STScI; JPL/Caltech)
Nominations for the ASP’s 2016 Awards

The Astronomical Society of the Pacific is accepting nominations for the organization’s national annual awards which recognize special achievements in astronomy research, technology, education, and public outreach. Nominations are welcome in seven categories, online or in writing, until February 15, 2016.

Honorees receive a cash award and engraved plaque, as well as travel and lodging to accept the award at a banquet which takes place as part of the ASP’s Annual Meeting this autumn. The awards for which nominations are accepted are as follows:

• The Maria and Eric Muhlmann Award recognizes recent significant observational results made possible by innovative advances in astronomical instrumentation, software, or observational infrastructure.

• The Robert J. Trumpler Award is presented each year to a recent recipient of the PhD degree in North America whose research is considered unusually important to astronomy.

• The Klumpke-Roberts Award recognizes those who have made outstanding contributions to the public understanding and appreciation of astronomy.

• The Richard A. Emmons Award celebrates outstanding achievement in the teaching of college-level introductory astronomy for non-science majors.

• The Thomas J. Brennan Award is given for excellence in the teaching of astronomy at the high school level in North America.

• The Amateur Achievement Award recognizes significant observational or technological contributions to astronomy or amateur astronomy by an individual not employed in the field of astronomy in a professional capacity.

• The Las Cumbres Amateur Outreach Award honors outstanding educational outreach by an amateur astronomer to K-12 youth and the interested lay public.

The nominations deadline is February 15, 2016. Submission guidelines, lists of past recipients and additional information may be found by clicking on each of the Award names. 

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NEW MEMBERS — The ASP thanks all those who recently renewed their membership, and welcomes new members who joined between September 16 and December 31, 2015.

**Individual**

Benjamin L. Brown, San Francisco, CA
Anthony J Canney Jr, West Seneca, NY
Don Corral, Belmont, CA
Todd Davis, Bellevue, WA
Karen Keck, Lubbock, TX
Davina M. Keiser, Long Beach, CA
Grant McKinney, San Ramon, CA
Doug Peltz, Walnut, CA
Norman Redington, Lubbock, TX
Wallace Tucker, Fallbrook, CA
Grace Wheeler, Eureka, CA
Bob Yoesle, Goldendale, WA

**Technical**

David Young, Watermans Bay, Australia
William Zimmerman, Albuquerque, NM

**Student**

Catherine Aitken, Danville, CA
Margaret Leising, Castle Rock, WA
Ryan Stark, Langley, WA
Lori St. John Baldwin, San Francisco, CA
Daryl Boardman, Fredericton, Canada
Don Bohr, Sequim, WA
Lewis A. Cook, Fayetteville, WV
Imke de Pater, Walnut Creek, CA
Thomas Ernst, Memphis, TN
William McCamy, Orange Park, FL
David Pundak, Jordan Valley, Israel
Frederick Repich, Charlottesville, VA
Gary Sharp, Friday Harbor, WA

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TABLE OF CONTENTS
sky sights

by Paul Deans

The Skies of February

One month after the start of the new year, there is still little to see in the evening sky (at least in terms of planets). A crescent Moon pops into view during the second week, but that’s it.

On the other side of the evening sky, Jupiter rises about 9:00 pm on the 1st and just after sunset by month’s end. Shortly after sunset on the 23rd, the Moon hangs slightly below this giant planet; both are rising in the east at that time.

If you’re up well before dawn on the 1st, you might spot reddish Mars about 2° to the lower right of the last quarter Moon. The red planet rises just after midnight at month-start, and just before midnight at month-end. And if you’re up early again, this time on the 29th, you’ll see Mars near the Moon once more, this time to Luna’s lower left.

Saturn rises about two hours after Mars, and is nicely placed in the south-southeast as dawn approaches. On the 3rd the ringed planet is about 4° away from the crescent Moon, and almost directly beneath it.

Continuing east as twilight heralds dawn, both Venus and Mercury rise into a slowly brightening sky. Venus, still brilliant, is slowly sinking back toward the Sun, while dimmer Mercury rises to meet it, doesn’t quite make it, and falls back Sunward. If you’ve never seen Mercury, now is a good time to spot it (assuming you are up and outside some 45 minutes before sunrise and you have a decently clear and low southeastern horizon). Between the 5th and the 21st, Mercury is less than 5° to the lower left of Venus. Closest approach (4°) is on the 13th. But your best chance may be dawn on the 6th. That’s when the crescent Moon is 5° to the left of Venus, while Mercury is about 3° below the Moon. All three will fit nicely into a binocular field of view.

The Skies of March

Although there are still no planets in the sunset sky, there is one rising in the east as darkness falls. Jupiter is at opposition on the 8th, which means it rises as the Sun sets, is visible all night, and sets as the Sun rises. (The nearly full Moon is just to the planet’s lower right on the 21st.) With the giant planet moving into the evening skies and the weather warming as spring approaches, it’s a great time to get out and study the planet with whatever telescope you have available. If you don’t have one, check with your local science center.

Use your hand to make rough estimates of angular sizes. Held at arm’s length, your little finger is about 1° across, your fist is about 10° across, etc. [NASA/CXC/M.Weiss]
or planetarium for any upcoming star parties, or go to the Night Sky Network to search for events such as star parties happening in your area. Astronomy Day, which is guaranteed to bring out the amateurs and their telescopes, is on Saturday May 14th.

Both Mars and Saturn rise well midnight on the 1st, and around midnight by the 31st, and both are well up in the south by dawn. Mars is the slightly brighter and redder of the two and opens the month more than 15° to Saturn’s upper right. On the 1st the Moon sits roughly midway between the two planets, and on the 2nd it’s about 3° to Saturn’s left. Mars is rapidly overtaking the ringed planet, and by month’s end they are separated by less than 10°. The Moon revisits this planetary pair, sitting well to the upper right of Mars on the 28th and again between the two planets on the 29th. By the way, don’t mix Mars and reddish Antares. Antares is the very twinkly star just below both planets.

As dawn breaks, Venus is still visible low in the east, but it continues to slide toward the Sun. (Little Mercury has already vanished into the solar glare.) Venus rises less than an hour before the Sun and will be difficult to spot. Perhaps you can spot either Venus or a thin crescent Moon (or both) very low in the east-southeast on the 7th.

A total eclipse of the Sun takes place on March 9th along a narrow path through Indonesia and out into the Pacific Ocean. A partial eclipse is visible across Indonesia and much of southeast Asia as well as all of Australia except the southeast. Partial phases are also visible before or at sunset on the 8th in Hawaii and Alaska.

On March 23 a penumbral eclipse of the Moon is visible in Asia, Australia and New Zealand, the Pacific, and the western Americas. Maximum eclipse occurs at 11:47:14 Universal Time — 4:47 am Pacific time; 01:47 in Hawaii. At this time the southern three-quarters of the Moon will be inside the Earth’s penumbral shadow, and a slight darkening of the Moon’s southern limb might be apparent. More details are available here.

The vernal equinox occurs on March 19th/20th and marks the astronomical start of spring in the Northern Hemisphere and autumn in the Southern. The actual equinox occurs at 04:30 Universal Time on the 20th, 00:30 Eastern time on the 20th, 21:30 Pacific time on the 19th. As a minor timekeeping note, Daylight Saving Time begins for most of North America on Sunday the 13th (and on the 27th throughout most of Europe).

The Skies of April
Although it’s not long for the sunset sky, Mercury pops into view as the month opens. This evening appearance is an excellent time to find this elusive little planet. Mercury is always going to be low, so you need a clear west-northwest horizon. Between April 14 and 20th, Mercury can be found about 10° above the horizon some 45 minutes after sunset and should be clearly visible in the darkening dusk sky. Two other dates to keep in mind. On the 8th Mercury is 10° to the lower right of the 2-day-old crescent Moon; the crescent should help you spot the planet. And greatest elongation of Mercury occurs on the 18th, when the planet sets more than 90 minutes after the Sun. As for Venus…it’s lost in the solar glare until late July.
**Jupiter** is a brilliant sight high in the southeast after sunset and is visible almost all night. On the 17th the Moon sits to the giant planet’s lower right.

**Mars** and **Saturn** rise around midnight on the 1st, and 10:00 pm by month’s end. The red planet is brightening every week and outshines both Saturn and the reddish star Antares (located about 5° beneath Mars). On the 25th the Moon rises with Mars to its lower right and Saturn beneath it.

During April, Mars approaches, and then recedes from Saturn. On the 19th or so, they’re separated by only 7°, their closest approach until late August when the red planet speeds by the ringed world.

On the 15th the **Lyrid meteor shower** peaks. It’s a brief show and not particularly strong. With an average of only 20 meteors per hour radiating from a spot near the Hercules-Lyra border, and light from the full Moon washing out fainter meteors, this year’s Lyrid shower is definitely not the best.

Under the heading of “much ado about nothing” is the whole supermoon discussion. In reality, there’s nothing super about a supermoon since you don’t see anything special or different about it — unless you photograph these two different full Moons with the same camera setup and compare them. But knowing when the closest (and most distant) full moons are each year can be a useful item of conversation at dinner parties. So with that in mind, note that the April 21/22 full Moon is at apogee (and hence will be the “smallest” full Moon of 2016). The “largest” falls on November 14th when the full Moon occurs only three hours after perigee.

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**Star Charts**

If you’d like a star chart to help you explore the naked-eye night sky, you have several options: purchase a star wheel (planisphere) or planetarium software, download a PDF showing the sky this month, find an online star chart, or locate an app for your tablet or smart phone.

**PDF Star Charts.** Skymaps produces a well-done chart that goes beyond a mere monthly star chart. It includes a list of monthly highlights and observable celestial objects. The downside: each month is available only at the very end of the previous month.

Another nice star chart is available from Orion Telescopes and Binoculars; you can download it one month in advance. If you’d like simple star charts that don’t show the planets, a set of 12 is available from the Canada Science and Technology Museum.

**Online Star Charts.** Sky View Café gives you control over the chart’s date, time, and location, plus a few other options. But the chart names only a few bright stars, doesn’t identify the constellations, and the printout of the resulting chart is poor. The star chart created on the Tau Astronomy Club website offers fewer options but a better printout. But it lists no star names and the stars are color coded based on their spectral type.

**Apps For Tablets and Smart Phones.** SkySafari 4 ($2.99 for the basic version; available for iPhone, iPad, and iPod touch; now available for Android) is a very well done star chart app and is the one I use consistently. TheSky by Software Bisque is one of the most popular planetarium programs out there, and is now available for the iPad and iPhone. If ASP stargazers have a favorite night sky app, regardless of the device, I’d like to hear about it.

— P.D.
High-Resolution Earthrise

NASA’s Lunar Reconnaissance Orbiter captured this unique view of Earth from the spacecraft’s vantage point in orbit around the Moon. In this composite image, Earth hangs over the lunar horizon from the viewpoint of the spacecraft. In the lunar foreground is a glimpse of the crater Compton, which is located on the lunar farside just beyond the eastern limb of the Moon. Click on the NASA link for more details. [NASA/Goddard/Arizona State University]