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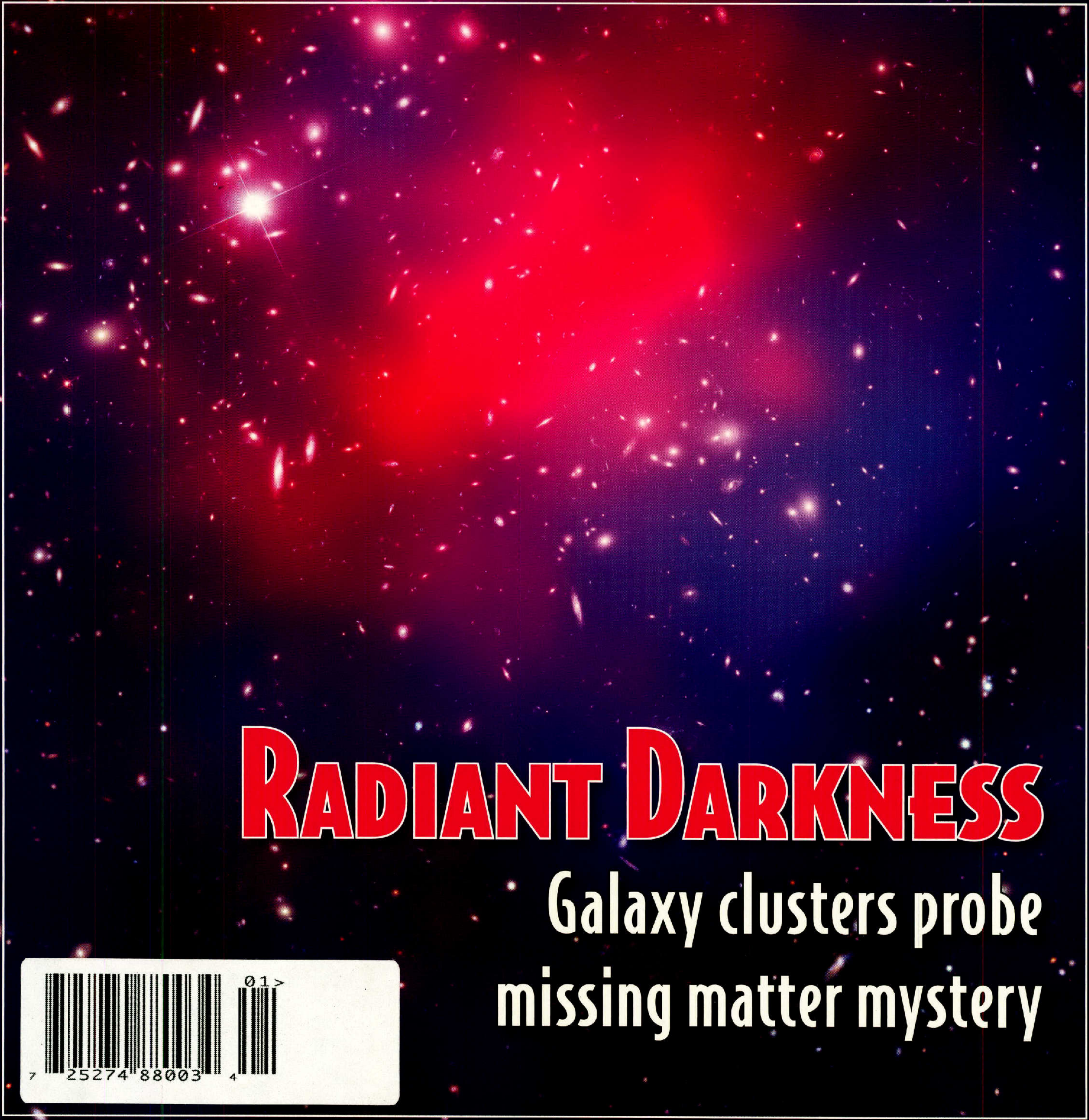

RADIANT DARKNESS

Galaxy clusters probe missing matter mystery

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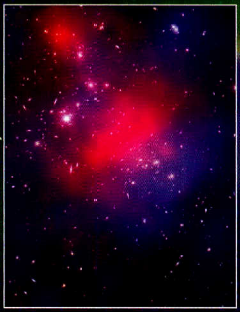

NASA/ESA/ESO, CXC/D. COE/J. MERTEN

On The Cover
Pandora's Cluster was likely created by a collision of four galaxy clusters. Hot X-ray gas is shown in pink; dark matter is indicatd in purple. For more on dark matter in galaxy clusters, see page 4.

This Page
Bright young stars (red, orange) up to 40 times the Sun's mass are forming in NGC 6334 (the Cat's Paw Nebula), seen here in infrared. The stars are warming nearby dust (green). Darker clouds mark high-density dust where the next stars will form.

Coming Up
In our November/December issue, learn about the massive swirling storms on our solar system's largest planets, called 'polar vortices.' Get holiday skywatching tips, and Merlin's answers to your questions.

S. WILLIS (CfA)/ESA/HERSCHEL/NASA/JPL-CALTECH/SSC/CTIO/NOAO/AURA/NSF

Merlin

Dear Merlin,

I've read a lot about black holes, and I have no fear. If we (as a planet) fell into one, I'm certain we would not know what hit us. But is there a black hole out there large enough to swallow the entire Earth? And could it sneak up on us or do we have ways to detect this phenomenon and take evasive action in time? Is there any constructive use which could be made of a black hole or are they simply like chuck holes in the roadway: something to avoid if at all possible!?

Richard D. Longstreth Jr.
Palo Alto, California

Black holes don't "sneak." They don't really care if you know they're coming because there's not a darn thing you can do about it.

Like T-shirts and fast-food meals, black holes come in several sizes. The smallest (not including possible "primordial" black holes, which are smaller than an atom and therefore not a problem) are a few times as massive as the Sun. A black hole 10 times the Sun's mass is only about 35 miles (60 km) in diameter. That's hardly big enough to swallow Earth whole.

Unfortunately for planets and stars everywhere, a black hole doesn't need to swallow something whole. The black hole's gravity rips apart anything that gets close to its event horizon — the black hole's visible "surface" — and pulls in the pulverized debris.

The second class of black holes, which are a few thousand times the Sun's mass, are roughly the size of Earth or a little bigger, so no problem in taking a big gulp. And the super-sized black holes, which occupy the centers of galaxies, range from millions to billions of miles across, so they are large enough to ingest entire solar systems in a single big bite.

Any approaching black hole should be easy to spot long before it neared Earth. Infalling gas, planets, and other debris are heated to millions of degrees or hotter, so they emit ultraviolet radiation and X-rays. The closer the black hole, the brighter its surrounding cloud of hot debris. A black hole's gravity also distorts the view of the universe beyond. Finally, an approaching black hole would scatter comets and asteroids and alter the orbits of the planets long before the black hole could get to Earth.

As for "productive" uses of a black hole, how about providing (almost) limitless energy?

One idea takes advantage of the fact that a spinning black hole drags the space around it like water circling a drain, creating a powerful magnetic field from which it's possible to extract energy. In this scenario, a large ring encircles the black hole's poles. Superconducting coils around the black hole's equator convert the magnetic energy to electrical current that would flow to the ring, where it's stored or transmitted to a receiving station.

In another scenario, a spaceship flies into the swirl of spacetime around the black hole and splits apart. Half of the ship falls into the black hole, while the other half is thrown back into space. The escaping half carries out more energy than the whole spacecraft carried in. (Present-day terrestrial spacecraft use a similar technique to steal orbital energy from a planet, getting a boost toward more-distant destinations.)

Dear Merlin,

I enjoyed the article by Lee Smolin on time in the recent StarDate, *but would like to have a clarification of his comment, "asymmetries in time point the same way — toward increasing disorder." I would think that asymmetries would point toward order. If heat transfers from a hot body to a cold body, as was one of his examples, doesn't that tend toward order?*

Dave Fried
Saint Paul

A cup of hot coffee getting colder is certainly an orderly process (although a sometimes annoying one). However, as Lee Smolin pointed out, it's also a one-way process. The now-cold coffee doesn't suddenly get hot again unless it's placed in a hot container or zapped in a microwave. So while this process is neat and orderly, it's not symmetrical because it works in only one direction.

In the greater universe, this means that as time passes, everything ages (Hollywood fantasies notwithstanding) in one direction. If time were symmetrical, a supernova would be as likely to unexplode and reintegrate into a shining star as to continue the explosion and disperse its fragments into space. Since we don't see that happening, we conclude that the universe is moving toward increasing disorder — it is getting older.

Merlin is unable to send personal replies. Answers to many astronomy questions are available through our web site:

stardate.org/astro-guide

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Dark Matters

Galaxy clusters figured prominently in the discovery of dark matter and continue to shed light, so to speak, on the enigma today

By Rebecca Johnson

A composite view of Abell 520, a collision between galaxy clusters. The clusters' galaxies (seen in optical light) have sailed through each other unscathed. The clusters' hot gas (green, seen in X-rays) has collided and piled up, giving evidence of the smash-up. Astronomers used gravitationally lensed background galaxies to figure out the location of dark matter from the clusters, indicated in blue.

Most of the matter in the universe is dark at all wavelengths telescopes can measure. No one knows for sure what it is. Dubbed "dark matter," astronomers detect it by its gravitational pull on visible objects.

Studies over the past half century have shown that galaxies like our own Milky Way and others are made of about 15 percent normal matter (stars, gas, and dust) and 85 percent dark matter. On larger scales, dark matter is even more prominent. Clusters of galaxies can contain up to almost 100 times more dark matter than normal matter. In addition to the dark matter in its member galaxies, a cluster has dark matter in between those galaxies.

Because galaxies and galaxy clusters are the basic building blocks of the universe, understanding dark matter is one of the most important keys to figuring out how structure came about in the cosmos.

Galaxy clusters in particular played a key role in the discovery of dark matter. Today, astronomers are weighing and mapping the dark matter in clusters to better understand the evolution of cosmic structure.

A galaxy cluster is a group of galaxies held together by their mutual gravitational pull. They come in a variety of sizes and shapes. The Milky Way resides in the Local Group, a collection of about three dozen galaxies spread over about 10 light-years. Much larger "rich clusters" like the relatively nearby Virgo Cluster can contain more than 1,000 galaxies. The galaxies may clump together to form a dense ball or spread out to form a wobbly, irregular shape.

Fritz Zwicky was the first astronomer to understand the nature of galaxy clusters. A Swiss astronomer teaching at Caltech, in the 1930s Zwicky posited that the galaxies in a cluster are orbiting each other, just as stars in a star cluster orbit each other.

Zwicky decided he could measure the mass in a cluster by clocking the speeds of galaxies within it and applying Newton's laws of gravity. He used a spectrograph to measure how fast individual galaxies in the Coma Cluster, a rich cluster in the constellation Coma Berenices, are moving away from Earth. He then averaged the galaxies' speeds to come up with the "recession speed" of the cluster as whole — the speed at which the universe's expansion was carrying the cluster away from Earth. (Edwin Hubble had discovered that the universe was expanding only a few years before.)

Once Zwicky knew the Coma Cluster's recession speed, he could subtract it from individual speeds of its component galaxies. This told him how the galaxies within the cluster were moving relative to each other. With that information in hand, he used Newton's laws to calculate the cluster's mass.

What Zwicky found was staggering: the Coma Cluster contained much more mass than could be accounted for in the galaxies he saw. He concluded that there had to be a vast amount of unseen mass in the cluster that was not in the form of stars or gas clouds. In a 1933 paper in the journal *Helvetica Physica Acta*, he dubbed it *dunkle materie*: dark matter.

Most of Zwicky's contemporaries thought his conclusions must be flawed, however. Zwicky did not receive credit for the discovery of dark matter for many decades — until Vera Rubin's studies of spiral galaxies in the 1960s and '70s proved that individual galaxies also must be full of some kind of mysterious unseen matter.

Several decades after Zwicky's work, and about the same time that Rubin was discovering dark matter in galaxies, a new invention sparked a novel way of studying galaxy clusters. The 1960s saw the launch of X-ray telescopes above Earth's atmosphere.

X-ray observations revealed that clusters contain a lot of hot gas between and around the member galaxies. In large clusters, this hot gas can hold up to seven times more mass than is locked up in the member galaxies' stars. This intra-cluster gas proved to be an exciting new way to address the problem of measuring the amount of dark matter in galaxy clusters.

The gas, which can reach upwards of 10 million degrees Fahrenheit, would naturally be pushing outward to escape the cluster. Assuming that the gas is being held back by the cluster's inward pull of gravity, then the amount of kinetic energy (the energy of motion) in the gas is determined by the cluster's gravitational pull.

The more kinetic energy in the gas, the hotter it is. And a cluster's gravitational pull is determined by its total mass. Therefore, the temperature of the gas in a galaxy cluster is directly related to the cluster's total mass. So by taking the temperature of the gas with an X-ray telescope, astronomers can measure the clusters' total mass.

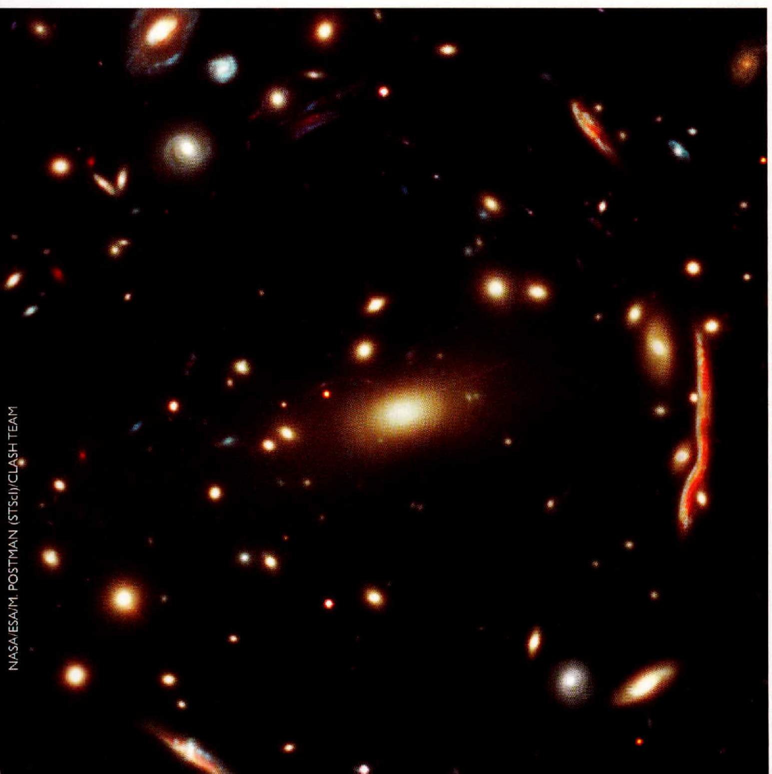
Comparing the total mass to the amount of mass in detectable matter like stars and gas tells astronomers how much dark matter is in the cluster. The X-ray findings agreed with Zwicky-type orbital studies, proving that galaxy clusters hold huge amounts of dark matter.

A third method for probing dark matter in galaxy clusters relies on cosmic coincidence. If aligned just right, a galaxy cluster can act like a giant lens and magnify and distort an object that lies behind it along our line of sight.

This phenomenon is called gravitational lensing. It's a consequence of Albert Einstein's 1916 General Theory of Relativity, in which he said that mass bends the space around it. Einstein didn't think that telescopes would ever be good enough to actually see a gravitational lens, but by 1979 the first one was detected.

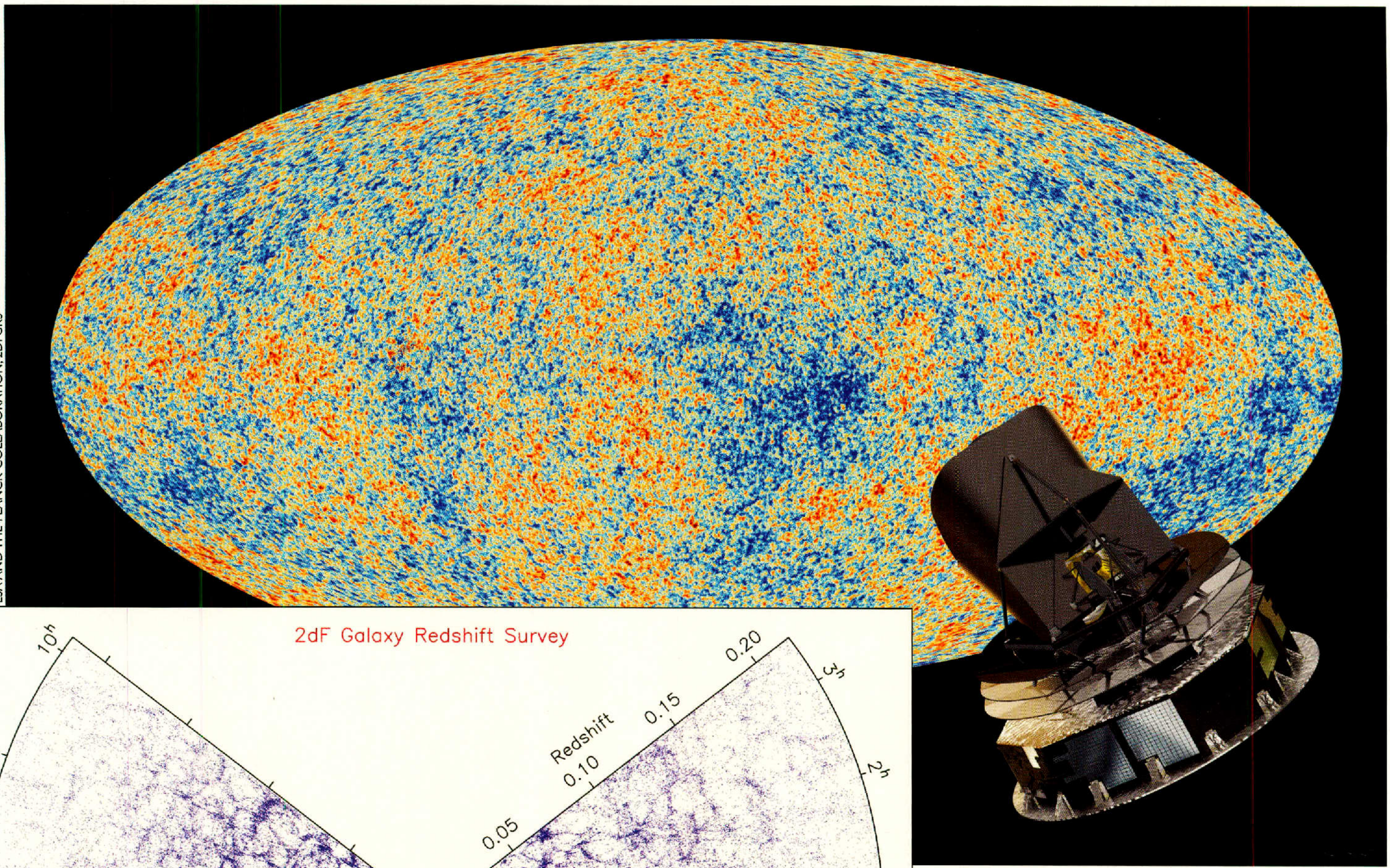
Galaxy clusters are some of the most massive objects in the universe. The light coming from a galaxy lying behind a cluster will be bent around the cluster as it travels toward the telescope. The giant lens — the cluster — might split the light from the background galaxy so that it shows up as multiple arcs surrounding the cluster in a two-dimensional photograph.

The degree at which the light from a background object is bent depends on the mass of the lens, so astronomers can measure the mass of the galaxy

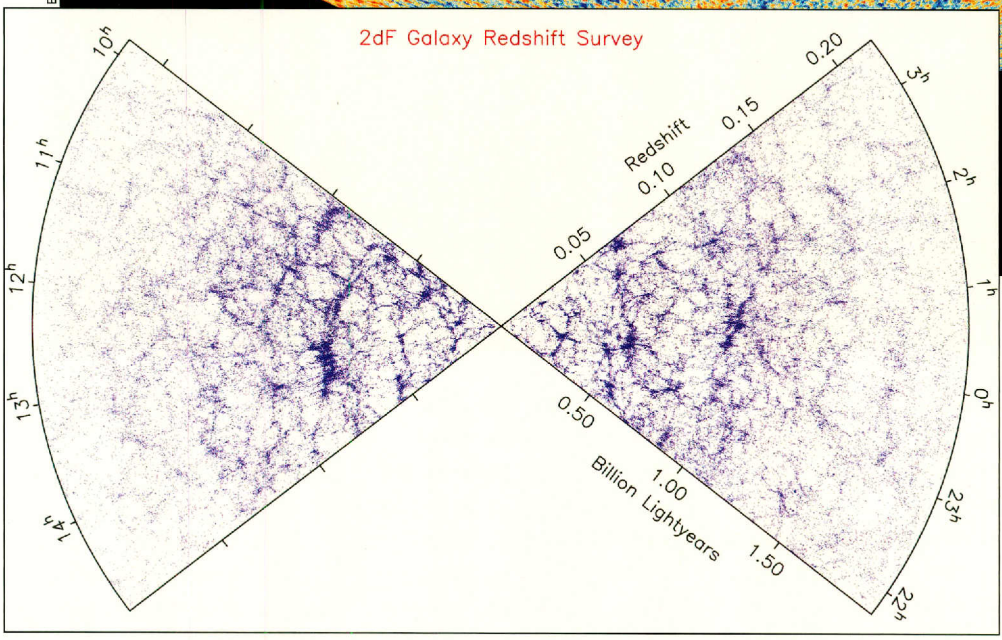


The galaxy cluster MACS J1206 is acting as a gravitational lens, projecting 47 images of a dozen background galaxies around it. The shapes of many of the background galaxies are distorted into arcs or crescents. MACS J1206 is part of the Cluster Lensing and Supernova Survey with Hubble project to make highly detailed dark matter maps of 25 galaxy clusters.

NASA/ESA/M. POSTMAN (STScI)/CLASH TEAM



ESA AND THE PLANCK COLLABORATION, 2DFGRS



Above: The earliest detected cosmic structure, seen as temperature fluctuations in the leftover radiation from the Big Bang captured by the Planck satellite. Left: Filaments and voids in today's cosmic structure, seen in the locations of almost 250,000 galaxies mapped by the Two-Degree Field Survey.

cluster by seeing how strongly it distorts images of background objects.

The masses astronomers calculate for galaxy clusters using this method agree with measurements from X-ray gas and orbital motions.

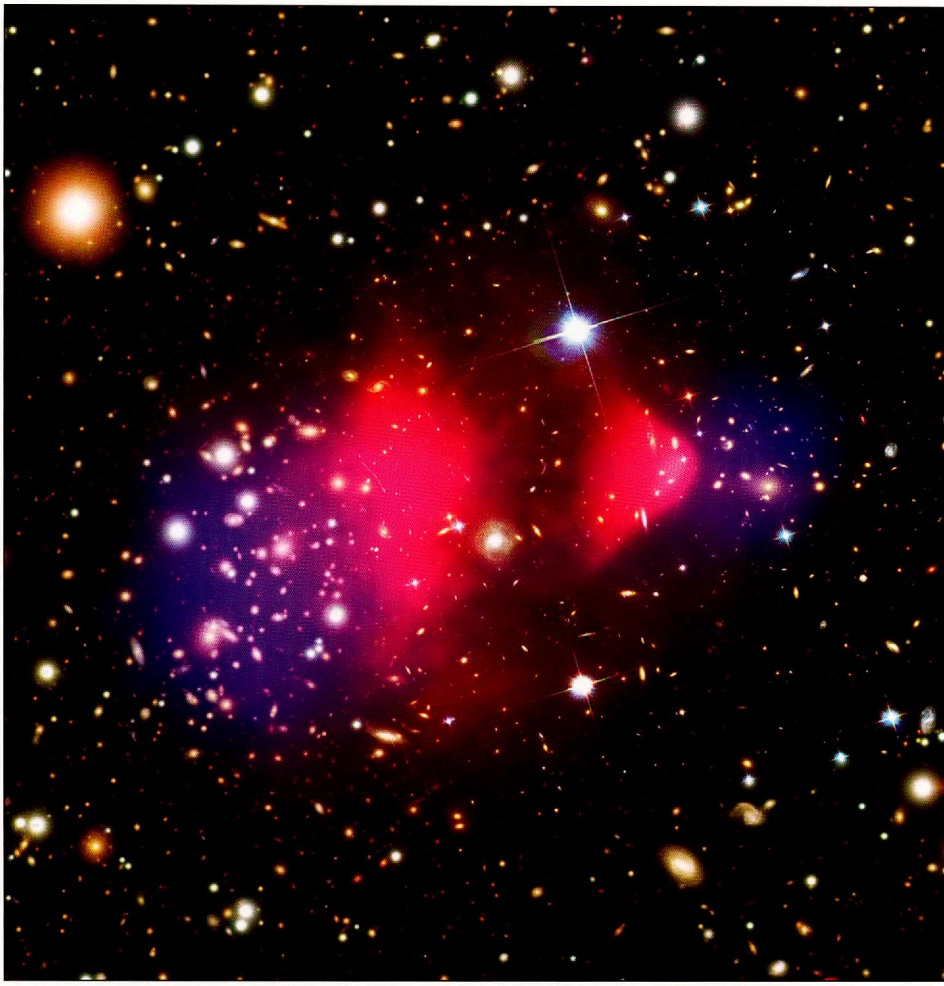
Not all of the methods of weighing a galaxy cluster — and therefore being able to weigh its dark matter — work on every cluster. In the best-case scenario, astronomers can use more than one to double-check their findings — an important factor in understanding dark matter, says John Jardel, a graduate student at The University of Texas at Austin who is studying dark matter. "They all have different weaknesses, different assumptions you need to make [which] may or may not be realistic," Jardel says, "so it's nice to have multiple methods to check."

Both Zwicky's method and the X-ray gas method assume that the cluster itself is in equilibrium, Jardel says, "and that's not always an easy thing to prove." Gravitational lensing studies are limited by astronomers' lack of knowledge of the viewing angle of the cluster. "It's basically projection," Jardel says, "the fact that you don't know what's happening along the line of sight."

Nevertheless, the three techniques "all play nicely together," he says. "There's a lot of cases where the … measurements overlap." Using more than one method to study a single galaxy cluster and getting consistent results is "the gold standard."

There is a larger purpose behind weighing galaxy clusters and determining their dark matter content. "We know that [dark matter] plays a very important role in forming structures in the universe, structures being galaxies and galaxy clusters," Jardel says. Measuring the masses of dark matter in galaxy clusters, and mapping the distribution of dark matter within them, is an important way to trace their formation.

X-ray studies of galaxy clusters made with Chandra X-ray Observatory and Europe's XMM-Newton satellite today provide highly detailed maps of temperature variations within a galaxy cluster. The hotter locations inside



NASA/CXC/CfA/M.MARKEVITCH/STScI/MAGELLAN/U.ARIZONA/D.CLOWE/ESO WFI

The Bullet Cluster is actually a collision of two galaxy clusters. Their visible galaxies and dark matter (shown in purple) have sailed through each other, but the hot X-ray gas clouds from the two clusters (pink) have interacted and dragged on each other. Analysis of gravitationally lensed background galaxies indicated the location of the dark matter from the two clusters.

a cluster hold the most matter, and therefore the most dark matter.

Gravitational lensing studies are being used to map dark matter on even larger scales than single galaxy clusters. "Weak lensing" surveys take images of entire swaths of sky and capture many subtle gravitational arcs at once.

In the Cosmic Evolution Survey, a team of more than 100 astronomers led by Richard Massey and Nick Scoville of the California Institute of Technology used Hubble Space Telescope to map an area of sky nine times the size of the full Moon. The team created a dark-matter map of the region by measuring the shapes of half a million distant galaxies. The tiny distortions in these galaxies' shapes were caused by unseen mass in front of them along the line of sight — dark matter. By mapping what they saw, the astronomers were able to reconstruct what went unseen in front of it.

Dark matter maps of both individual clusters and large swaths of sky are helping astronomers trace the formation of structure in the cosmos. And they are working to connect this dark-matter framework with maps of the earliest cosmic structures ever detected — tiny temperature variations in the cosmic microwave background (CMB) radiation, the radiation left over from the Big Bang.

These variations are seen as ripples in all-sky maps of the CMB from the Wilkinson Microwave Anisotropy Probe, and more recently, the European Planck satellite. "The variations we observe in the ancient microwave sky represent imprints that developed over time into the cosmic dark-matter scaffolding for the galaxies we see today," says Berkeley cosmologist George Smoot, the lead scientist for the CMB mission that preceded the Wilkinson probe.

The largest surveys of structure in today's universe, such as the Sloan Digital Sky Survey, the Australian Two-Degree Field (2dF) survey, and others show that galaxies lie in long lines, called filaments, that snake through vast cosmic voids. Galaxy clusters lie where the filaments intersect. The dark-matter scaffolding is the underpinning for the filaments and knots.

Now that astronomers can weigh and map dark matter, are they any closer to identifying it? "Almost all current scientific knowledge concerns only baryonic [or normal] matter," Caltech's Massey says. "Now that we have begun to map out where the dark matter is, the next challenge is to determine what it is, and specifically its relationship to normal matter."

There are lots of ideas about the identity of dark matter, from exotic particles to cold, dead stars.

Some of the dark matter almost certainly is caught up in black holes, the cooling stellar cinders called white dwarfs, and the failed stars called brown dwarfs. But studies show that this "stellar dark matter" can make up only about 20 percent of the total, not enough to account for the gravitational effects seen in galaxies and clusters.

For the identity of the lion's share of dark matter, scientists today are leaning toward the idea of a heavy subatomic particle that does not interact with other matter much, if at all. This as-yet-undetected particle has been nicknamed the WIMP: weakly interacting massive particle.

Scientists have evidence that WIMPs exist, and the most key piece of evidence comes from the 2006 study of a pair of colliding galaxy clusters collectively called the Bullet Cluster. "It's just this cosmic coincidence that we happened to catch," Jardel says. Two galaxy clusters are caught in the aftermath of a collision. The galaxies from the two clusters have sailed through each other and continue to travel away in opposite directions. The hot gas from the two clusters, however, collided and is now piled up in the center, marking the location of the collision.

The Bullet has been studied with several different techniques. X-ray images from Chandra show the piled-up gas. Visible-light images from Hubble Space Telescope, the European Southern Observatory's Very Large Telescope, and the Carnegie Institution's Magellan telescopes show the location of the clusters' galaxies, as well as a plethora of gravitationally lensed galaxies behind the colliding clusters.

It's those lensed galaxies that allowed astronomers to map the location of the dark matter clouds from the two clusters, showing that the dark matter clouds had sailed through each other along with the visible galaxies. "That's very strong evidence that dark matter is a particle," Jardel says. "Not a normal particle like protons and neutrons — it can't interact with itself." This makes the Bullet Cluster the "smoking gun" of particle dark matter theory, he says, "the strongest piece of evidence that dark matter is a WIMP.

"My opinion, and I think the most general opinion, is that WIMPs are *the* dark matter," he adds. "But then it's a totally unknown question whether it's one WIMP or two WIMPS or 17 different flavors of WIMPs."

One of the top candidates for the WIMP is a hypothetical particle called a neutralino, which is predicted by the physics theory known as supersymmetry. Physicists are looking for evidence of neutralinos and other possible WIMPs in detectors on Earth and in space.

Because WIMPs almost never interact with normal matter, building a detector that can catch one is tricky. Giant experiments costing millions of dollars hope to catch only a handful of WIMPs per year, though millions of them theoretically are passing through the detectors every second.

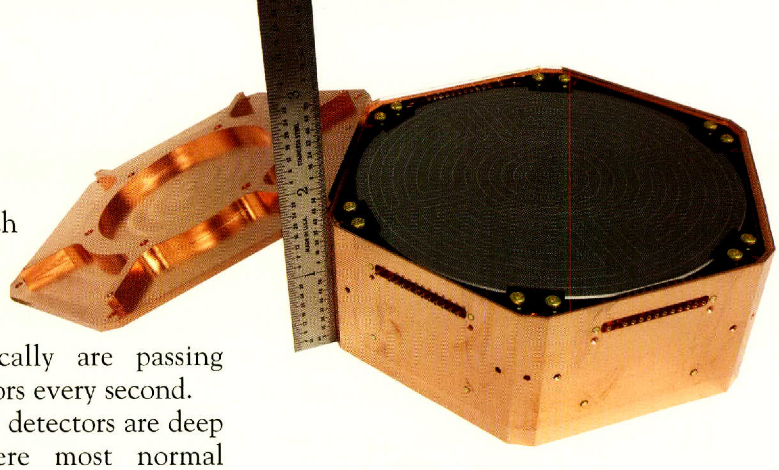
The Earth-bound detectors are deep underground, where most normal particles are blocked by the rock lying above. Dark matter doesn't interact with the rock, so it streams through.

A few months ago, a detector housed in a former mine in Minnesota reported the possible detection of three WIMPs by its silicon detectors. These detections from the SuperCDMS experiment remain unconfirmed, though. About a year ago, an experiment at Italy's San Grasso Laboratory reported no evidence of WIMPs despite many months of looking. That experiment uses liquid xenon as its target medium. And a new detector that uses water plus a chemical found in fire extinguishers recently began operations at SNOLAB in Ontario.

Aboard the International Space Station, a detector looks for the products of dark matter interactions. The Alpha Magnetic Spectrometer looks for positrons, which should be produced when two neutralinos collide (a predicted but extremely rare event). In April, a team led by Samuel Ting of MIT announced that the experiment had detected 400,000 positrons. The catch is, though, that they could be created by pulsars or by dark matter interactions. The researchers say they need more data before they can tell which.

The quest to detect and understand dark matter is far from over. Physicists around the world will continue to try to catch the elusive but heavy particles, while astronomers and cosmologists will continue their efforts to understand how this unseen stuff could underlie the structure of galaxies, galaxy clusters, and thus, the entire cosmos.

Rebecca Johnson is editor of StarDate.



In the SuperCDMS experiment, these thin silicon detectors try to catch heavy dark matter particles from within a cryostat deep underground.

Resources

Books

Heart of Darkness: Unraveling the Mysteries of the Invisible Universe, by Jeremiah P. Ostriker and Simon Mitton, 2013

The 4% Universe: Dark Matter, Dark Energy and the Race to Discover the Rest of Reality, by Richard Panek, 2010

Dark Side of the Universe: Dark Matter, Dark Energy and the Fate of the Cosmos, by Iain Nicolson, 2007

Internet

StarDate Astro Guide
stardate.org/astro-guide/btss/cosmology/dark_matter

Dark Energy, Dark Matter
science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

Latest in Dark Matter
www.scientificamerican.com/topic.cfm?id=dark-matter

Sky Calendar

by Alan MacRobert

As autumn leaves are turning, the bright stars of the Summer Triangle still hang high overhead. Starry swaths of the Milky Way are on view in evening, passing through the triangle. Venus continues to dominate the dusk into fall. Jupiter is on the rise after midnight in late October.

SEPTEMBER 1 - 15

The deepest imprint that a movie scene ever made on me came in the summer of 1968, toward the end of *2001: A Space Odyssey*. Our surviving hero, now alone in a space pod orbiting Jupiter, confronts the third black monolith to appear at key points in human history. The monolith is slowly revolving in open space. The camera pans from the monolith up to the star swarms of the Milky Way, far beyond the scene of action up to that point. As the unearthly music built, I was sure I knew what was coming. And I was right — though it came in a manner I did not expect, as a rift in space opened wide and the pod was hurtled through a tunnel of light into the unknown.

After that, the star swarms of the real Milky Way never looked quite the same. Previously, I had considered the starry panorama an image of peace and changeless eternity. Now, it seemed full of incredible and even frightening promise, though almost certainly for the far future, ages out of our reach.

This September, the star swarms of the Milky Way arch high across the zenith, with no naked-eye planets high up to distract from the endless light-years. For the first week of the month, there's no Moon either. Bright Vega, the star of another classic first-contact movie (Carl Sagan's 1997 *Contact*) shines nearly overhead after dark. Vega is only a nearby waystation, just 25 light-years out.

Look east of Vega by a couple of fist-widths at arm's length for Deneb, shining a little dimmer. In reality, Vega is no match for Deneb, a supergiant lying about 1,500 light-years away. Deneb is a highlight in our spiral arm of the Milky Way, and would be visible as a tiny, individual point in a good image of our galaxy taken from, say, a nearby galaxy like the Large Magellanic Cloud. If other space mappers exist within a few thousand light-years of us — a volume encompassing many millions of stars and planets — Deneb would be on their charts. I wonder what they call it?

To us, the name Deneb encodes bits of the history of our civilization. The word is Arabic for "tail," carried into Latin and English by the Europeans of the Middle Ages. Arab star catalogers got it from the ancient Greeks, who considered this star to mark the tail of Cygnus, the swan. The Ionian Greeks in the 6th century BC were the first culture to invent the way of thinking we call "science." And so it's the Greeks' star names, constellations, and legends that dominate sky maps today.

Look a little lower in the south for Altair, the third bright star of the Summer Triangle. Altair is the sharp eye of Aquila, the eagle.

A fist and a half to Altair's left, the dim but compact constellation Delphinus, the dolphin, leaps toward the upper left.

One of the Milky Way's richest skywatching swaths passes through the big quadrilateral of Vega, Deneb, Altair, and Delphinus. The brightest sec-

Bright knots of star formation dot this infrared view of the plane of the Milky Way where it flows through Cygnus. The unaided eye can catch a subtle glow from the Cygnus Star Cloud near the zenith on autumn evenings, below Deneb and Vega (see maps on pages 12 and 13).

MSX

Meteor Watch

The Shower

Orionids

Named for the constellation Orion, the hunter, which is notable for its three-star belt and for the Orion Nebula, which is visible below the belt as a hazy smudge of light. At its best, this shower produces perhaps 15-20 meteors per hour.

Peak

Nights of October 20, 21

Notes

The gibbous Moon, which is about 90 percent full on the night of the 21st, rises by mid-evening and soars high across the sky during the night. Its light will overpower all but the brightest of the meteors.

tion is the Cygnus Star Cloud, just below Deneb and Vega as you face south soon after dark. Crane your neck high. Even if light pollution hides most of the Milky Way where you live, you might still make out the Cygnus Star Cloud's subtle glow. It's about two fist-widths long.

By no coincidence, this is the direction the Sun and solar system are flying toward at about 150 miles per second as the galaxy rotates. The Milky Way appears especially star-rich here, because we're looking right along our spiral arm of the galaxy.

SEPTEMBER 16 - 30

Look low in the west-southwest as evening twilight fades to find the brightest of planets: Venus. It's been there for months, hardly moving as the seasons change and the constellations of the zodiac slide behind it. If you look too early, the sky will still be too bright. Look too late, and Venus will have set.

A much fainter, farther planet passes Venus as summer heads into fall. On September 15 or 16, look for pale Saturn almost directly above Venus by about four degrees (two or three finger-widths at arm's length). The two planets appear closest together on the 17th and 18th, three-and-a-half degrees apart. Thereafter, Saturn moves to Venus' right, then farther to its lower right heading down toward its November conjunction with the Sun.

The fall equinox occurs on September 22 this year, at 3:44 p.m. CDT. That's when the Sun crosses the equator heading south and fall begins here in the northern hemisphere. The September equinox is also when the sky undergoes a different transition: Deneb replaces Vega as the bright star closest to the zenith just after dark (for skywatchers at mid-northern latitudes).

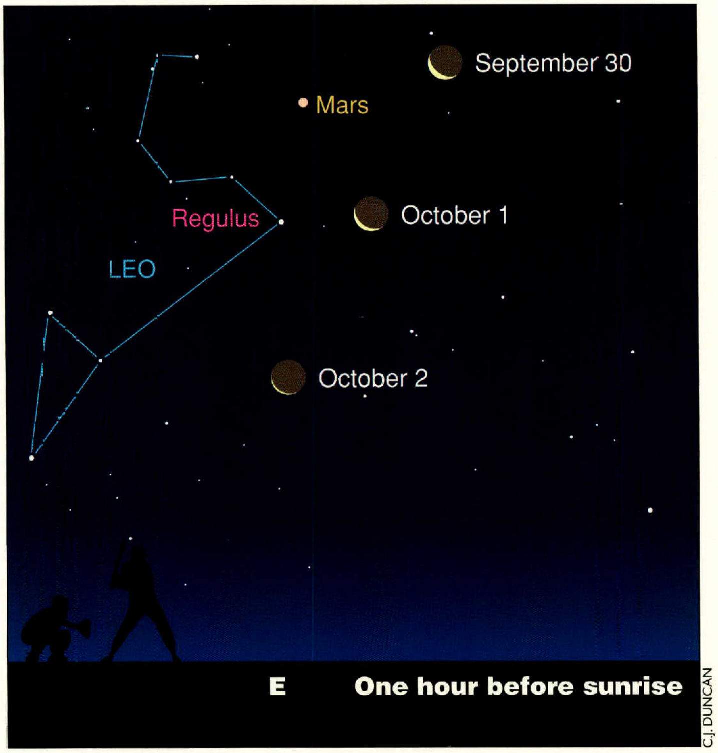
Meanwhile, new fall skywatching scenery is on the rise in the east. Look straight up from the eastern horizon, moderately high, for the Great Square of Pegasus. It's tipped on one corner, as it always is when it's on either the east or west side of the sky.

From the Great Square's left corner, extending slightly down and to the left, a line of three fairly bright stars forms the backbone and one leg of the Greek constellation Andromeda

In the northeast, to the upper left from Andromeda's foot as if she kicked it there, look for the broad, flattened W of Cassiopeia (Andromeda's legendary mother). The W is tilting to the left. Its uppermost three stars (those forming the W's right side) are the brightest. If you're looking through a heavily light-polluted sky this may matter, but in a dark sky, all of Cassiopeia's main stars shine big and bright. Beneath Cassiopeia, Perseus is rising.

OCTOBER 1 - 15

Venus continues to hang low in the southwest in twilight, creeping only a little higher week by week. But interesting things keep passing behind the bright planet. Saturn glimmers way off to Venus' right. Saturn is sinking, soon to disappear for the year. To Venus' left, sparkly orange Antares is closing in. At the beginning of October, Antares and Venus are separated by more than a fist-width at arm's length. But mid-month, only a finger-width separates them. They will pass each other on the 16th. Binoculars will come in handy.



The waxing crescent Moon poses to the right of Venus on October 7 and above Venus and Antares on the 8th.

Look far to the upper right of Venus in the early-October dusk for Arcturus, moving lower as the stars come out. Farther to the right of Arcturus, the Big Dipper is scooping down in the northwest. Turn to face northeast and you'll see that Cassiopeia is quite a bit higher now than the Big Dipper — a sign that we're heading into the cold-weather season.

OCTOBER 16 - 31

Venus is a bit higher now in the southwest. Little Antares twinkles just one-and-a-half degrees to its lower left on the 16th, then moves farther below it and to the right.

This being October, Fomalhaut, "the autumn star," is on evening display. Look for it low in the east-southeast at nightfall and higher in the south by around 9 or 10 p.m.

Deneb remains near the zenith if you look as soon as darkness arrives. Bright Vega burns very high toward the west. Altair shines not quite as high toward the southwest.

A little later, turn around to the northeast and there's bright Capella, still low in the sky. The little Pleiades cluster shines to the right of Capella by two or three fists. The Pleiades cluster is "little" compared to constellations, but with a width of more than one degree, it's the most striking star cluster in the sky. It's so close (440 light-years) that it looks to the unaided eye the way a lot of similarly loose clusters appear in a telescope.

If you stay up until midnight (or a bit later at southern latitudes), you'll find bright Jupiter rising in the east-northeast, while wintry Orion is rising in the east-southeast for its late-night October previews. Jupiter is in Gemini. Spot Gemini's leading stars, Pollux and Castor, to Jupiter's left and upper left, respectively. The waning Moon shines to the right of Jupiter late on the night of October 24.

Alan MacRobert is a senior editor of Sky & Telescope *magazine.*

SEPTEMBER

How to use these charts:
1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

August 20	**11 p.m.**
September 5	**10 p.m.**
September 20	**9 p.m.**

U Uranus (visible through binoculars)
- open cluster
- globular cluster
- nebula
- planetary nebula
- galaxy

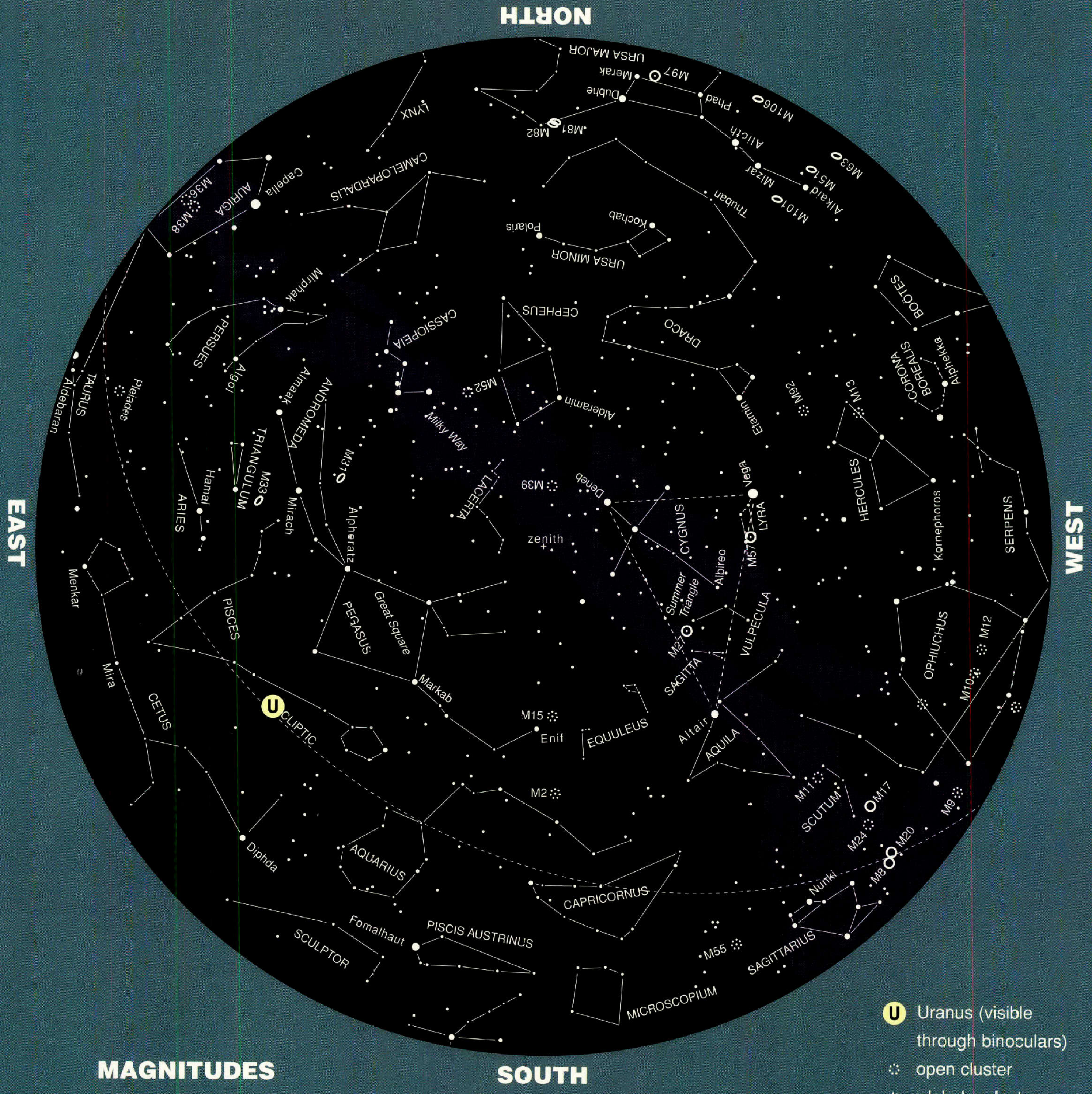
MAGNITUDES
- 0 and brighter
- 1
- 2
- 3
- 4 and fainter

October

How to use these charts:

1. Determine the direction you are facing.
2. Turn the chart until that direction is at the bottom.

September 20	**11 p.m.**
October 5	**10 p.m.**
October 20	**9 p.m.**



MAGNITUDES

- 0 and brighter
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- Uranus (visible through binoculars)
- open cluster
- globular cluster
- nebula
- planetary nebula
- galaxy

SKY HIGHLIGHTS

by Damond Benningfield

SEPTEMBER

Moon phase times are for the Central Time Zone.

1 Brilliant Jupiter stands directly above the Moon at first light, with much fainter Mars about the same distance to the lower left of the Moon and the star Procyon to the lower right of the Moon.

2 Little orange Mars is to the upper left of the Moon at first light.

5 The star Spica is quite close to the lower left of Venus, the "evening star," in the west as night falls. Venus will move away from Virgo's leading light over the next few nights.

8 Venus and the Moon stage an eye-catching encounter. Evening-star Venus will stand just a couple of degrees to the right of the crescent Moon at nightfall. The star Spica is close to their lower right, with the planet Saturn farther to their upper left.

9 Saturn is to the right of the Moon at nightfall, with brilliant Venus to their lower right.

11 Antares, the orange "heart" of Scorpius, stands below the Moon this evening.

16 Saturn is directly above brilliant Venus at nightfall. Over the next few evenings, Venus will move up and to the left, and will stand even with Saturn on the evening of the 25th before leaving its fainter sibling behind.

19 The Moon is full today. As the full Moon closest to the autumnal equinox, it is the Harvest Moon.

22 The September equinox is at 3:44 p.m. CDT, when the Sun crosses the celestial equator from north to south. It marks the beginning of autumn in the northern hemisphere and spring in the southern hemisphere. The days grow shorter and colder north of the equator until the December solstice.

Su	M	T	W	Th	F	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

OCTOBER

1 The Moon, Mars, and Regulus, the heart of Leo, form a tall triangle in the dawn sky. Regulus is to the left of the Moon, with Mars above them.

2 Regulus and Mars line up above the Moon at first light.

3 The planet Uranus is at opposition, lining up opposite the Sun.

7 Venus, the "evening star," poses just to the left of the Moon shortly after sunset.

8 Venus is to the lower right of the Moon in early evening, with the orange star Antares, the heart of Scorpius, about the same distance to the lower left of the Moon.

Su	M	T	W	Th	F	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

14-16 Mars scoots past Regulus in the early morning sky. Orange Mars is a bit to the upper left of the brighter star on the 14th, roughly even with it on the 15th, and to its lower left on the 16th.

15-17 The dazzling planet Venus sweeps over the top of Antares, the brightest star of Scorpius.

18 The Moon passes through Earth's outer shadow this evening. The eclipse is so faint, however, that it is tough to see.

21 Aldebaran, the orange eye of Taurus, rises just below the Moon in mid-evening.

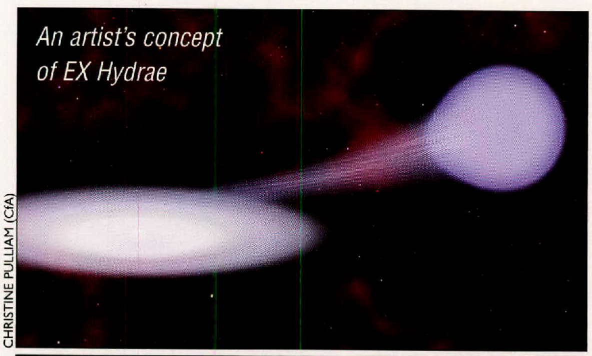
25/26 Jupiter stands to the upper left of the Moon at first light on the 25th, and farther to the upper right of the Moon on the 26th.

29 The Moon, Mars, and Regulus form a tall triangle in the early morning sky. Mars is to the left of the Moon, with Regulus above them.

The Variable-Star Blues (and Ballad, Fugue, and Bossa)

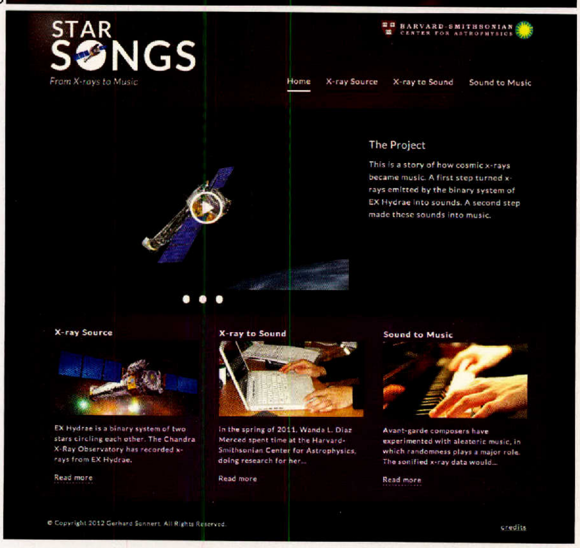
After physics student Wanda Diaz-Merced lost her sight a few years ago, she discovered a new way to see the universe: through sound. She began converting astronomical data to sound, then worked with a composer to convert the results to music. The result is a suite of musical pieces, done in different styles, about a binary star system known as EX Hydrae, in which a stellar corpse steals gas from the surface of its companion. The music, Diaz-Merced's original sounds, and background on the star and the process of converting data to sound form "Star Songs," a website created by Gerhard Sonnert of the Harvard-Smithsonian Center for Astrophysics.

www.cfa.harvard.edu/sed/projects/star_songs



An artist's concept of EX Hydrae

CHRISTINE PULLIAM (CfA)



Buzz Aldrin stands in front of the Eagle lander in July 1969.

NASA

Looking Forward and Back

It's been more than four decades since the first manned lunar landing, and Apollo 11 moonwalker Buzz Aldrin has spent most of that time lobbying for bolder steps in space exploration. His latest volley is *Mission to Mars: My Vision for Space Exploration*, a book that lays out a path to permanent habitation of the Red Planet.

Aldrin proposes using the Martian moons, particularly the larger and closer one, Phobos, as first steps, with astronauts controlling robotic Mars landers and rovers from a station on its surface. Aldrin also would establish a non-stop shuttle service that continually loops between Earth and Mars, with astronauts hopping on and off, and long-term Martian outposts that would lead to permanent bases.

Mission to Mars synthesizes lots of studies and proposals, but in the end it proposes what Aldrin (and fellow Mars enthusiasts) have been longing for since the heady days of Apollo: the moment when humans take the first "small step" on the surface of Mars.

You can also relive the original steps of Aldrin, Neil Armstrong, and their fellow moonwalkers through an updated version of *Apollo: The Epic Journey to the Moon, 1963-1972*. This beautifully illustrated coffee-table book recalls the key steps on the path to the Moon and vividly describes all of the Apollo missions to our satellite world.

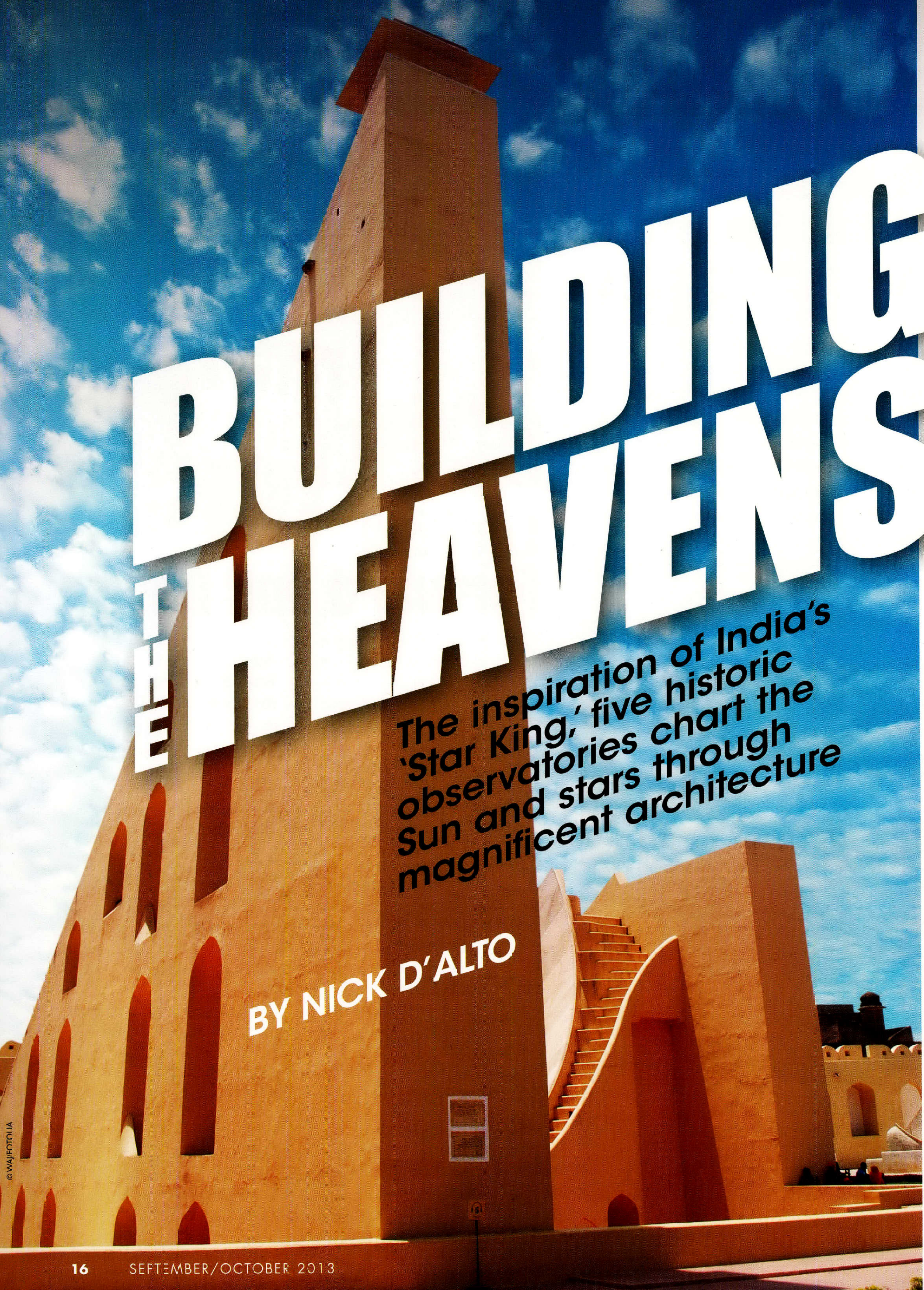
Apollo
The Epic Journey to the Moon, 1963-1972
By David West Reynolds
June 2013; $40 hardcover

Mission to Mars
My Vision for Space Exploration
By Buzz Aldrin
May 2013; $26 hardcover

BUILDING THE HEAVENS

The inspiration of India's 'Star King,' five historic observatories chart the Sun and stars through magnificent architecture

BY NICK D'ALTO



©WAJFOTOLIA

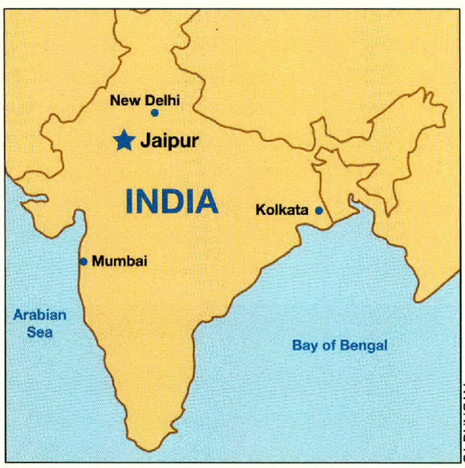
With its curving walls, picturesque columns, and soaring staircases, it might be mistaken for a modern sculpture garden. Instead, though, it's one of Asia's most historical astronomical observatories, in the city of Jaipur. Yet the buildings do not house any astronomical instruments; they are the instruments themselves. Built in the early 1700s, this last of the great non-telescopic observatories charts the heavens as the play of light and shadow across beautiful buildings, offering a unique way to observe the universe.

Like wonders out of the Arabian Nights, Jaipur's beautiful astronomical devices rise across several acres near the heart of the city. They are the brainchild of Maharajah Sawai Jai Singh II, India's "Star King." Fascinated by the sky since childhood, he built the observatory, *Jantar Mantar* ("calculating instrument"), as the flagship of a network of five observatories spread across his kingdom.

This was the Age of Observatories. France's Observatoire de Paris, the first modern observatory, was erected in 1671, England's Greenwich Observatory in 1675. But Jai Singh's response was uniquely Indian, inspired by his land's penetrating sunshine. At almost 30 degrees north latitude, Jaipur stands near the Tropic of Cancer, where the Sun passes directly overhead at noon on the summer solstice. Sun and shadow would guide the Maharajah's vision.

To construct his instruments, Jai Singh tapped astronomy sources worldwide, blending Indian and Western cosmologies. He had Ptolemy's Almagest, an astronomical reference work, translated into Sanskrit, and consulted the tables of the 14th-century Persian astronomer-king Ulugh Beg. He scoured major Arabic sources and acquired the best European works, including John Flamsteed's *Historia Coelestis*. Then, convinced that the size of an instrument improves its accuracy, he ordered his architects to enlarge classic stargazing devices to gigantic scale.

His *Samrat Yantra* ("supreme instrument") remains the world's largest equatorial sundial. Its 10-story gnomon, which casts the shadow, aligns with Earth's axis and points due north, while its curving dial plate parallels the equator. This immense device is a model of our planet in miniature. Just behind it, the twin *Jai Prakash* ("mirrors of heaven") are engraved armillary spheres — giant stone bowls which duplicate the night sky. Behind that, twin *Ram Yantras* ("Sun instruments") rise like circular temples. Yet their purpose is astronomical — they are solar calendars. In all, 19 major devices measure time and track the movements of celestial bodies.



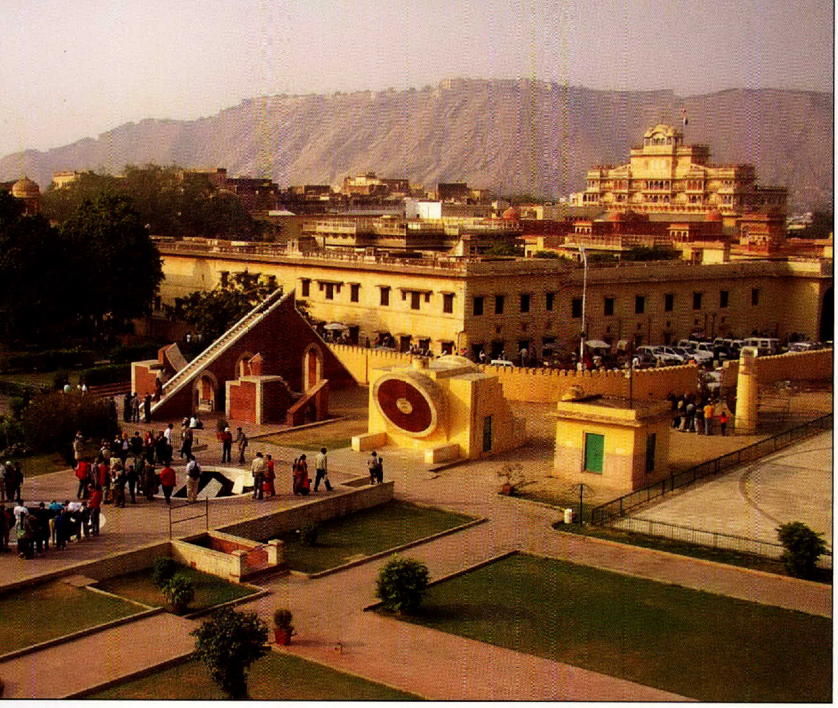
C.J. DUNCAN

Left: The 10-story Samrat Yantra, the world's largest equatorial sundial, reaches skyward.

Wonders awaited these instruments' users. The great sundial marks time to within two seconds. Its shadow is so large that an observer can detect its movement on the dial, literally seeing the passage of time. Chambers on either side of the dial act as *cameras obscuras*, projecting images of the Sun through pinholes.

Although it is described as a sundial, the Samrat is a 24-hour clock. By night, time was ascertained by measuring the angular distance between a bright star and the local meridian (the line that runs due north-south through the point directly overhead), the observers working by torchlight while scaling the rising stairs of the gnomon and the curving staircases around the dial plate. Stairs and passageways cut into the great armillary spheres let observers "walk with the stars," following points of light in the sky.

The Maharajah prided himself on inventive design. Both his armillary spheres and his solar calendars were built as complementary pairs — identical instruments with alternate halves of the stonework removed. Each set would form one complete device. The open spaces let observers take readings without blocking the Sun or stars. In effect, the Raja found a way to make room for the astronomer



— a unique requirement when the instrument dwarfs the observer.

In places, the ingenuity is uncanny. Tiny holes through the armillary spheres let sunlight strike an indicator only at noon each March 21, marking the spring equinox.

A modern stargazer would recognize the astronomy performed at this site immediately. In today's terminology, the great sundial determines the declination of the Sun, stars, and planets (their "latitude" north or south of the equator), as well as their right ascensions (their "longitude"). By contrast, the solar calendar measures the Sun's altitude and its azimuth (its compass heading). The armillary spheres are doubly engraved, to use both these systems.

In addition to Jaipur, Jai Singh erected four similar observatories, at the cities of Delhi and Mathura to the north, Varanasi to the east, and Ujjain to the south. At each site, more than 20 paid astronomers took daily readings, scrambling across the gargantuan devices. Their work provided celestial data vital to daily life: charting the tides and planting cycles, as well as tracking India's seasonal monsoons. Impending eclipses were announced to the beating of drums from the cupola atop the sundial. Data from all sites were combined to compile a new, more accurate catalog of the known stars and their positions.

Using the Vedic star system, Jai Singh's astronomers would have seen the sky in ways we can easily recognize today. They would have used their instruments to follow Ravi (the Sun) and Chandra (the Moon) along their daily paths. They could easily discern the visible planets, from Budha (Mercury), to Shani (Saturn). And like the western system of planets, Kuja (Mars) is a warlike figure, and Guru (Jupiter) is a king. Unlike our system, though, Shukra (Venus) is a male deity. The constellations are similar, too. With names derived from the ancient Greeks, Simha (Leo) envisions the same set of stars we see as the familiar lion.

Ancient and modern concepts often coexisted. Astrology and divination remained an honored cultural practice, so the best days for business and affairs of state could be selected only by consulting the stars. (It is said that the young Jai Singh was first inspired to build his observatories after overhearing a quarrel about the most auspicious days for travel.) Meanwhile, years of data allowed the Raja's observers to measure the angle of the ecliptic (the Sun's path across the sky) relative to the equator at 23 degrees, 28 minutes, which was the correct value for the time.

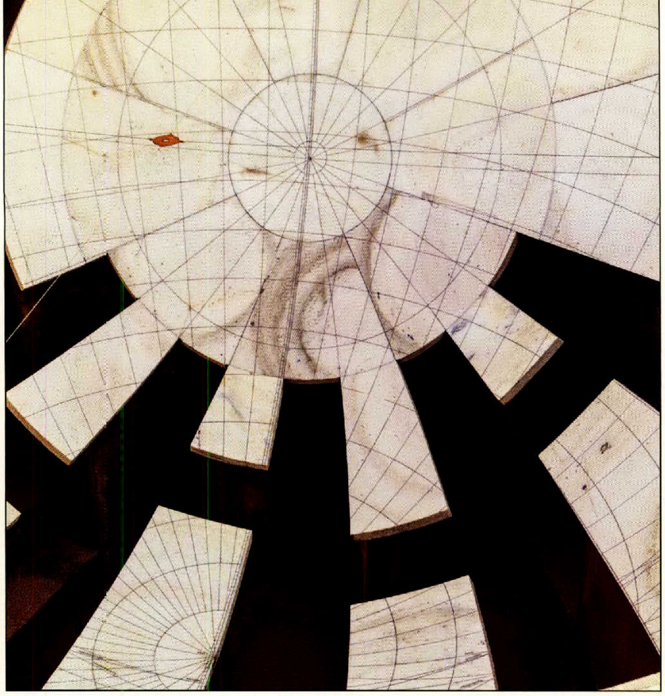
One device at the Dehli observatory may have displayed local times for different cities around the world, foreshadowing the walls of chronometers in modern airports. In 1728, Jai Singh dispatched a scientific delegation to Europe, "to report on recent astronomical advances reported there." In response, Jesuit astronomers and later a royal Portuguese representative arrived to work in India.

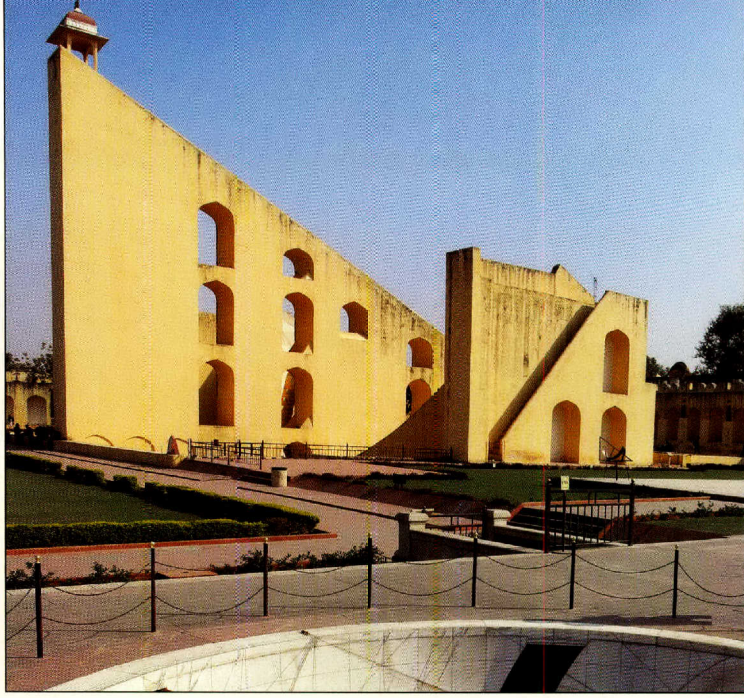
A central puzzle of Jai Singh's observatories is why, despite the exchanges of knowledge with the west, they ignored the developments of the day's modern science. All of the impressive astronomy practiced at Jaipur and the other sites was performed without telescopes, even though they had been used in the west for more than a century, and within a world view which still envisioned the Sun turning around Earth and the stars as fixed points on a celestial sphere, ignoring the work of Copernicus, Galileo, and others. That created an astronomical contradiction: an "ancient" observatory built in modern times.

Doubly puzzling is that Jai Singh owned a telescope, even recording in his notes some of the revolutionary science, from sunspots to the moons of Jupiter, that this new instrument could reveal. Yet he also wrote, "Since the telescope is not readily available to an average person, we base

Monumental Astronomy

The ancient practice of using monuments to follow the Sun and stars continues into our modern age. The angled suspension tower of Sundial Bridge in Sacramento, California, both supports the structure and marks the hour with its sweeping shadow. At 101 stories, Taiwan's Taipei Tower is both a skyscraper and the gnomon of an even larger sundial, casting its immense shadow onto hour stations marked in an adjoining park.





KNOWLEDGE SEEKER/WIKI; ©ERICKN/FOTOLIA; ©JORG HACKEMANN/FOTOLIA; ©KOKHANCHIKOV/FOTOLIA

our rules ... on the naked eye only."

Historians of science have noted that since Jai Singh's chief interest lay in tracking the positions of celestial bodies, and not in understanding their underlying physics, his methods likely served him well. It's worth noting that despite our advances, we still use an Earth-centered universe in many modern star-related activities, such as navigation. Within these narrow parameters, the Raja's instruments may well have approached telescopic accuracy. He boasted of correcting errors in lunar position in Flamsteed's tables, which had been compiled with the help of telescopes.

More to the point, however, Jai Singh, who ruled during tumultuous times, likely sought balance between Indian traditions and an emerging scientific universe. His unique observatories honored the simplest connection between sky and Earth: shadows. Politics played a role as well. Erecting observatories in cities across his empire made Jai Singh a kind of rising star, too — a ruler of both people and ideas.

In the end, India's historic observatories form a bridge from earlier stargazing traditions. Yet they also share much in common with today's observatories. They were erected as a network of widely separated sites to reduce observational error (still a good practice). Each site housed redundant instruments, which could calibrate each other (astronomers still do this today). And each was staffed and coordinated to make regular observations, which is also a modern practice. Though present tallies dwarf Jai Singh's 1,200 known stars, modern astronomers still update their star catalogs — often, like the Raja, by finding sites which offer unique views of the sky. (For example, at 16,000 feet in the Himalayas, the Indian Astronomical Observatory is the highest optical observatory on Earth.)

Yet sadly, the reality that science depends on official support was true in Jai Singh's day as well. After his death, all of his observatories fell prey to war and civil unrest. The instruments at Jaipur were badly damaged when its stones were scavenged for building materials. They were restored in 1901, and the site remains the most completely reconstructed of Jai Singh's observatories. Today a protected UNESCO World Heritage Site (joining the Taj Majal, just to its east), the complex fascinates travelers, who are awed by its otherworldly appearance and its connection to the stars. And it continues to help us explore the heavens; in 2004 and 2012, Indian astronomers used the Jaipur site to observe the transits of Venus across the face of the Sun.

The city of Jaipur, named for Jai Singh, rose around his observatory, to serve its needs, making it perhaps the first "star city." Today a modern metropolis of more than three million residents, it surrounds its unique stargazing devices, which you can see quite clearly on Google Earth — in effect, allowing us to look down from the sky where a Star King once looked up.

Nick D'Alto is a freelance writer in Bellmore, New York.

From left: An overview of the site, with a triangular sundial at center; a close-up of the sundial; detail of one of the armillary spheres; an overview of Samrat Yantra.

Resources

Internet

The Jantar Mantar, Jaipur
whc.unesco.org/en/list/1338

Jantar Mantar: The Astronomical Observatories of Jai Singh II, by Barry Perlus
www.jantarmantar.org

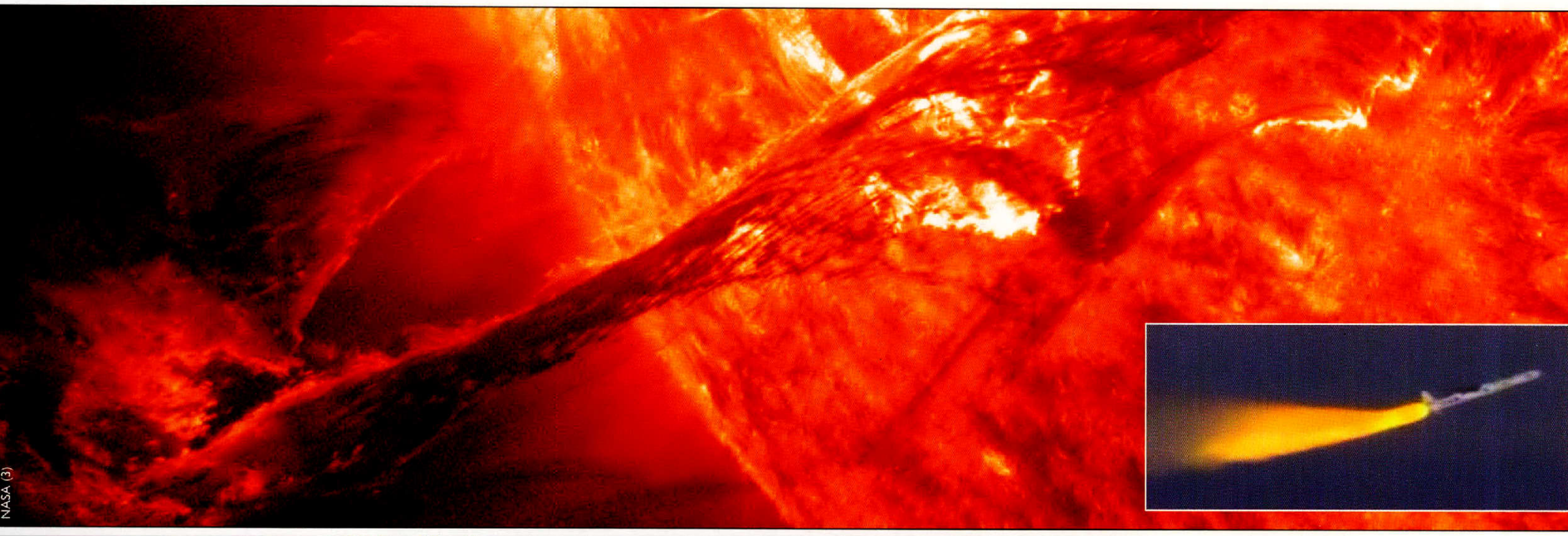
"Jai Singh and the Jantar Mantar," by Paul Lunde, *Saudi Aramco World*, March/April 1991
www.saudiaramcoworld.com/issue/199102/jai.singh.and.the.jantar.mantar.htm

"Solar Nexus," by Sharon Tregaskis. *Cornell Alumni Magazine*, July/August 2001
www.jantarmantar.org/SolarNexus.pdf

A Walk Around Jantar Mantar
www.wmf.org/sites/default/files/wmf_publication/A%20Walk%20around%20Jantar%20Mantar.pdf

18th Century Observatories of Maharaja Sawai Jai Singh II
users.hartwick.edu/hartleyc/jantar.htm

by Rebecca Johnson and Damond Benningfield



NASA (3)

ABOVE: A plume of hot gas erupts from the surface of the Sun, expelling energy and charged particles. INSET: IRIS heads for space. LEFT: An artist's concept shows a space rock hitting the Moon, gouging out dust particles. Such impacts may add material to the lunar exosphere.

New Missions Link Sun, Moon

Although their targets are 93 million miles apart, two new NASA spacecraft will study the same basic phenomenon: the Sun's extended atmosphere. The first is looking at the Sun itself, while the second will examine wisps of the solar wind around the Moon.

IRIS (Interface Region Imaging Spectrograph) was launched June 27 to study the region between the Sun's visible surface and its extended outer atmosphere, known as the corona.

Energy and electrically charged particles stream away from the surface. This heats the corona to millions of degrees, compared to a surface temperature of about 10,000 degrees Fahrenheit (6,000 C), yet just how this happens is poorly understood. Some of the charged particles eventually stream into space as the solar wind, which blows past Earth and the other planets at millions of miles per hour.

IRIS consists of an ultraviolet camera and spectrograph that will study a small region of the Sun, allowing it to get a detailed look at the lowest regions of the solar atmosphere, the chromosphere and transition zone. The observations should help scientists understand how the Sun's magnetic field and other factors accelerate particles of the solar wind and heat the corona.

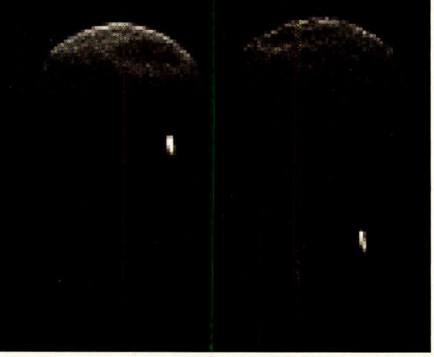
The second mission, LADEE (Lunar Atmosphere and Dust Explorer), which is scheduled for launch in September, will examine the Moon's extremely thin atmosphere, known as the exosphere. It consists of a few atoms of hydrogen, helium, and other elements. Some of this exosphere probably consists of particles of the solar wind, while some may consist of particles kicked off the surface by the impact of the solar wind or small space rocks. LADEE will measure the content of the exosphere, which will help scientists determine its origin.

LADEE also will study a mysterious twilight glow detected in the 1960s and '70s. Because the Moon is airless, the sky should go dark as soon as the Sun sets, and remain dark until after sunrise. But the robotic Surveyor landers photographed a twilight glow that persisted for hours after sunset, while Apollo astronauts reported rays of sunshine like those seen here on Earth.

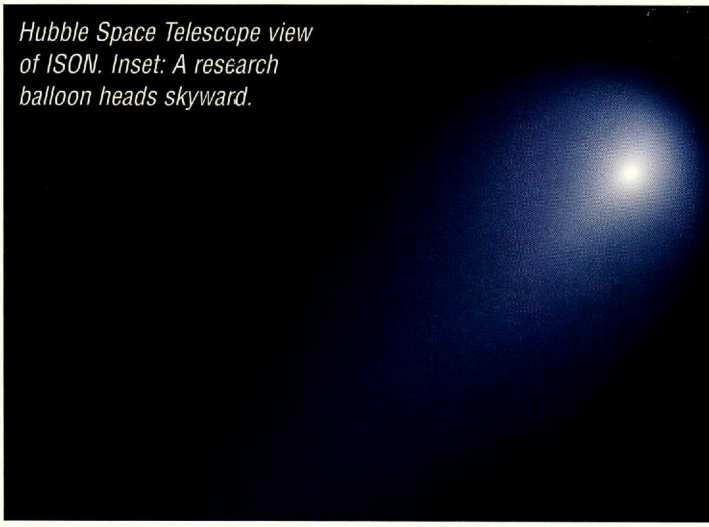
One theory says this glow is caused by sunlight reflecting off tiny grains of moondust that are given an electric charge by solar energy, causing them to levitate high above the lunar surface. LADEE should help confirm or refute that theory. **DB**

Traveling Companion

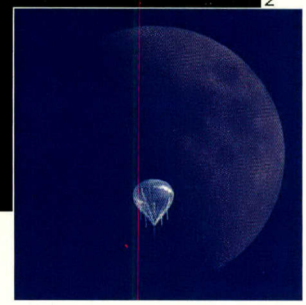
Radar observations by Marina Brozovic of NASA's Jet Propulsion Lab revealed that an asteroid passing by Earth in late May had a companion: a tiny moon. Using the Deep Space Network antenna in Goldstone, California, Brozovic studied asteroid 1998 QE2 over 12 hours, when it was 3.75 million miles (6 million km) from Earth, or about 15 times the distance to the Moon. Her observations showed that the main asteroid is about 1.7 miles (2.7 km) wide, rotates in less than four hours, and has several dark spots that suggest divots in its surface. The asteroid's moon (bright spot, below) is only about 2,000 feet (600 m) wide.



NASA/JPL-CALTECH/GSSR



Hubble Space Telescope view of ISON. Inset: A research balloon heads skyward.



NASA (2)

Climbing to Meet a Comet

Astronomers will take an early peek at a potentially spectacular comet with a balloon mission scheduled for launch as early as mid-September. It will be the first balloon-borne telescope to study a comet, and the first balloon mission to study any solar system object since 1963.

Balloon Rapid Response for ISON (BRRISON) will spend several hours observing Comet C/2012 S1 (ISON), which was discovered in September 2012 as part of a comet- and asteroid-hunting project. The comet will pass less than one million miles from the Sun on November 28, and if it survives the fiery plunge it could be easily visible to the unaided eye for several weeks.

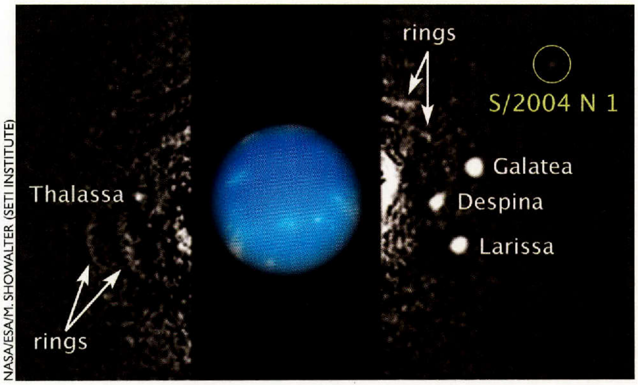
BRRISON, which will launch from eastern New Mexico, will use a one-meter telescope to study the composition of ISON, which is making its first trip to the inner solar system. The comet comes from the Oort Cloud, a shell of comet-like bodies that extends up to one light-year from the Sun. These objects are frozen relics of the solar system's formation, so they contain the same mixture of materials that gave birth to Earth and the other planets. Studying Oort Cloud comets can therefore help scientists better understand the process of planet formation.

Over the coming months, a flotilla of spacecraft, including several at Mars and Mercury, will take aim at ISON, as will many ground-based telescopes.

NASA/SWIFT/S. IMMLER (GODDARD)/M. SIEGEL (PENN STATE)

A Detailed Look at the LMC

Scientists combined more than 2,000 images taken over about 5 days by the Swift satellite to create the most detailed ultraviolet view ever of the Large Magellanic Cloud, a satellite galaxy of the Milky Way. Nearly a million ultraviolet sources appear in the mosaic. Viewing in ultraviolet light emphasizes hot young stars and star-formation regions. The Large Magellanic Cloud lies about 160,000 light-years from the Milky Way, and is about one-tenth the size of our galaxy, with one-hundredth as much mass.



NASA/ESA/M. SHOWALTER (SETI INSTITUTE)

Second-Look Moon

A second look at 150 Hubble Space Telescope images of Neptune has revealed the planet's 14th moon, provisionally designated S/2004 N1. SETI Institute scientist Mark Showalter discovered the moon in July after detecting a tiny white dot in the HST pictures, which were snapped beginning in 2004. His analysis showed that the dot was a moon no more than 12 miles (20 km) in diameter that orbits Neptune once every 23 hours. It is embedded inside the giant planet's dark rings, which are made of tiny dust particles, which made the moon difficult to find. Astronomers will name the moon for a mythological character associated with the sea god Neptune or Poseidon. This composite image shows Neptune in the center, flanked by an image of several of its moons and rings, with the newly discovered moon circled.

Shaping the Milky Way

Pair of studies sheds new light on the structure of our home galaxy

Astronomers agree that the Milky Way is a spiral galaxy. But unlike spirals viewed through a telescope, it's difficult to discern the Milky Way's exact shape from our vantage within. The number and locations of its spiral arms have long been in dispute.

Our solar system lives in the Local Arm, generally considered to be a minor spur between two major spiral arms, the Sagittarius Arm and the Perseus Arm.

From 2008 to 2012, astronomers including Alberto Sanna of Germany's Max-Planck Institute for Radio Astronomy used the Very Long Baseline Array to measure distances to star-forming regions in the Local Arm, and to track their motions around the galactic center.

"Based on both the distances and the space motions we measured, our Local Arm is not a spur," Sanna said. "It is a major structure, maybe a branch of the Perseus Arm, or possibly an independent arm segment."

Another recent study finds that all spiral galaxies are much larger and more massive than previously thought.

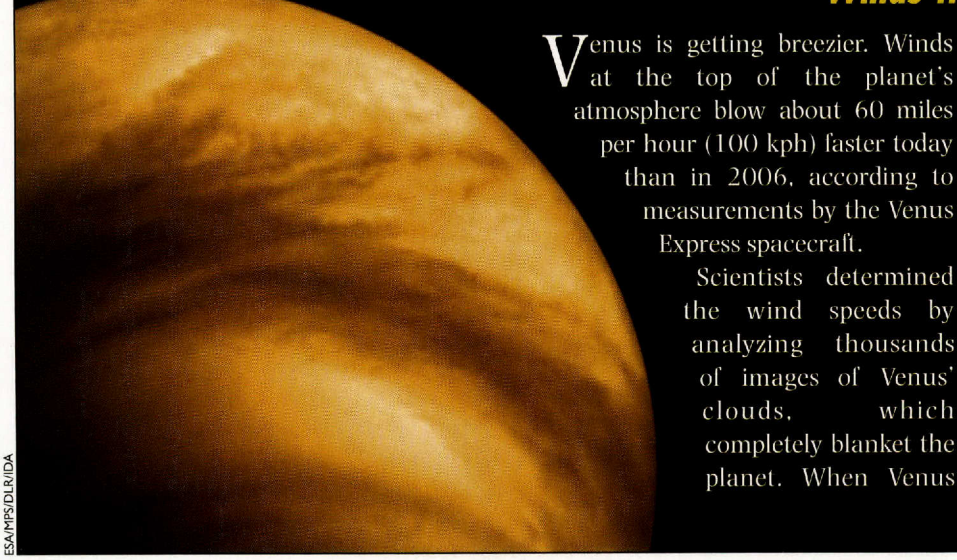
John Stocke of The University of Colorado Boulder used Hubble Space Telescope to look for gas halos around spiral galaxies. He studied light from distant quasars that would have to pass through these halos, if they exist. Stocke found that the galaxies indeed are surrounded by gas halos that can reach more than 1 million light-years wide.

The gas comes from supernovae, Stocke said. "This gas is stored and then recycled ... falling back onto the galaxies to reinvigorate a new generation of star formation."

The halos contained as much or more mass than the galaxies' stars. "This was a big surprise," Stocke said. "The new findings have significant consequences for how spiral galaxies change over time." **RJ**

Gale Warning

Winds freshen on neighboring planet


ESA/MPS/DLR/IDA

Venus is getting breezier. Winds at the top of the planet's atmosphere blow about 60 miles per hour (100 kph) faster today than in 2006, according to measurements by the Venus Express spacecraft.

Scientists determined the wind speeds by analyzing thousands of images of Venus' clouds, which completely blanket the planet. When Venus Express arrived, winds at an altitude of about 45 miles (70 km) blew cloud features at speeds of almost 190 mph (300 kph). By earlier this year, however, the clouds were breezing along at more than 250 mph (400 kph).

Venus' high-altitude winds were already a puzzle because they carry clouds around the planet in just four Earth days, while the length of a Venusian day is about eight Earth months. The sustained increase in speed just adds to the mystery of Venus' windy skies.

A pair of galaxies is locked in a gravitational embrace in this recent Hubble Space Telescope view. NGC 2936 is a former spiral galaxy that is being pulled apart by its encounter with NGC 2937, the yellow ellipse at bottom. The encounter is squeezing together clouds of gas and dust in the former spiral, which collapse to give birth to new stars, creating the bright blue filaments and knots. Dark clouds of dust have been expelled from the galaxy, forming dark lanes in front of its stars. The combined system is 326 million light-years away in the constellation Hydra. The bright blue galaxy at top is in the foreground and is unrelated to the other two.

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