StarDate™

PENDULUM SWING
PAGE 16

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HOW A STAR IS BORN

Astronomers are finding that magnetic fields matter

THE UNIVERSITY OF TEXAS AT AUSTIN McDONALD OBSERVATORY

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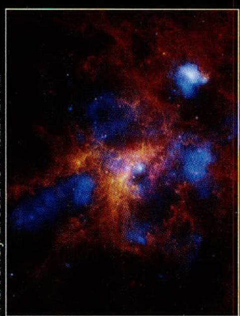
Features

Departments



NASA/CXC/JPL/PSU/L.TOWNSLEY ET AL.

On The Cover

Massive young stars light up 30 Doradus, a region in the Large Magellanic Cloud where many young stars are still being born. Astronomers are now learning that magnetic fields have a big impact on star formation. For more, see page 4.

This Page

Using the Atacama Large Millimeter/submillimeter Array (ALMA) to identify dust (red), oxygen (green), and carbon (blue), astronomers recently found that B14-65666 is the earliest known example of a pair of merging galaxies. This composite image of the object, which is 13 billion light-years away, also shows light from stars (white) from Hubble Space Telescope.

Coming Up

In our November/December issue, we bring you an update on astronomers' hopes to send probes to the Alpha Centauri star system, including a flyby of the recently discovered planet Proxima Centauri b. We'll also fill you in on some telescopes that could be built on the Moon.

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MERLIN

Dear Merlin,

What happened to the "stardust" collected from a comet 10 years or so ago?

G.K. Stanton
Norman, Oklahoma

Planetary scientists are still going through the collection, one dust grain at a time.

The Stardust spacecraft flew close to Comet Wild 2 in January 2004. As it sped by at 13,600 miles per hour (22,000 kph), it deployed a paddle containing cells filled with aerogel, a substance that's mostly air. Tiny grains shed by the comet slammed into the cells and were embedded in the aerogel.

A capsule containing the bits of comet dust parachuted to Earth two years later, and was taken to the astromaterials office at Johnson Space Center in Houston, which stores and processes samples from the Apollo missions to the Moon and other non-terrestrial goodies.

Technicians have taken millions of images of the grains and their tracks through the aerogel. Scientists have analyzed some of the grains, leading to some interesting discoveries.

For example, the comet contained solid particles that were formed in the blast furnace near the young Sun, not farther out in space as scientists had expected. That tells us that the young solar system was being churned, with material from the inner regions pushed far away from the Sun, into the cold region beyond the realm of the planets.

The comet also contained organic compounds, plus an amino acid known as glycine — one of the basic chemical building blocks of life.

Scientists also have discovered several grains that blew into the solar system from interstellar space (hence the mission's name: Stardust).

Many of the discoveries were assisted by volunteers working through Stardust@Home, an online site that allows them to categorize images of the grains and their tracks through the aerogel.

Many of the dust grains remain embedded in the aerogel, awaiting analysis in the decades ahead.

Dear Merlin,

How has the orientation for our galaxy, the Milky Way, been determined? Does it vary? What is the relationship to Earth and Earth's equator? Solar system?

William Drezdzon
Des Plaines, Illinois

That's one you can answer yourself on a summer night. If you get away from city lights, just look into the dark night sky for the glowing band of the Milky Way. You can easily see its path across the sky. It's at a pretty severe angle to the ecliptic, which is the rough alignment of the planets of the solar system, and to Earth's equator — an orientation that takes nothing more than the eye to determine.

Of course, it's taken a lot of work to map the Milky Way Galaxy. By counting stars, measuring the locations of giant gas clouds, and making many other observations, astronomers eventually worked out the galaxy's shape (a flat disk), the direction to its center (in the summer constellation Sagittarius), and its appearance from outside (a "pinwheel," with spiral arms wrapping around a "bar" of stars in the middle).

Merlin encourages all his readers to experience the summer Milky Way, which is a never-to-be-forgotten sight.

Dear Merlin,

Since energy cannot be created or destroyed, is there a finite quantity of energy in the universe? If so, what is this quantity?

Monica Adams
Ruckersville, Virginia

Merlin congratulates you on your understanding of conservation of energy, which does indeed tell us that energy can be neither created nor destroyed. It can change form, however. When sunlight strikes the ground, for example, the ground gets warmer — a transition from visible light to heat. The ground then radiates some of that heat back into space in the form of infrared energy.

One thing to keep in mind is that, according to Einstein's equations, mass and energy are equivalent. In other words, you can change mass to energy. So in calculating the total energy in the universe, you have to convert all the matter — the material that makes up stars, planets, and wizards, among other things — into its energy equivalent. The combination of energy and the "potential" energy of matter adds up to a lot of energy, the total of which doesn't change as the universe evolves.

What's the total? According to most physicists, it's zero.

Energy and its matter equivalent are considered "positive" energy. But they are almost exactly balanced by "negative" energy, in the form of gravity. In this view, it takes energy to overcome the pull of gravity and keep any two objects apart, so gravity is acting as a negative form of energy. When you total things up, the positive and negative energy balance each other — leaving the universe with a net energy of zero.

Isn't physics grand?

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

stardate.org/astro-guide

SEND QUESTIONS TO
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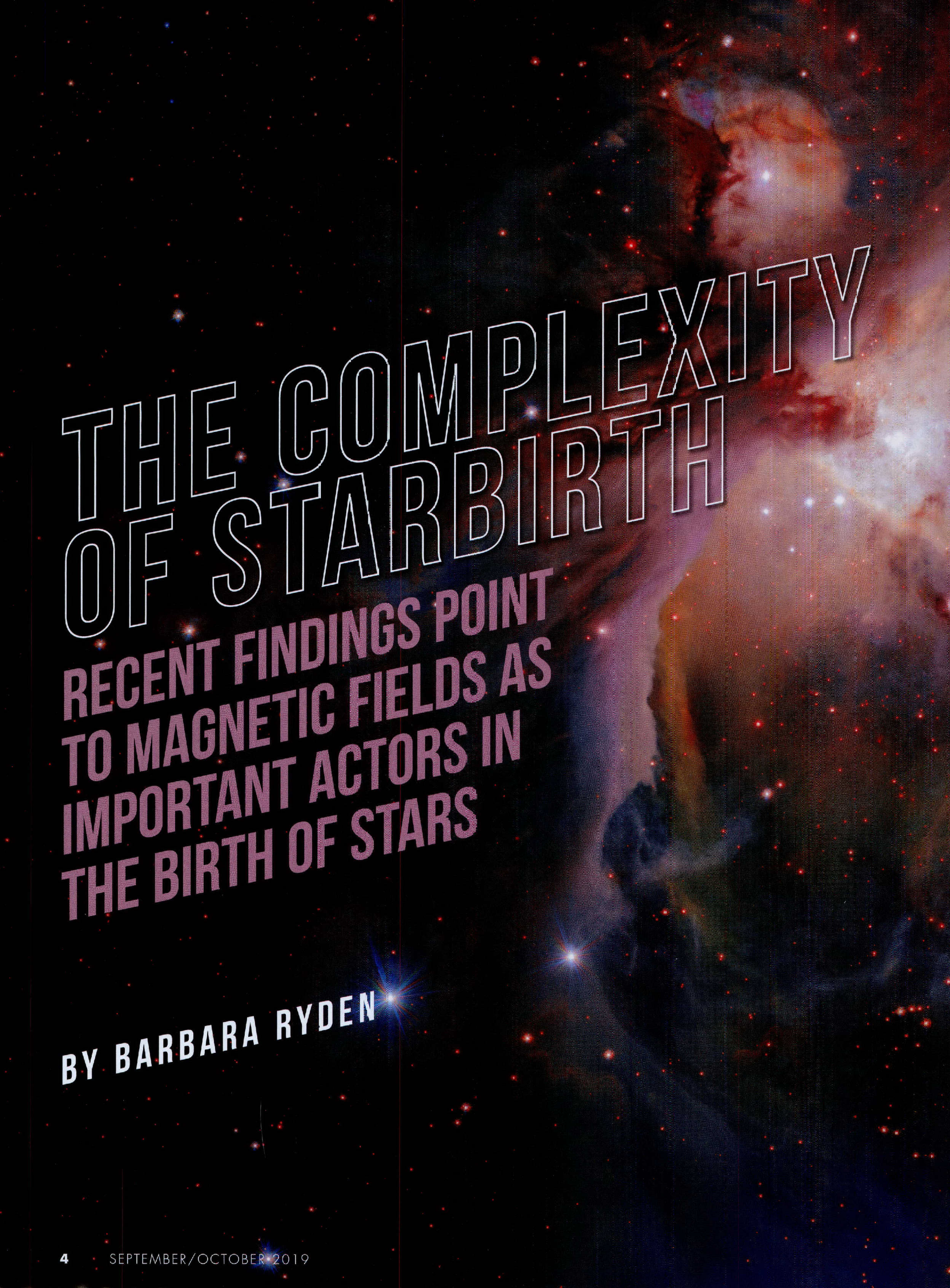
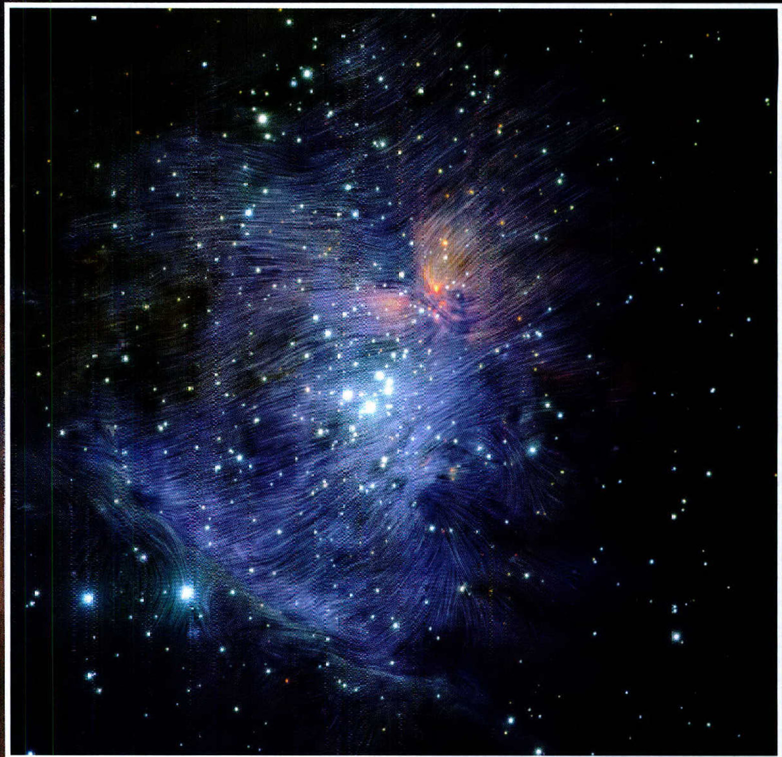


THE COMPLEXITY OF STARBIRTH

RECENT FINDINGS POINT TO MAGNETIC FIELDS AS IMPORTANT ACTORS IN THE BIRTH OF STARS

BY BARBARA RYDEN



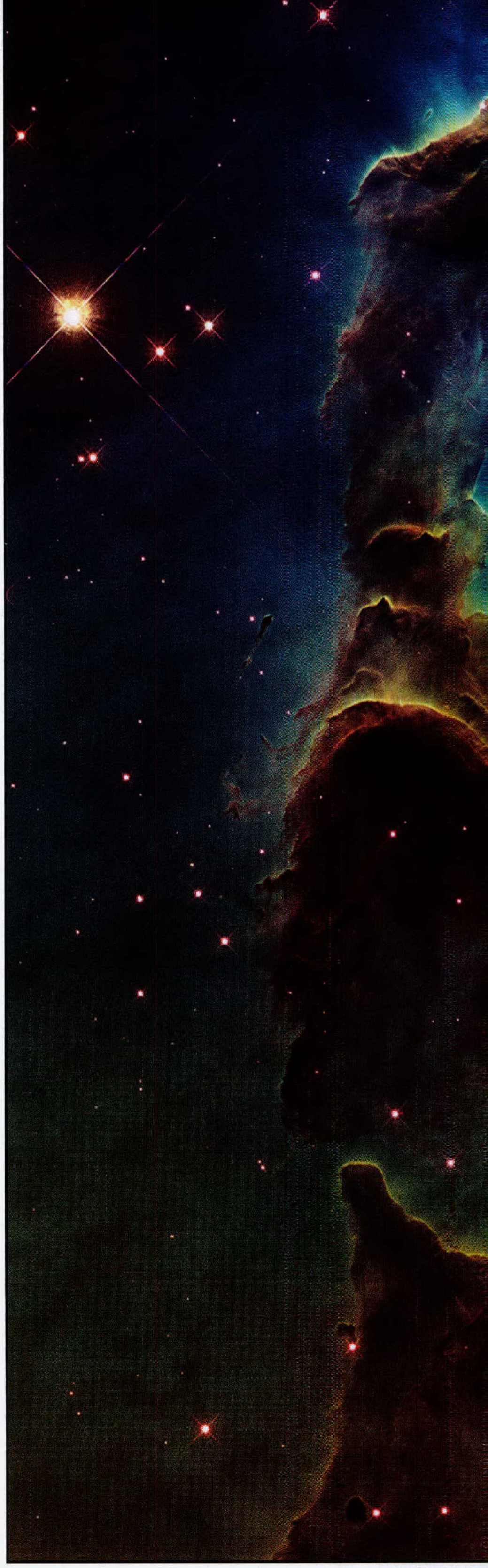
NASA/SOFIA/D. CHUSS ET AL./ESO/M. MCCAUGHREAN ET AL.

NASA/JIM ROSS

Massive stars are forming in the Orion Nebula, the closest stellar nursery to Earth. Inset, top: This close-up of the heart of the Orion Nebula is overlaid with magnetic field lines detected with the SOFIA airborne observatory. Bottom: SOFIA in flight over the Sierra Nevada mountains. Its telescope is at the rear of the aircraft, inside the open door.

ESO/G. BACCARI

For as long as people have looked up at the night sky, they have wondered about the origin of the stars. The path to understanding how stars form has been long and difficult, and has required tackling two of the most vexing mysteries in physics. The first mystery was that of gravity: Why do apples fall toward Earth? The second mystery was that of magnetism: Why does a compass needle point north? The fall of an apple and the swing of a compass needle may seem like simple things, but understanding them eventually led to an understanding — at least in part — of how stars form.



Isaac Newton made the first great step toward understanding gravity, when he realized that Earth's gravitational pull on an apple was just one example of a universal force. Gravity, as Newton saw it, was an attractive force that pulled together every pair of massive objects, everywhere in the universe. The apple falls toward Earth, while Earth falls continuously toward the Sun at the same time that it moves "sideways" along its orbit. Meanwhile, the Sun and the rest of the hundreds of billions of stars in the Milky Way Galaxy, pull on each other.

But how did the Milky Way's stars form in the first place? Although Isaac Newton wasn't rash enough to tackle that subject in his published work, he was willing to discuss it in less formal settings. In 1692, for instance, Newton wrote a letter to the theologian Richard Bentley. In describing to Bentley his view of how stars formed, he imagined low-density matter spread throughout infinite space.

That matter, he wrote, "could never convene into one mass; but some of it would convene into one mass and some into another, so as to make an infinite number of great masses, scattered at great distances from one to another throughout all that infinite space. And thus might the sun and fixed stars be formed, supposing the matter were of a lucid nature."

Once Newton pointed the way, astronomers realized that gravity provided the required force to squeeze the low-density gas into the dense, compact spheres that we call stars. Consider the star that we know best: the Sun. Its average density is 1.4 grams per cubic centimeter, about 40 percent denser than liquid water. (The Sun remains gaseous, despite its high density, because it is made of extraordinarily hot gas, with a central temperature of more than 27 million degrees Fahrenheit (15 million C)).

For contrast, consider a region of the Milky Way where stars are forming now, such as the Pillars of Creation in the Eagle Nebula, about 7,000 light-years away. Full of the cold, dusty gas of which stars are made, the elongated pillars have an average density of only 50,000 hydrogen molecules per cubic centimeter. That may sound like a lot, but it's 8 billion billion times less dense than the Sun's average density.

So how large an area inside one of the Pillars of Creation would it take to hold as much mass as the Sun? Answer: a sphere 10,000 Astronomical Units across (an Astronomical Unit is the distance between Earth and the Sun, about 93 million miles).

How then does a mass of gas spread out over such a huge area of space get shrunk down to become a star? Gravity can do the job. It is a relentless, inevitable force that always makes the densest regions of interstellar gas, like those in the Pillars of Creation, become even denser over time.

This 2018 image of the 'Pillars of Creation,' a star-forming region in the Eagle Nebula, was taken by Hubble Space Telescope. Inset: This view shows magnetic field lines, observed by the BISTRO survey team using the James Clerk Maxwell Telescope in Hawaii, superimposed over an older Hubble view of the Pillars.

NASA/ESA/HUBBLE HERITAGE TEAM (STScI/AURA)/EAO/K PATTLE AND D WARD-THOMPSON (UNIV. OF CENTRAL LANCASHIRE)

The problem with gravity, however, is that when left unchecked by other forces, it makes stars far too quickly. Let's look again at that sphere we carved out of a Pillar of Creation. Given its density, it is possible to compute how long it would take to collapse under its own unchecked gravity. The answer, in round numbers, is 200,000 years.

This is a calculation that Isaac Newton could have done, using his law of gravity and his new-fangled mathematical invention called calculus. There is no evidence that Newton actually did a detailed calculation of the collapse time for low-density gas. However, he did realize that using gravity to form stars would take far longer than the single day permitted by a literal reading of the book of Genesis. Writing about the formation of stars to another theologian, Thomas Burnet, Newton stated, "I do not think their creation from beginning to end was done the fourth day, nor in any one day of the creation."

Although a 200,000-year timescale for making stars was unacceptably long for biblical literalists, it is alarmingly short compared to the time during which our galaxy has been forming stars. The oldest stars in the Milky Way Galaxy are more than 10 billion years old. Our own star, the Sun, is a middle-aged star, about 4.6 billion years old. Some hot, luminous stars, like the newborn stars illuminating the Pillars of Creation, are less than a million years old.

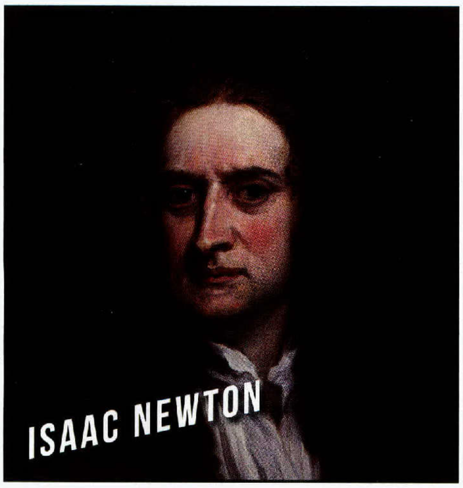
If the gas that our galaxy started with, 12 billion years ago, had all been converted to stars in just 200,000 years, then the galaxy would have begun with a furious fireworks display of star formation. However, the star-formation rate would then have dropped dramatically, fed only by a trickle of "recycled" gas ejected when stars died in supernova explosions or puffed off slowly as aging, unstable red giants.

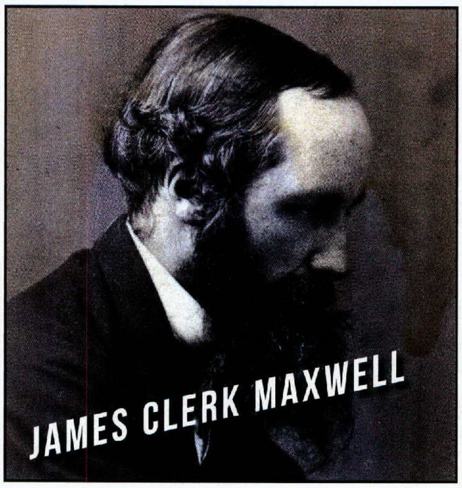
But that is not what happened. The Milky Way has been chugging along forming stars for billions of years.

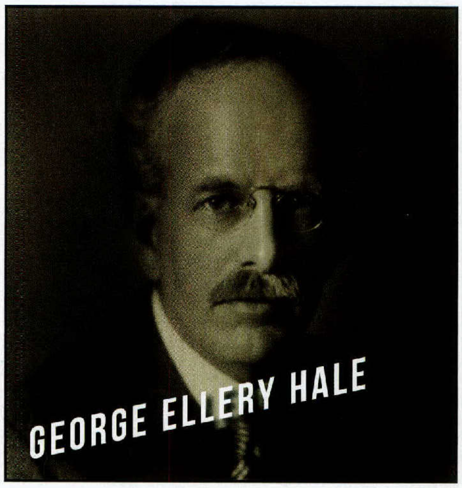
If we look at our galactic neighbor, the Andromeda Galaxy, we see a similar reluctance for interstellar gas to collapse into stars. The Andromeda Galaxy currently contains about 400 million Sun's worth of cold molecular gas. Since most stars are less massive than the Sun, this is potentially enough raw material to make well over a billion new stars.

If all of that gas in the Andromeda Galaxy collapsed to form stars over 200,000 years, this would mean an average star formation rate of 2,000 solar masses of new stars per year. But this is not what astronomers see. Observations of newborn stars in the Andromeda Galaxy indicate that the actual star formation rate is *less than one solar mass* each year. Something is preventing gravity from compressing the cold gas enough to form stars.

One way of preventing gas from collapsing under its own gravity is using ordinary gas pressure. Near sea level on Earth, for example, the molecules of Earth's atmosphere pummel every square inch of the planet's surface with a force of 15 pounds. The reason why Earth's air isn't squashed flat to the ground by the force of gravity is that air pressure steadily decreases with altitude. At the summit of Mount Everest, air pressure is only one-third of its value at sea level. Since gas tends to be squirted from regions of high pressure to regions of low pressure, the upward squirting force due to the difference in gas pressure balances the downward force of gravity.







NATIONAL PORTRAIT GALLERY; SMITHSONIAN INSTITUTION; UNIV. OF CHICAGO; UNIV. OF AMSTERDAM

Important discoveries leading to today's understanding of the interplay between gravity and magnetism in star formation came from Newton, who first described gravity; Maxwell, who showed the relationship between electricity and magnetism; Hale, who first realized that the Sun is magnetized; and Zeeman, who figured out how to detect magnetism in starlight.

Similarly, if interstellar gas clouds had a pressure at their center that was large compared to the pressure at their edges, the outward force from gas pressure could balance the inward force of gravity, and the cloud would not collapse.

It is true that interstellar gas clouds are partially held up by their pressure. However, the pressure of a gas is directly related to its temperature. The centers of these gas clouds are extremely cold — as low as 10 degrees above absolute zero! At this chillingly low temperature, the pressure of a gas cloud's center is billions of times less than Earth's air pressure at sea level. This tiny pressure is not nearly enough to save the cloud from gravitational collapse. An additional source is needed to keep a gas cloud from quickly collapsing under its own weight.

This support, it was gradually learned, is supplied by magnetic fields.

Although Isaac Newton found a useful mathematical formula for the force of gravity, he did not explain magnetic forces. He simply observed that magnetism is a force "by which iron tends to the lodestone." (Today, we know that lodestones are a naturally magnetized form of iron ore; in the 17th century, however, they were regarded as having nearly mystical powers.) It wasn't until the early 19th century that scientists realized that magnetism is not just a freakish property associated with one type of iron ore, but a fundamental force that permeates the universe. Experimenters found that running an electric current through a wire produces a magnetic field; conversely, moving a magnet through a closed loop of wire produces an electric current. In the latter part of the century, James Clerk Maxwell synthesized all of this into a set of equations governing the relationship between electricity and magnetism.

In a universe filled with electrically charged particles that are constantly in motion, it is not surprising, then, that magnetic fields are everywhere. In 1908, astronomer George Ellery Hale looked at the structure surrounding a sunspot and thought it suspiciously resembled the pattern of iron filings surrounding a magnet. Hale was able to verify his suspicions that the Sun was magnetized by looking at specific features in the Sun's spectrum (the pattern of light and dark lines produced when an object's light is passed through a prism and spread out into its component wavelengths). A decade earlier, physicist Pieter Zeeman had predicted that strong magnetic fields would cause the splitting of lines in a star's spectrum, producing two or more lines where only one line would ordinarily be seen. When Hale discovered this "Zeeman splitting" in the light from sunspots, he confirmed that the Sun was magnetized.

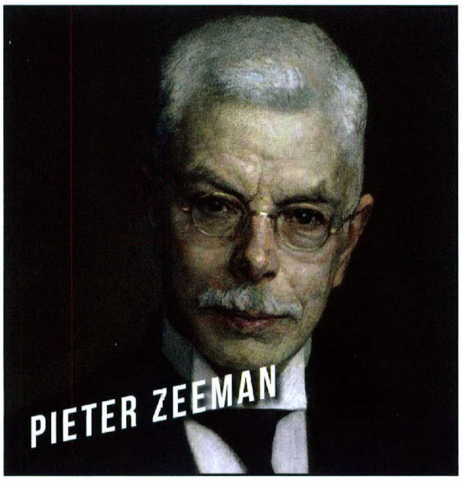
As astronomers realized that all stars, not just the Sun, have magnetic fields, they started to wonder whether magnetic forces could play a role in the formation of stars from gas clouds. This required, first of all, discovering whether magnetic fields existed at all in interstellar space. This was a difficult task: Just as interstellar gas is vastly less dense than the hot gas inside the Sun, the interstellar magnetic field is vastly weaker than the magnetic fields of sunspots. The relatively simple techniques Hale used were not sensitive enough to measure the feeble interstellar magnetic fields.

Astronomers use an indirect method to detect the magnetic fields that run through interstellar gas clouds. It involves the fine dust grains that make clouds like the Pillars of Creation look dark at visible wavelengths of light. If the individual dust grains were made of iron, we would expect them to align themselves parallel to magnetic field lines, like iron filings near a bar magnet. In interstellar space, though, it's more complicated.

Dust grains are not made of iron — they are mostly made of silicates, like the minerals found in rocks on Earth. The response of a bit of rock to a magnetic field is more subtle than the response of an iron needle to a magnetic field. The rocky dust grains have a slight — but noticeable — tendency to align themselves with their long axis perpendicular to the magnetic field lines.

As the dust grains align themselves in a preferred orientation, they polarize the light that passes through the dusty cloud on its way to our telescopes. (Polarizing sunglasses work in a similar, but much more efficient, fashion; they contain liquid crystals with a strongly preferred orientation that polarize the sunlight passing through.)

Consider the light from a distant star that passes through a dusty gas cloud on its way to us. If magnetic fields are present in the cloud, the starlight will be polarized. The discovery of polarized starlight in the 1940s convinced astronomers that magnetic fields exist in the dusty gas clouds where stars form.



Interstellar magnetic fields are not very strong. In the units used by astronomers, the magnetic field strength in a sunspot is about 1,000 gauss. By comparison, the interstellar magnetic field strength is 10 millionths of a gauss. However, the force exerted by the interstellar magnetic field is comparable to, or even greater than, the feeble gas pressure in cold molecular gas clouds. Thus, a combination of gas pressure and magnetic forces work together to keep gas clouds from plummeting inward to form stars at too rapid a rate.

The longer astronomers have studied the process of star formation, the more they have realized that magnetic fields play a vital role. Large active star-forming regions, like the Orion Nebula, are complex, highly dynamic regions. Newly formed hot stars pound the surrounding dusty gas with high-energy ultraviolet photons. These photons kick out electrons from the dust grains, giving the otherwise neutral gas a slight negative electric charge. Copious protostellar winds, from stars still in the process of forming, blast through the gas, churning up turbulence. With so many energetic processes going on, it is tempting to expect that the Orion Nebula would be a place of utter chaos. However, the magnetic field within the nebula imposes a degree of order upon the chaos.

The Orion Nebula, at a distance of 1,300 light-years, is the closest major star-forming region in our galaxy. As such, it is a prime target for studies of how magnetism affects star formation. The dust grains in the nebula are heated by newly formed stars to a temperature of about 30 degrees above absolute zero. At this temperature, they emit far-infrared radiation. Because the dust grains align themselves perpendicular to the magnetic field lines in the Orion Nebula, the infrared light emitted by the dust is polarized, just as the visible starlight scattered by the dust is polarized.

Studying the polarization of light emitted by warm dust can be used to deduce the orientation of the otherwise undetectable magnetic field lines in star-forming clouds, but it's not easy.

It can be done, however, by HAWC+ (High-resolution Airborne Wideband Camera-Plus), a camera installed on the Stratospheric Observatory for Infrared Astronomy (SOFIA), a Boeing 747 aircraft modified to carry a 106-inch (2.7-meter) telescope to high altitudes. Going to high altitudes is necessary to observe at far-infrared wavelengths, since water vapor in Earth's atmosphere is good at absorbing infrared light. SOFIA flies high enough to avoid this problem.

The polarization of dust-emitted infrared light in the Orion Nebula was observed by the HAWC+ camera on a series of SOFIA flights from 2016 through 2018. The deduced magnetic field lines, when superimposed on an image of the Orion Nebula, reveal an extremely orderly structure. The field lines look neatly "combed," as opposed to being snarled and tangled.

Astronomers are now discovering that neatly ordered magnetic fields are commonly found in star-forming regions. In the Pillars of Creation, for instance, the magnetic field lines are combed out along the length of the pillars. Orderly magnetic fields have an important influence on star formation. Most important, they control the direction the nebula's gas can flow.

The gas in the Orion Nebula has a slight negative charge, thanks to the electrons kicked out of dust grains by starlight. Because the gas is electrically charged, it is forced by the magnetic field to move along the magnetic field lines, rather than perpendicular to them. (This is another example of the interplay between magnetic fields and electric currents.) In a region where the magnetic field lines are converging, then the flowing gas will be compressed as the field lines become closer together; this enhances star formation. However, although the magnetic field can help compress gas in the direction parallel to the magnetic field lines, it prevents compression in the perpendicular direction. This means that gas tends to "pancake" rather than collapse into a sphere. The formation of stars is thus not a straightforward victory for gravity, as Isaac Newton proposed. Instead, it is a complex interplay among gravity, pressure, and magnetism, whose subtle details remain to be explored.

Barbara Ryden is a professor of astronomy at The Ohio State University, and a longtime contributor to StarDate.

Resources

Internet

A Star is Born
helios.augustana.edu/~lc/star1.html

Star and Planet Formation
cfa.harvard.edu/COMPLETE/learn/star_and_planet_formation.html

Magnetic Fields Versus Gravity
aasnova.org/2018/04/06/magnetic-fields-versus-gravity/

Cosmic Magnetism
skatelescope.org/magnetism/

Astrophysical Magnetism
manchester.ac.uk/research/research-groups/sun-stars-and-galaxies/astrophysical-magnetism/

SOFIA
sofia.usra.edu

HAWC+ Instrument
www.sofia.usra.edu/science/instruments/hawc

SKY CALENDAR

by Alan MacRobert

Fall is here, and its signature constellations are beginning to appear. By the end of September, Pegasus, the flying horse, and Andromeda, the princess, are riding high across the nighttime sky. Moving into October, earlier sunsets and cooler temperatures make for perfect stargazing conditions. Look for Jupiter and Saturn in the west after dark. By month's end, morning skies reward early risers with a view of the Red Planet.

SEPTEMBER 1 - 15

The two granddaddy planets of our solar system readily draw the eye on September evenings. King Jupiter, in the south-southwest, is the brightest and the first to find as twilight fades away. This year, Jupiter lives in the constellation Ophiuchus, just above Scorpius. As twilight deepens, look for orange Antares, Alpha Scorpii, coming into view 7 degrees (less than a fist-width at arm's length) to Jupiter's lower right.

Jupiter is three months past opposition now, so it's a slightly lesser thing to the naked eye and a smaller disk in a telescope than it was at its closest in June. But not by much. And it's still reasonably high for fairly good telescopic viewing if you catch it near the end of dusk.

Look to Jupiter's east by about 30 degrees (left, by about three fists) for its lesser, more distant sibling: Saturn. They're both mostly made of hydrogen and helium — but not only is Saturn smaller and spectacularly ringed, its uppermost cloud haze has a different chemistry. So while Jupiter shines creamy white, Saturn looks a bit yellowish.

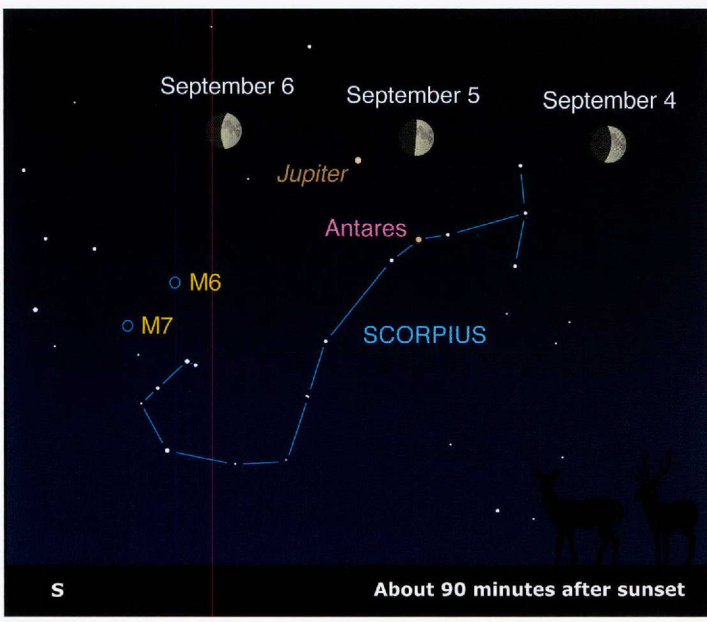
The four-star handle of the Sagittarius teapot lies below Saturn. The whole Teapot pattern is about the size of your fist at arm's length, with its handle on the left and its triangular spout on the right. As summer grows old, the Teapot tilts as if to pour out the season's last remaining days.

The waxing Moon keeps company with Jupiter on the evening of September 5, then with Saturn on the 7th and 8th.

Look far off to Jupiter's right, by about five or six fists, and you'll come upon Arcturus, the bright "Spring Star" now twinkling on its way to setting in the west. Its pale yellow-orange tint always helps to give it away.

Turn farther to the right and there's the Big Dipper angling down in the northwest. The Dipper is continuing its scoopy swing away from the upside-down heights that it sped through in late spring.

The Pointer stars forming the end of the Big Dipper's bowl — currently the Dipper's right-hand end — point to the upper right toward Polaris, three fists away and, of course, due north. Polaris is the handle-end of the dim Little Dipper. Back on hot nights around the June solstice, the Little Dipper extended upward from Polaris like a helium balloon on a string let loose from the fairgrounds. Now the balloon is falling over to the left, deflating in these chillier times.



CJ DUNCAN/TIM JONES

SEPTEMBER 16 - 30

Jupiter glares ever lower in the southwest right after dark, but Saturn now awaits your telescope at its highest point in the south around that time.

So do many of the deep-sky wonders of the summer Milky Way. The Large Sagittarius Star Cloud, hinting of the Milky Way's concentrated center, glows a fist or two to the lower right of Saturn. The Sagittarius Star Cloud is forever linked with the Teapot, like steam puffed from its spout.

Just above the star cloud and the spout's tip is the Lagoon Nebula, M8, one of the finest emission (glowing-gas) nebulae in the sky. People blessed with a truly dark sky often are surprised to realize that M8 is rather easily visible to the naked eye. Binoculars make plain its nebular nature.

Summer officially turns to fall during the night of September 22-23; the equinox occurs at 2:50 a.m. CDT, when the Sun crosses the equator heading south for the season.

Late September is also a time of transition among the ever-turning constellations. Vega, one of the brightest stars in the sky, has been shining nearly overhead through the summer evenings. In early September, Vega is at its crowning height right at nightfall. But the arrival of fall seems to tip a balance. Around the equinox, Vega yields its title of zenith star at nightfall to Deneb, which has been following along behind it, a couple of fists to the east.

Meanwhile, new fall scenery is pushing up in the east.

Straight above the eastern horizon, moderately high now, look for the Great Square of Pegasus. It's tipped on one corner, as it always is when not high overhead. Your fist fits inside it.

From the Great Square's left corner, extending leftward and slightly downward, is the line of three fairly bright stars (at 2nd magnitude) forming the backbone and one leg of the constellation Andromeda.

In the northeast, to the upper left of Andromeda's foot, as if she just kicked it, is the broad, flattened W of Cas-

Meteor Watch

The Shower

Orionids

Named for the constellation Orion, 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

Night of October 21

Notes

The last-quarter Moon will erase most of the meteors from view.

siopeia. 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 serious light pollution this may matter, but in a darker sky all of Cassiopeia's main stars shine so big and bright that their ranking hardly makes a difference.

Beneath Cassiopeia, Perseus is on the rise. Both lie on the narrow band of the "winter" Milky Way, which is thinner and frankly no match for the "summer" stretch of the Milky Way now departing in the southwest.

If you can see the Perseus Milky Way, can you also see the famous Double Cluster in Perseus? It lies just below Cassiopeia and just above Perseus's main pattern, like an oblong little patch of Milky Way enhancement.

The Double Cluster is just about as easy, or difficult, to spot with your bare eyes as the Andromeda Galaxy, positioned off the Andromeda constellation figure's upper knee. If you suspect you're seeing either of them, look for the other. Binoculars will confirm what you've found.

OCTOBER 1 - 15

Jupiter continues sinking lower in the southwest after dark. Look for Antares even farther down, twinkling vigorously almost one fist to Jupiter's lower right.

Saturn remains three times as far to Jupiter's upper left, presiding over the Sagittarius Teapot.

The Moon, coming around through its waxing phases again, pairs closely with Jupiter on October 3 and then closely with Saturn on the 5th.

Meanwhile, the solar system's other two gas giants, smaller, much dimmer, and farther, have been climbing into the southeastern side of the sky. Uranus and Neptune lurk out of naked-eye sight to the left and right of dim Pisces. They're quite high by 10 p.m., well placed for hunting out with good binoculars or a small telescope.

Too faint? The brightest two stars in the evening sky are Vega, high to the west of the zenith, and its zero-magnitude equal Arcturus, *very* far under it, low in the west.

OCTOBER 16 - 31

Maybe, just maybe, you can detect Venus now creeping up into view over the bright post-sunset horizon. Scan for it with binoculars low to the west-southwest a mere 15 minutes or so after sundown. You'll need a low open view and clear air. Mercury, several degrees to Venus' left, is probably too dim to hope for.

After dark, the "Autumn Star" Fomalhaut is entering its autumn evening display. Look for it low in the east-southeast at nightfall, and higher in the south by 10 p.m.

Deneb remains near the zenith if you look as soon as darkness arrives. Vega burns brighter to its west. Altair, not quite as bright as Vega but outdoing Deneb, shines less high toward the southwest.

Vega, Deneb, and Altair form the big Summer Triangle, currently hanging high like a giant, south-pointing arrowhead — like a direction signal for night birds on their fall migration. The Summer Triangle spent the summer rising up the eastern sky. Now it spends the fall declining in the west, a long-lasting reminder of mild evenings gone by.

Like Sagittarius sinking low in the southwest, the Summer Triangle hosts one of the brightest parts of the Milky Way. The Cygnus Star Cloud runs from Deneb toward the Triangle's center, along the shaft of the Northern Cross.

You can still find Arcturus twinkling low in the west in late twilight, and make a point of doing so. In the evenings leading up to Halloween, Arcturus takes on its role as the Ghost of Summer Suns. Every year, for several days around October 25, Arcturus occupies just about the same point over your landscape as the Sun did at the same clock time during hot June and July — in broad daylight, of course! Now the Sun is gone, evenings are chilly, and Arcturus steps in as a ghostly reminder of where our own star recently shone.

Alan MacRobert is a senior editor of Sky & Telescope.

Balancing Day and Night

Autumn arrives in the northern hemisphere on September 23, at the autumnal equinox.

Equinox means "equal nights," so day and night should be the same length. But that's not quite the case. Daytime — the interval from sunrise to sunset — lasts a few minutes longer than nighttime. In the northern hemisphere, they won't balance out until a few days after the equinox.

For day and night to be equal, we would have to think of sunrise and sunset as the moments the Sun is bisected by the equator, when half of it is below the horizon.

Instead, sunrise is the moment the top of the Sun first peeks into view, while sunset is the moment when the Sun fully disappears. That adds a minute or so to the "daytime."

Also, Earth's atmosphere bends the Sun's rays around the planet. So when you see the setting Sun touch the western horizon, it's actually already set.

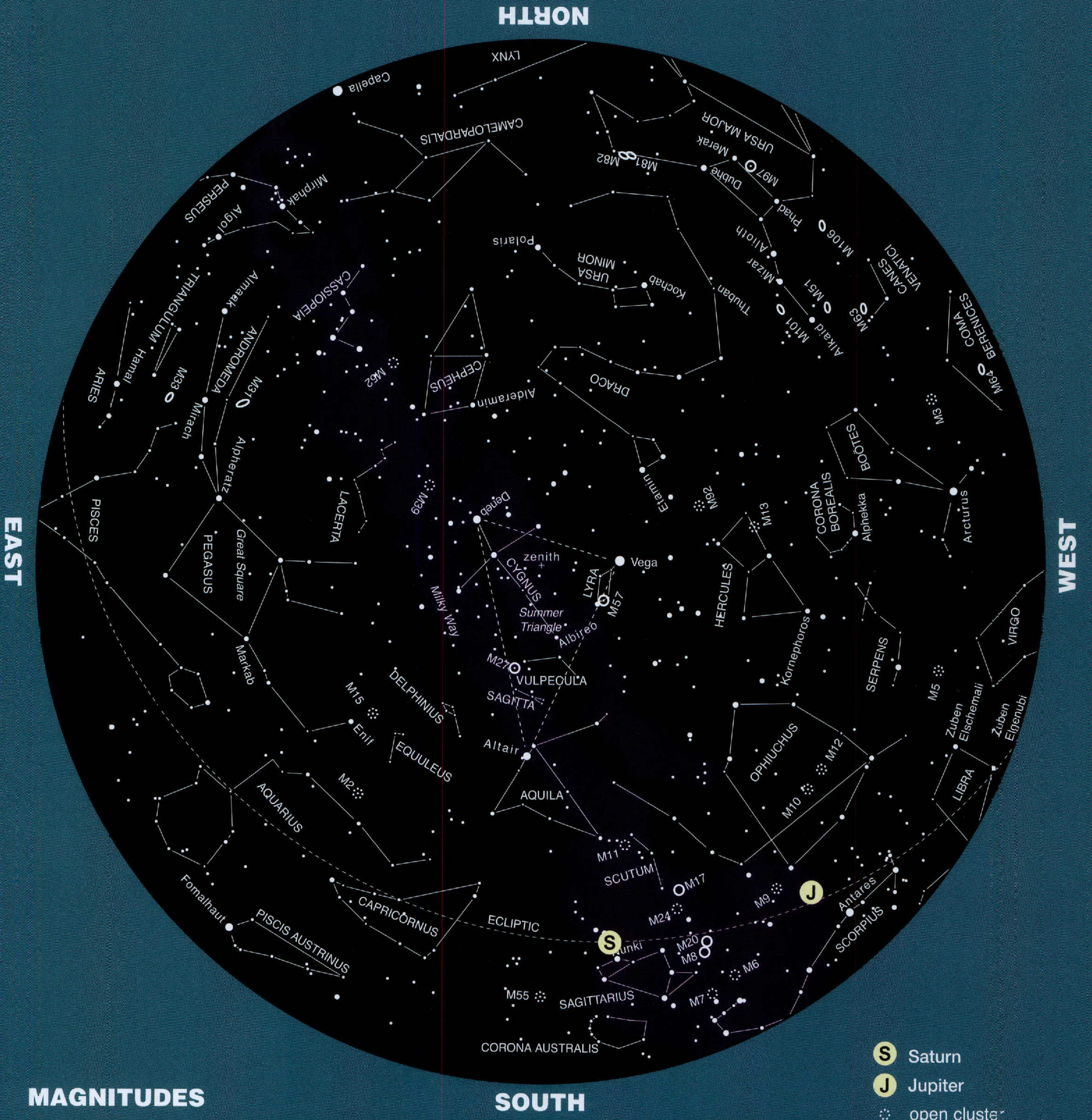
Moon phase times are for the Central Time Zone.

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.**



MAGNITUDES

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

- S Saturn
- J Jupiter
- open cluster
- globular cluster
- nebula
- planetary nebula
- galaxy

OCTOBER

How to use these charts:

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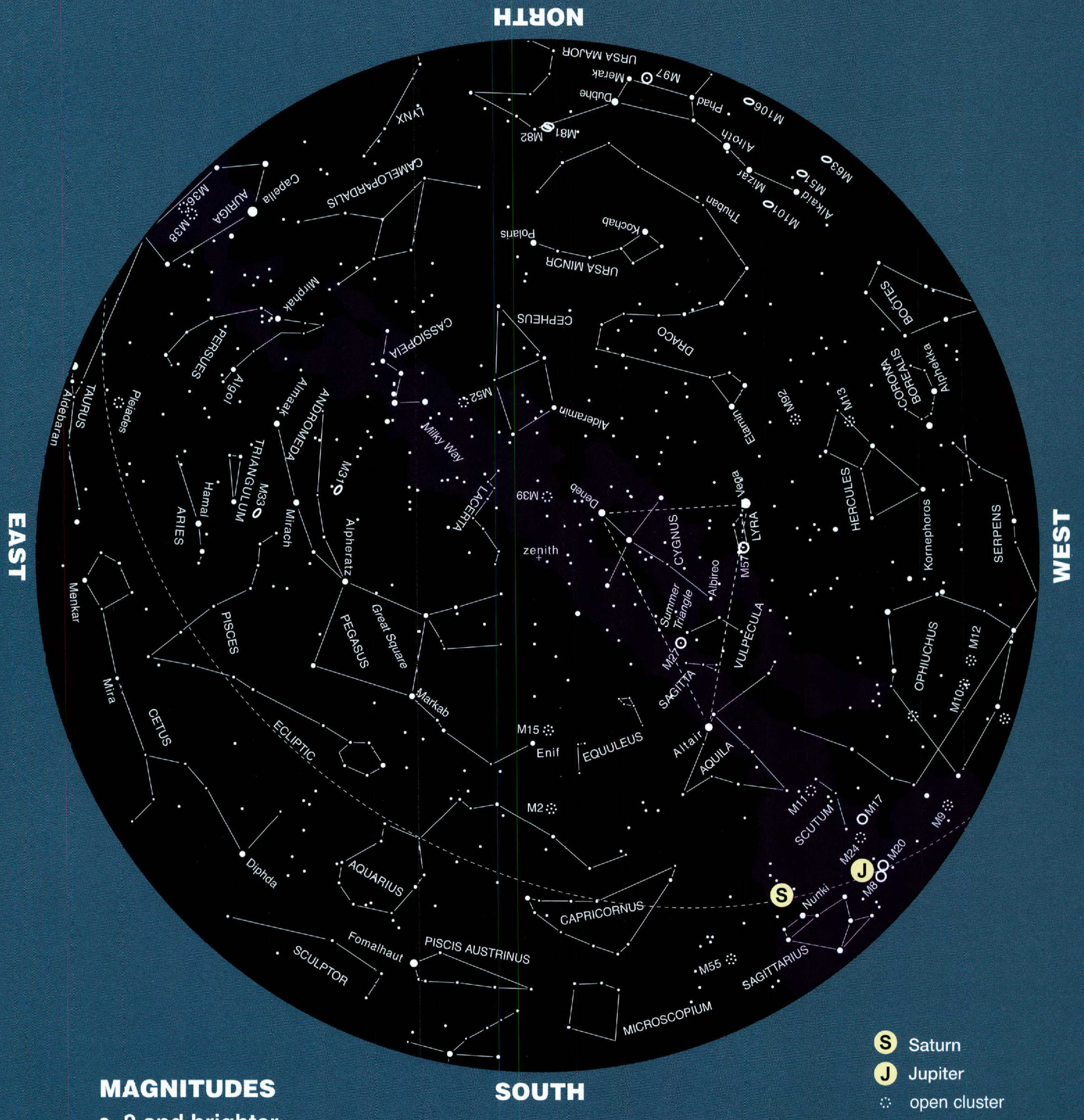

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- galaxy

Saying Goodbye to our Stellar Voice

Sandy Wood retires after 28 years as the narrator of StarDate radio

When Sandy Wood finished her audition for the job of StarDate radio announcer more than 28 years ago, she was exuberant. "I'm outta here!" she enthused. "I'm going to the Bahamas!" Fortunately for StarDate, though, she returned a couple of weeks later to accept the position she held for 28 years.

Health problems recently forced her to retire from the program, however, with her last broadcast airing on July 16. "Since 1991 I've been with you every day, telling you about the wonders of the universe," she said at the end of the program. "Recent health problems, though, have left me unable to continue, so this is my final episode. My thanks for all of the support from our StarDate audience — the best in the universe!"

"This really breaks my heart," said StarDate producer Damond Benningfield, who has worked with her since her original audition. "Not only is she an amazing announcer, she's one of the kindest and most thoughtful people I've ever known. She's also a hoot, so our recording sessions are probably going to be duller without her."

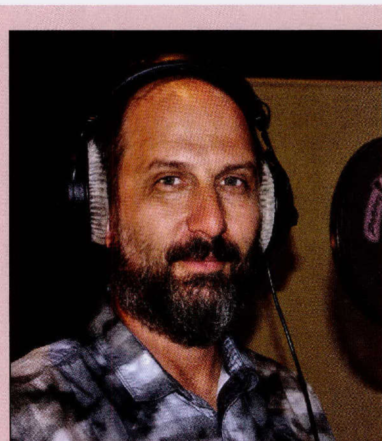
Wood's first episode aired September 16, 1991, and she recorded a total of 10,166 programs. She also recorded several podcasts for McDonald Observatory projects, and she narrated videos that play at the observatory's Frank N. Bash Visitors Center and other venues at the Fort Davis campus, as well as on various web sites.

"I very much appreciate Sandy Wood's dedicated service to McDonald Observatory," said observatory Director Taft Armandroff. "Her enthusiastic and consistent delivery of astronomy news for StarDate has built a large and committed audience of astronomy enthusiasts. As I travel the country and speak with fans of astronomy and The University of Texas, there are always questions and good wishes for Sandy Wood and StarDate."

The New Voice

Billy Henry, an Austin voice talent, musician, composer, and college lecturer, succeeds Sandy Wood as StarDate announcer. His first broadcast aired July 17. He is just the third announcer in the program's 41-year history.

Henry lectures at Texas State University and has taught at The University of Texas at Austin and done sound design and other creative projects for its theater department. He has written music for commercial clients ranging from Chili's to Southwest Airlines. In recent years he has joined the world tours of The Court Yard Hounds, Shakira, and the Dixie Chicks.



Billy Henry in the studio while recording his first StarDate episodes

Charting the Universe

Sun and Moon: A Story of Astronomy, Photography and Cartography ends with a series of spectacular images of the planets and moons of the solar system snapped by robotic spacecraft, plus some all-time-great views of dying stars, galaxies, and other deep-space objects by Hubble Space Telescope.

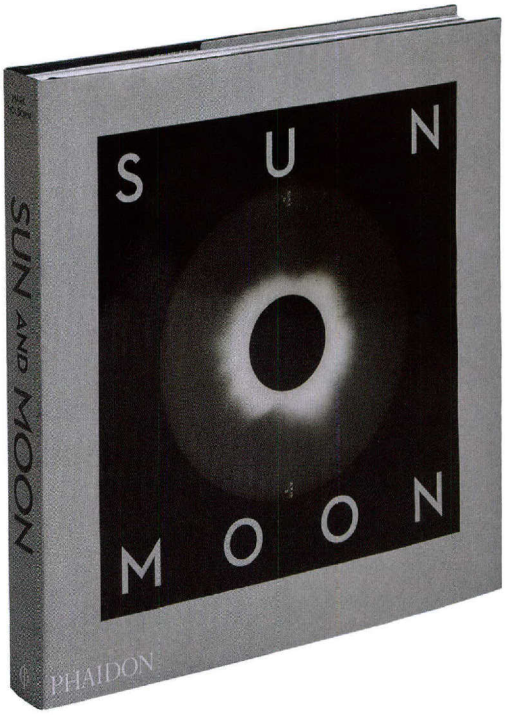
Yet what came before those Space Age images — both chronologically and in the book — is perhaps even more impressive. Author Mark Holborn guides the reader through the history of astronomy imagery, from Neolithic sites in Ireland and Egypt to early 20th-century observatories in the United States. His weighty tome (all 7.2 pounds of it) explains how people began recording their impressions of the Moon and Sun, how they applied the newly invented telescope to that effort, and how they began to learn the secrets of the heavens from their spying.

Sun and Moon features almost 300 images, all displayed in a large format. The first section discusses skywatching before the invention of the telescope, and offers such wonders as the ceiling of the tomb of Senenmut, an Egyptian official, which depicted constellations and sky myths, and the terrestrial and celestial globes of Gerardus Mercator, a pioneer cartographer.

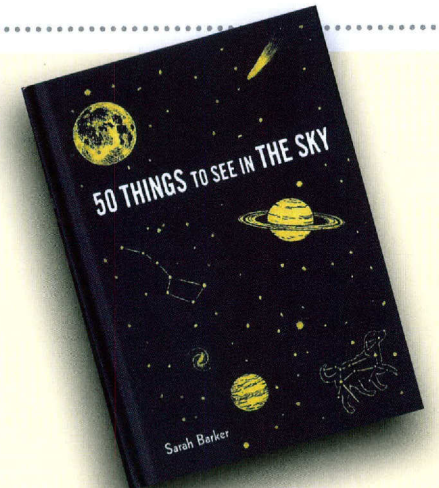
Selections from the early days of the telescope include Isaac Newton's second reflecting telescope, which consisted of small glass lenses inside two cardboard tubes, and early maps of the Moon drawn from telescopic observations.

Later sections present instruments for displaying the motions of the solar system, the first photograph of the Sun, relief models of the surface of the Moon, and images of a solar eclipse snapped in Spain in 1860.

The images are astonishing and beautifully reproduced, and the text, though a bit dense in places, does a good job of guiding readers through the millennia, helping us understand how we developed our modern view of the Sun, Moon, and the rest of the universe.



Sun and Moon
A Story of Astronomy, Photography and Cartography
By Mark Holborn; Hardback, $79.95
www.phaidon.com



50 Things to See in The Sky
By Sarah Barker; Hardback, $16.95
Publication date October 1
www.papress.com

By the Numbers

Checking off some of the best views of night and day

Publishers have released several guidebooks in the last couple of years offering listings of some of the best objects to see in the sky. The most recent, *50 Things to See in the Sky*, journeys from the solar system to the edge of the visible universe.

The first section, "Naked Eye," explains how to find such treats as the Milky Way (good luck if your skies are light polluted!), the North Star (and its successor), the International Space Station, and more. Several of the sights are visible in the daytime, not at night, such as blue skies and sundogs.

Section two, "Farther Afield," offers such treats as M31 (the Andromeda Galaxy), Jupiter's moons and its Great Red Spot, the Double Cluster (two star clusters in Perseus), and the giant globular cluster M13, in Hercules.

And the final section, "Far, Far Away," journeys to galaxies and galaxy clusters, quasars, and other remote wonders.

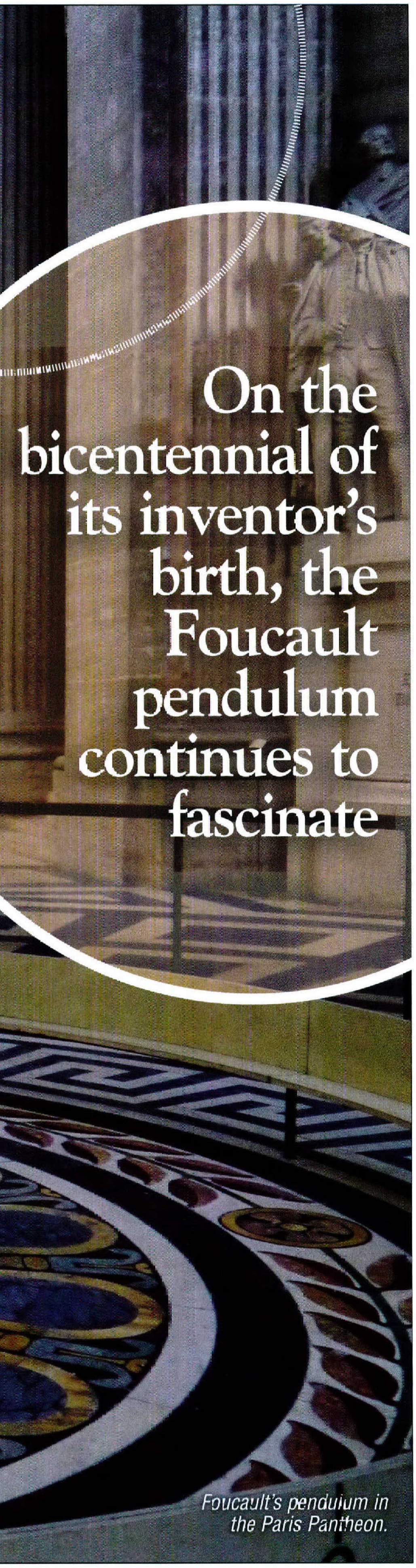
The book is a small format, so it's easy to leaf through, and the explanations are basic but engaging — a nice way to prepare for a night (or day) of skywatching.

Watching the World Turn

By Nick D'Alto

ZAIRON

On the bicentennial of its inventor's birth, the Foucault pendulum continues to fascinate

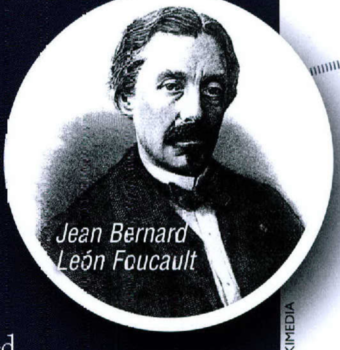


Foucault's pendulum in the Paris Pantheon.

Of course Earth turns. But you can't feel it — everyone knows that! Yet as you watch a giant Foucault pendulum, swinging to and fro at a museum or planetarium (perhaps toppling obstacles set up along its path), you are suddenly presented with direct, immediate proof that we are all living on a planet that is spinning rapidly in space.

While it still surprises some today, this revelation astonished audiences in 1851. That was when Léon Foucault invited the residents of Paris to "come see the Earth turn."

It was already well known in the mid-nineteenth century that Earth turns on its axis. One could easily chart our planet's daily rotation against the Sun and stars. Yet there was no direct, terrestrial way to appreciate that motion. In theory, weights dropped from towers should land just to one side, as Earth turned during their fall, although by such a minuscule amount that it would be almost impossible to detect.



Jean Bernard Léon Foucault

WIKIMEDIA

Jean Bernard Léon Foucault, who was born September 18, 1819, in Paris, was a former medical student (he left medical school after fainting at the sight of blood), in poor health. Only modestly trained in math and physics, he assisted more accomplished scientists. But Foucault was curious. In 1845, he took the first-ever photograph of the Sun. Five years later, he measured the speed of light with surprising accuracy. He also was a fine instrument maker.

Inspiration struck Foucault in the basement workshop of his Paris home. While fashioning an astronomical clock, he noticed that a thin metal rod clamped in his lathe continued to vibrate in the same plane, even as he turned the lathe. The rod could "remember" its path, despite everything rotating around it. As Isaac Newton's first law of motion says, "An object in motion stays in motion unless acted on by an outside force."

Foucault later recalled that at this realization, he instantly imagined a pendulum, swinging in its own plane as Earth turned beneath it. But could that work? To find out, Foucault would need to invent a new kind of pendulum: one that could oscillate freely in any direction. Gathering a weight and some wire, he began experimenting.

He set his device in motion in the pre-dawn hours of January 3, 1851, to avoid any vibration from the street above. He watched the pendulum swing until its arc began to trace an imperceptibly different path along his basement floor, suggesting that the planet itself had turned beneath it. Foucault had seen the world turn! His audaciously simple apparatus — just a weight and a wire — had revealed what the greatest minds believed impossible.

At the time, Foucault was employed by the Paris Observatory, and he was invited to demonstrate his discovery there. From the ceiling of its Meridian Room, so named because a line in the floor marks the exact latitude of Paris, Foucault strung a pendulum 35 feet (11 meters) long, arranged so its initial swing would pass precisely over the line. Then a mysteriously worded invitation was mailed to the scientific elite of the city. "Gentlemen," it read, "You are invited to come see the Earth turn, in the Southern hall of the Paris Observatory, tomorrow, at half-past-two."

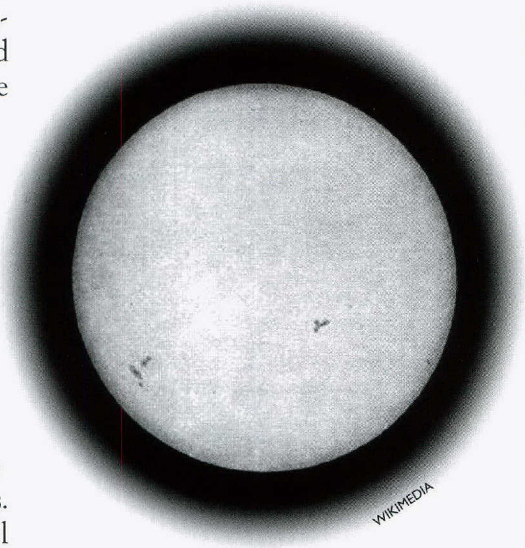
Foucault released the bob by touching a thin restraining cord with a lighted match. (This careful starting technique is still used today.) After a few oscillations, the pendulum's sweep varied by one millimeter, then two, from the line in the observatory floor. This demonstration left the dignitaries in attendance dumbfounded. Louis Napoleon Bonaparte, then Prince-President of France, was among them. Himself an avid scientist, Louis championed an even grander trial.

This event was set in the Pantheon of Paris. Part cathedral, part museum, and part national shrine, it's one of France's most iconic structures. From its dome, Foucault strung a steel wire almost 200 feet (67 meters) long. The wire carried a 62-pound (28 kg) brass-coated lead bob that had been perfectly machined and balanced.

On the floor below, he laid out a wooden circle 20 feet (6 meters) across that was marked in 360 degrees and richly decorated. He partly covered the circle with a thin layer of wet sand. This allowed a point on the end of the bob to trace Spirograph-like patterns in the sand as the pendulum swung. Each complete oscillation (the pendulum's period) required 16 seconds. And crucially, each oscillation advanced the bob about a third of a millimeter around the edge of the platform.

On March 31, 1851, the device was set in motion. The audience was transfixed. Foucault explained to the assembled nobility and commoners how "the pendulum swung, while we, and the planet, rotated beneath it." Successive demonstrations became the toast of Paris.

Expertly made, the device could operate for about five hours before it stopped. In theory, from Paris it would take just under 32 hours to precess around the entire circle — *not* the roughly 24 hours of one Earth rotation. The period would match the planet's rotation rate only at the north and south poles, Foucault explained. And at the equator, the pendulum would simply swing back in forth and never change direction at all. Between these extremes, he deduced that there would be a complex interplay between the pendulum and Earth's curved, rotating surface. As a result, a pendulum's period would vary by latitude, with its rotation faster near the poles than near the equator. This means, essentially, that the device not only knew Earth turned — it knew where on Earth it was.



First image of the Sun, a deguerrotype by Hippolyte Fizeau and León Foucault taken in 1845.

This fact would soon become spectacularly apparent, as Foucault's demonstration of the turning world quickly spread around the world itself.

Foucault fever began to transform great cathedrals, humble barns, and private homes into Earth-sensing observatories. "Pendulum-mania" spread quickly throughout Europe, as astronomers in London, Dublin, and other centers confirmed the experiment, issuing reports and calculations. Inside Germany's towering Cologne Cathedral, then the tallest building on Earth, a towering pendulum was swung from 500 feet (150 meters) up. Clergyman-scientist Angelo Secchi even set one oscillating in the Vatican, seeming to vindicate Galileo Galilei's claims of a moving Earth, which centuries before had resulted in Galileo's censure by the Church. (Secchi would later become famous for claiming to discover canals on Mars.)

The U.S. response was typically American. Across the nation that summer, town after town tried the experiment, often pressing their tallest structures into service and securing the help of local scientists. Inside the Reading Railroad's enormous engine house in Pennsylvania, then the fourth-largest dome in the world, an iron ball was swung from an 80-foot wire. The famed Circular Church, in Charleston, South Carolina, hosted another demonstration.

The pendulum's majestic sweep seemed to evoke history. At Massachusetts' Bunker Hill monument, craftsmen repurposed a colonial-era cannonball into a pendulum bob, suspending it down the granite obelisk's 221-foot (67-meter) central shaft. It was so delicately balanced that minute variations in its swing were traced to sunlight, which caused the monument's stones to heat and expand. "The motion of the pendulum is beautiful in the extreme," exalted *The Boston Transcript*. "The revolution of the Earth," added *The Richmond Enquirer*, "is perceptible with every oscillation." In Washington, D.C., a 116-foot (35-meter) pendulum was hung from the dome of the U.S. Capitol, then set swinging precisely north and south, a hardly veiled reference to politics of the day.

The craze garnered headlines from New York to Hawaii, as stories full of physics and astronomy appeared side by side with more customary news events. "If a heavy body be out of contact with the Earth," explained the *Savannah Republican* earnestly, "does not partake of its motion."

Exchanges between readers debating the pendulum's workings seemed to anticipate social media by more than a century. And it seemed anyone could perform this wonder. "The experiment can be repeated … by persons in their own homes," the *Madison County Whig* assured the curious, suggesting readers use picture wire and weights from a grocer's scale for bobs. Readers responded instantly. One "well-adjusted pendulum," reported *The Boston Traveller*, "when hung down an ordinary staircase," demonstrated Earth's rotation "quite perceptibly to the eye."

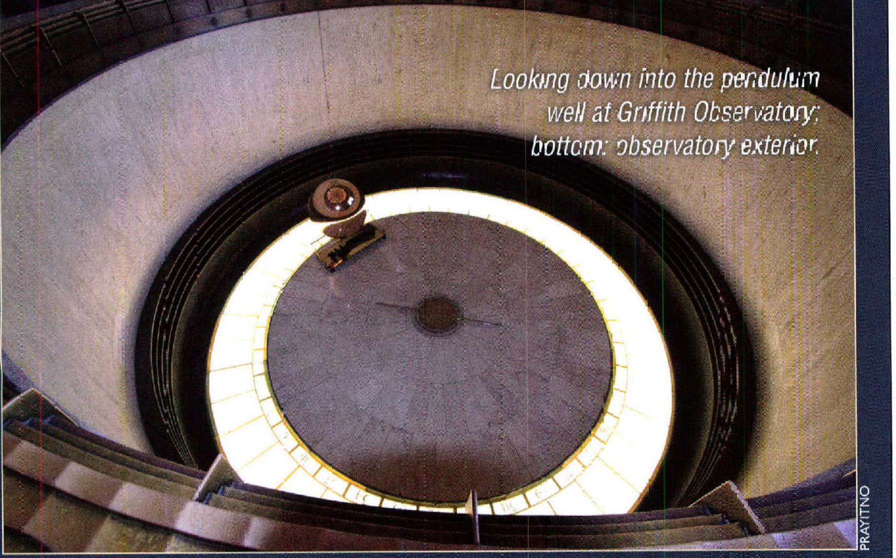
Education reformers clamored to introduce the pendulum's lessons in the classroom. "There is nothing better adapted to enlarge the minds of the people than the study of the laws on which the universe it built," extolled one supporter.

An inventor patented a miniature globe that could demonstrate "the Foucault effect" anywhere on Earth. This device fulfilled a seeming need, as a new unit of time had emerged: the pendulum-day. This marked one complete rotation at a given locale. For the Victorians, the episode marked a new realization of living on a whirling planet, just as the more rapid modern age of railroad, telegraph, and steamship was born. And Foucault helped mankind travel beyond Earth itself: The same year he invented his pendulum, he also invented the gyroscope. These devices work superbly for keeping spacecraft on their desired trajectories.

Foucault's pendulum continues to delight audiencies today, as more than 200 continue operating in public places. The heaviest, at 950 pounds (430 kg), can be found at the Oregon Convention Center in Portland. The longest, at 129 feet (39.3 meters), is the Centennial Pendulum in Boulder, Colorado. An outdoor device, surrounded by glass, graces a harbor in Valdivia, Chile. One in the United Nations Building in New York signifies world unity. Amazingly, Foucault's original 1855 pendulum continued to operate until 2010, when it was lost in a fall.

These instruments are still studied by scientists in modern times, too. In 2001, one of Foucault's most difficult-to-test predictions was finally verified: A pendulum set up at the South Pole, at the U.S. National Science Foundation's Amundsen-Scott Station, took exactly one day to precess through an entire cycle.

Nick D'Alto is an engineer and science writer in New York state, and a frequent contributor to StarDate.



Looking down into the pendulum well at Griffith Observatory; bottom: observatory exterior.

PRAYITNO

Swinging With the Stars

The Foucault pendulum in the glorious art deco atrium of Los Angles' Griffith Observatory is original, installed prior to the planetarium's opening in 1935. That makes it one of the longest-operating examples in the world.

Its 240-pound gunmetal bob swings from a 40-foot arm of piano wire. "Long and heavy gives lots of momentum," says David Reitzel, a lecturer at Griffith. It has a period close to seven seconds and it makes a complete rotation in 42.7 hours, which dovetails perfectly with Los Angles' latitude, according to Foucault's law.

The location has made this pendulum almost as famous as Foucault's, as it's appeared in movies like 1954's "Rebel Without A Cause" and 2016's Oscar-winning "La La Land."

Behind the scenes, keeping this giant-but-delicate apparatus going can resemble a Hollywood production. "It was originally restarted daily," Reitzel says. "A staff member would climb down in the pit, draw the heavy bob back … and then get out of the way, very quickly!"

The device does receive some help. A ring electromagnet near its pivot pushes the device enough to compensate for the loss of momentum without affecting its path. The technique, invented by Foucault himself, allows modern pendulums to run continuously.

More than a million visitors see the pendulum each year, peering over a circular parapet to watch its bob knock over racks of pegs arranged around an ornate floor rose. "Once a quorum of people gather," Reitzel says, "museum staff begin to explain, 'you're on a moving planet!,' and people begin to grasp it."

"It's simple and beautiful," Reitzel says, "and it's dramatic to watch." ND

MATTHEW FIELD

RESOURCES

BOOKS

Pendulum: León Foucault and the Triumph of Science by Amir D. Aczel, 2003

The Pendulum: Scientific, Historical, Philosphical and Educational Perspectives edited by Michael R. Matthews, Colin F. Gauld, and Arthur Stinner; 2005

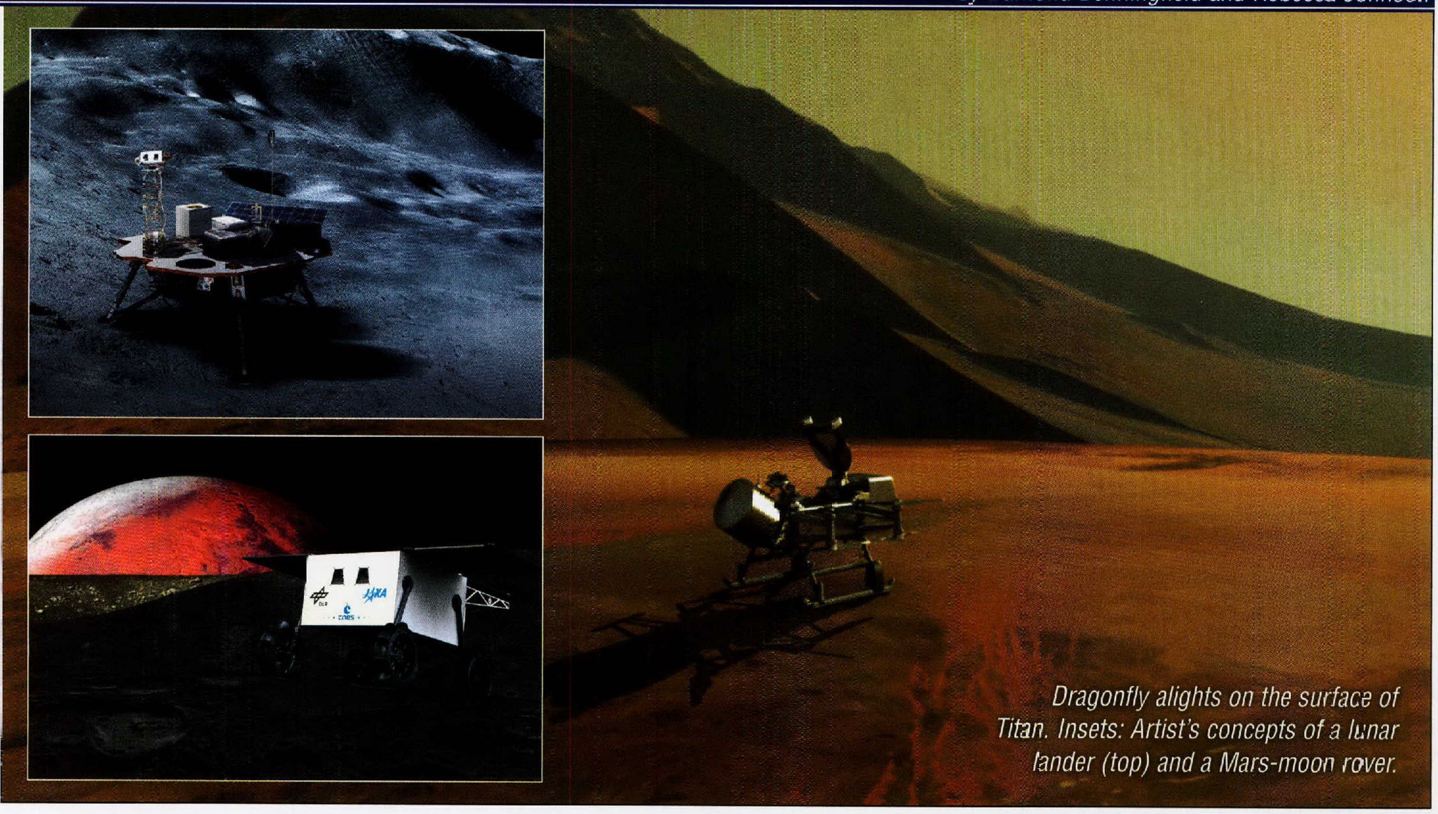
The Life and Science of León Foucault by William Tobin, 2003

INTERNET

How Does Foucault's Pendulum Prove the Earth Rotates?
smithsonianmag.com/how-does-foucaults-pendulum-prove-earth-rotates-180968024

León Foucault: Biograpy, Facts and Pictures
famousscientitsts.org/leon-foucault/

by Damond Benningfield and Rebecca Johnson



JHUAPL; INSETS, FROM TOP: NASA; CNES

Dragonfly alights on the surface of Titan. Insets: Artist's concepts of a lunar lander (top) and a Mars-moon rover.

Buzzing Around the Solar System

New mission targets range from the Sun and Moon to a cold moon of Saturn

Drones are almost everywhere these days, buzzing around like mosquitoes on a summer evening. And they'll soon expand their range. A small one will head for Mars next year, while a much larger and more complicated one will be dispatched to the biggest moon of Saturn in 2026, with arrival eight years later.

It's the most ambitious of a plethora of new missions to the worlds of the solar system approved by NASA and other space agencies in recent months. They include several missions to the Moon, as well as craft for studying the Sun, a comet, and one of the moons of Mars.

The drone is known as Dragonfly. It will be about the size of a lawnmower, and its nuclear generator will power it for years, allowing it to fly more than 100 miles across Titan's surface.

Titan is as big as Mercury, the smallest planet. Its atmosphere is denser than Earth's and contains abundant organic compounds — the basic chemistry of life.

Titan also has clouds, rains, rivers, and lakes, but because the surface temperature hovers near –290 Fahrenheit (–180 C), their liquids are methane and ethane, not water. A giant ocean of water may lie many miles below the surface, however.

Dragonfly will land in a dune field near Titan's equator. Each Titan day, which lasts about 16 Earth days, it will fly to a new location. At each stop it will analyze rocks and dirt on the surface, listen for quakes below the surface, and measure Titan's weather. In particular, the drone will look for complex building blocks of life and for evidence of current life.

In May, NASA selected three commercially built craft to land on the Moon. One of the winning companies later withdrew, however, leaving only two confirmed missions. Both are scheduled for launch as early as 2021.

And in July, the space agency selected a dozen scientific payloads for the landers, including a small rover, laser reflectors to help scientists more precisely measure the Earth-Moon distance, and devices for gathering and packaging lunar samples for return to Earth.

NASA also approved two new craft to study the Sun, with launch in two years. The primary craft will focus on the Sun's hot but faint outer atmosphere, the corona, while a second will study the effects of the solar wind on parts of Earth's magnetic field.

The European Space Agency announced a mission of its own, even though no one yet knows where it's going. Comet Interceptor will consist of three craft that will be placed in a parking orbit. When a new comet enters the inner solar system, they will be sent to study it.

European agencies also announced a new rover, to crawl across one of the moons of Mars. It will hitch a ride on an already planned Japanese mission, which will bring samples of either Phobos or Deimos back to Earth. Launch is scheduled for 2024. **DB**

Death by Dark Matter?

Report says we're safe from possible cosmic 'bullets'

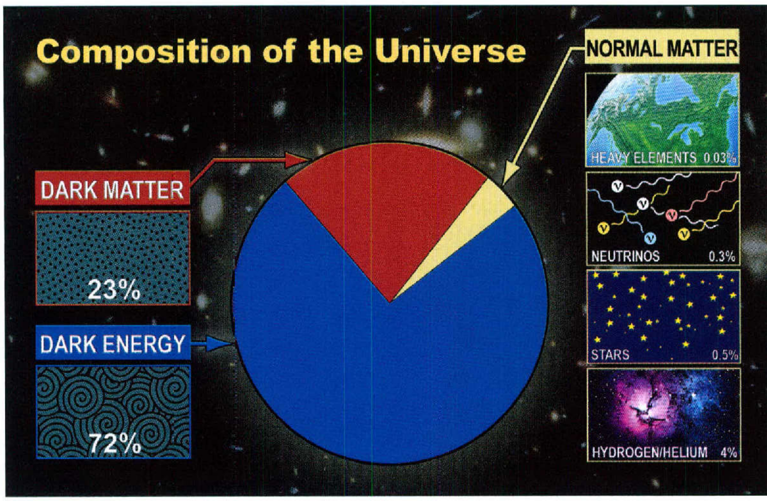
The titles of most research papers are dense and dull. A paper published in July, though, would draw just about anyone's attention: "Death by Dark Matter." In the article, researchers looked to see if people were being killed by a possible form of dark matter. The conclusion? We're safe.

Dark matter is far more abundant than normal matter, which makes up stars, planets, and people. Astronomers can't see dark matter because it doesn't interact with normal matter, but they know it's there because it exerts a gravitational pull on the visible matter around it.

Scientists have proposed many possible explanations for dark matter, ranging from tiny subatomic particles to black holes left over from the Big Bang. The leading idea says it consists of particles that are much heavier than a proton, but efforts to find them have turned up empty.

Another idea says dark matter could consist of tiny clumps of normal particles. They would be arranged and held together in odd ways, though, so they would be extremely dense and heavy.

A team led by Jagjit Singh Sidhu of Case Western University calculated the effects on the human body of dark-matter clumps that, though sub-microscopic, could weigh more than 100 pounds (50 kg). In a paper published online, the researchers found that such a clump would act like a powerful bullet, boring a narrow hole and heating the tissue around it to millions of degrees.



TIM JONES/DAMOND BENNINGFIELD

Unknown dark matter is far more common than 'normal' matter.

To assess the risk of death by this form of dark matter, the researchers analyzed 10 years of medical records from the United States, Canada, and western Europe, but found no likely cases. Luckily for us, that reduces the chance that a form of dark matter in that mass range exists. It doesn't rule out heavier particles, although such particles are calculated to be less likely to cause harm if they ram into a human being. **DB**

Ancient Galactic Collision Provides Dark Matter Clues

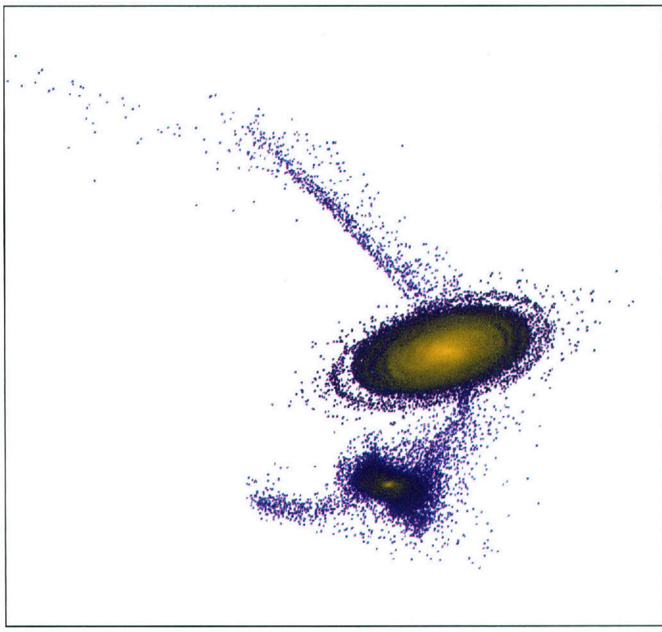
A team of astronomers led by Sukanya Chakrabarti of the Rochester Institute of Technology has found that a collision millions of years ago between the Milky Way and one of its satellite galaxies left ripples in our galaxy's outer disk that are seen today.

Chakrabarti predicted a decade ago that an unknown dwarf galaxy made mostly of dark matter — unseen matter that is detectable by its gravitational pull on other objects — was responsible for some of the characteristics seen in the Milky Way's outer disk. Antila 2, a satellite galaxy only recently discovered by the Gaia space telescope, was found at the location she predicted for the prviously unseen galaxy.

The discovery could help astronomers develop methods to hunt down dark galaxies, and even solve the mystery of what dark matter is made of.

"If Antila 2 is the dwarf galaxy we predicted, you know what its orbit [around the Milky Way] had to be. You know it had to come close to the [Milky Way's] galactic disk," Chakrabarti said.

"That sets stringent constraints, therefore, on not just the mass [of the dark satellite galaxy], but also its density profile. That means that ultimately you could use Antila 2 as a unique laboratory to learn about the nature of dark matter." **RJ**



SUKANYA CHAKRABARTI/RIT

This frame from a simulation of the interaction between the Milky Way (top) and Antila 2 (bottom) over millions of years shows the characteristic ripples in the Milky Way's outer disk caused by the dance of the two galaxies.

Astronomers Pinpoint Mysterious Outburst

A modest galaxy produced a major eruption late last year, providing a new clue to help astronomers learn what powers this mysterious class of outbursts.

An array of radio telescopes in Australia discovered Fast Radio Burst (FRB) 180924 last September. The outburst lasted less than a thousandth of a second. Minute differences in the time the outburst's radio waves arrived at the array's 36 antennas allowed astronomers to pinpoint its location in the sky, on the outskirts of a small galaxy in the southern constellation Grus, the crane.

Follow-up observations with three giant optical telescopes this year showed that the host galaxy is about four billion light-years away. Knowing the distance allows astronomers to calibrate the outburst's energy and study its environment.

More than 80 FRBs have been detected, but before 180924, astronomers had been able to pinpoint the location of only one. That one has popped off more than 150 times, making it easier to track down. It belongs to a galaxy that is manufacturing many new stars. The host of 180924, on the other hand, is producing almost no new stars. That suggests that FRBs could be born in a variety of environments or that they could be powered by more than one mechanism.

Current ideas suggest the bursts are related to black holes or neutron stars, but the lack of details makes it impossible to complete the models. Pinpointing a second FRB will help astronomers begin to narrow down the possibilities.

ET Keeps Quiet

Search for alien civilizations expands

Years of observations of more than 1,300 nearby stars hasn't revealed a peep from other civilizations. Even so, astronomers are planning to add new telescopes to their search, extending their reach to more than a million more stars.

Breakthrough Listen, launched in 2015, uses giant radio telescopes in West Virginia and Australia to monitor billions of frequencies for evidence of extraterrestrial intelligence. The project also uses an optical telescope to look for alien laser signals.

Breakthrough Listen released years of observations in June. Automated search techniques eliminated most suspicious signals, while scientists ruled out the few that remained. The project released its observations to other scientists, who can sift through the data for signals from ET or for natural signals produced by stars and other objects.

Breakthrough Listen is incorporating observations made by a radio-telescope array in South Africa, which extends its range to include a million more stars. It also announced plans to use observations by an array of telescopes in Arizona, which detects flashes of light produced by gamma rays. The array will look for possible laser signals from other civilizations.

Mud Mountain, Big Impact in the Asteroid Belt

Studies fill in histories of Ceres, Vesta

The tallest mountain on Ceres, the largest member of the asteroid belt, is made of salty mud that bubbled up from below the surface, a recent study reported. And a second study supported the idea that Vesta, the second-largest member of the belt, was pummeled by a giant impact roughly 30 million years after its formation.

The Dawn spacecraft visited both small worlds. It orbited Vesta from July 2011 to September 2012 then swung over to Ceres, where it arrived in March 2015. It operated until late 2018, when it exhausted its fuel supply.

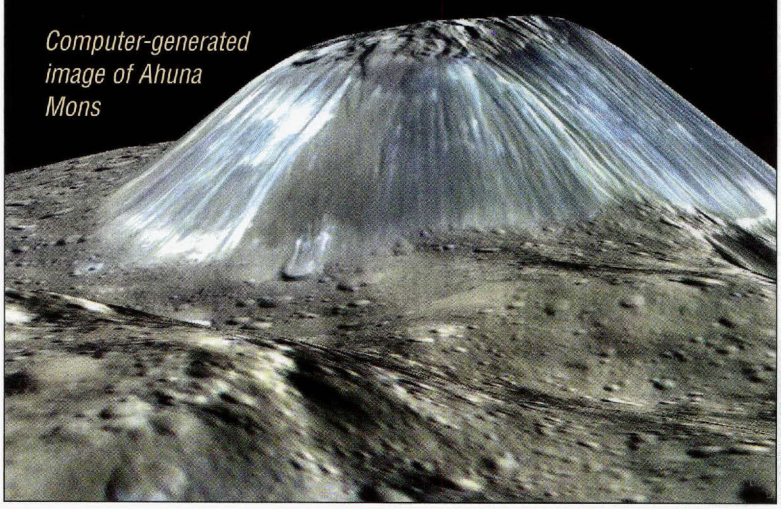
Dawn discovered a 13,000-foot (4,000-meter) mountain protruding from the surface of Ceres, which scientists named Ahuna Mons. It has steep, smooth, even sides, indicating that it is relatively young.

Scientists in Germany combined observations of the mountain's composition with measurements of Ceres' shape and gravitational field to deduce its likely history. They found that it probably formed when a bubble of saltwater, mud, and rock rose from deep inside Ceres. It formed a dome on the surface, then broke through a weak spot in Ceres' icy crust. As the material piled up it cooled and solidified in the vacuum of space, making a giant mountain.

The study supports earlier findings that as much as one-quarter of the mass of Ceres consists of water (liquid or frozen). Plumes of salty water have pooled on the surface, leaving behind bright white salt deposits as the water evaporated.

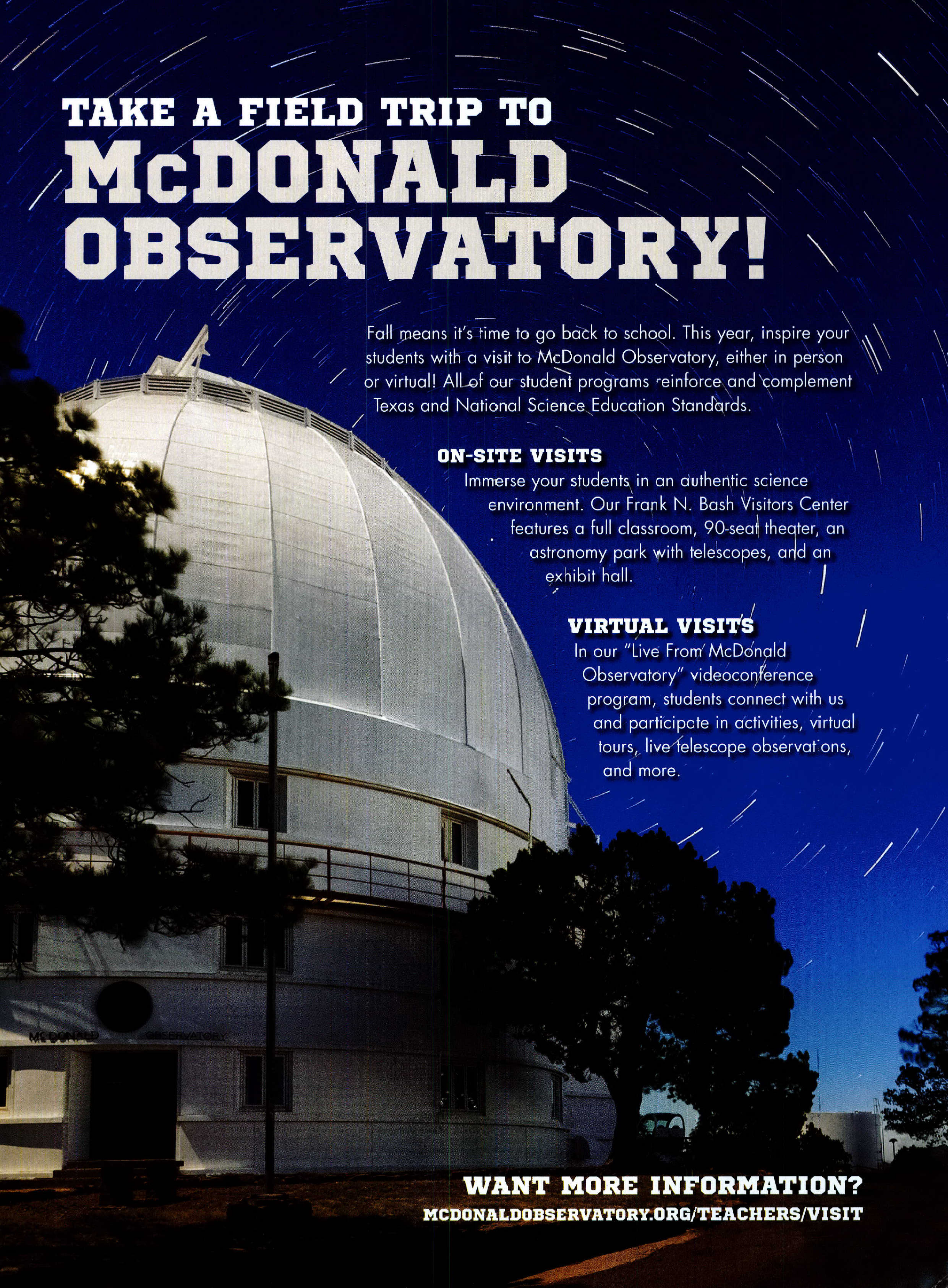
Dawn found that Vesta's crust is especially thick at the south pole. Scientists had proposed that the northern crust was thinned by a collision with another asteroid. Research by a team from Japan and Switzerland supports that conclusion.

The team measured the ages of zircons found in meteorites that likely came from Vesta. The researchers found that the little world's crust formed 4.559 billion years ago, with the giant impact occurring roughly 33 million years later. The work also supports the Vesta origin of two classes of meteorites, the researchers said. **DB**



Computer-generated image of Ahuna Mons

NASA/JPL/UCLA/MPS/DLR/IDA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VIRTUAL VISITS
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Images taken through several filters were combined to produce this view of the solar eclipse of July 2. The merged image shows details in the Sun's corona, its hot outer atmosphere. The image was snapped at La Silla Observatory in Chile.