South Downs Mercury

The monthly circular of South Downs Astronomical Society
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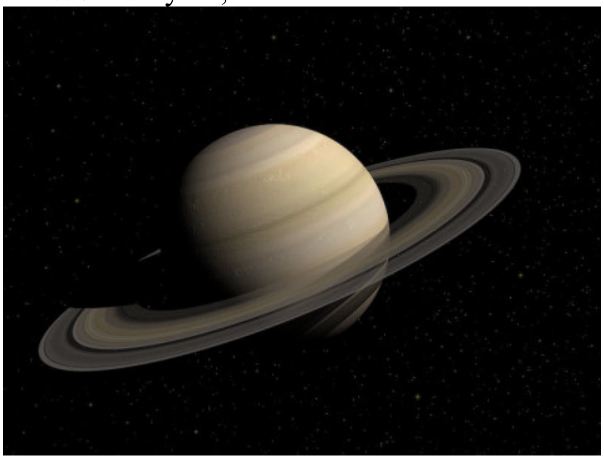
THE FEBRUARY MEETING IS CANCELLED DUE TO COVID-19

We have a virtual meeting Friday 5th February Zoom Meeting 19:30 Hugh Allen Spectroscopy and the Hertzsprung-Russell Diagram . Email me for joining instructions if you have not already received them

- Saturn's tilt caused by its moons, researchers say

Date: January 21, 2021



Saturn illustration (stock image).
Credit: © Dimitar Marinov / stock.adobe.com

Two scientists from CNRS and Sorbonne University working at the Institute of Celestial Mechanics and Ephemeris Calculation (Paris Observatory -- PSL/CNRS) have just shown that the influence of Saturn's satellites can explain the tilt of the rotation axis of the gas giant. Their work, published on 18 January 2021 in the journal *Nature Astronomy*, also predicts that the tilt will increase even further over the next few billion years.

Rather like David versus Goliath, it appears that Saturn's tilt may in fact be caused by its moons. This is the conclusion of recent work carried out by scientists from the CNRS, Sorbonne University and the University of Pisa, which shows that the current tilt of Saturn's rotation axis is caused by the migration of its satellites, and especially by that of its largest moon, Titan.

Recent observations have shown that Titan and the other moons are gradually moving away from Saturn much faster than astronomers had previously estimated. By incorporating this increased migration rate into their calculations, the researchers concluded that this process affects the inclination of Saturn's rotation axis: as its satellites move further away, the planet tilts more and more.

The decisive event that tilted Saturn is thought to have occurred relatively recently. For over three billion years after its formation, Saturn's rotation axis remained only slightly tilted. It was only roughly a billion years ago that the gradual motion of its satellites triggered a resonance phenomenon that continues today: Saturn's axis interacted with the path of the planet Neptune and gradually tilted until it reached the inclination of 27° observed today.

These findings call into question previous scenarios. Astronomers were already in agreement about the existence of this resonance. However, they believed that it had occurred very early on, over four billion years ago, due to a change in Neptune's orbit. Since that time, Saturn's axis was thought to have been stable. In fact, Saturn's axis is still tilting, and what we see today is merely a transitional stage in this shift. Over the next few billion years, the inclination of Saturn's axis could more than double.

The research team had already reached similar conclusions about the planet Jupiter, which is expected to undergo comparable tilting due to the migration of its four main moons and to resonance with the orbit of Uranus: over the next five billion years, the inclination of Jupiter's axis could increase from 3° to more than 30°.

- Solar system formation in two steps

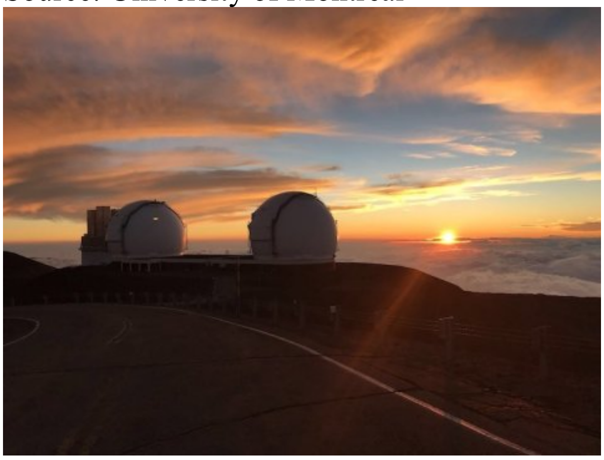
Date: January 21, 2021
Source: University of Oxford

An international team of researchers from the University of Oxford, LMU Munich, ETH

Zurich, BGI Bayreuth, and the University of Zurich discovered that a two-step formation process of the early Solar System can explain the chronology and split in volatile and isotope content of the inner and outer Solar System.
Their findings will be published in *Science*.
The paper presents a new theoretical framework for the formation and structure of the Solar System that can explain several key features of the terrestrial planets (like Earth, Venus, and Mars), outer Solar System (like Jupiter), and composition of asteroids and meteorite families. The team's work draws on and connects recent advances in astronomy (namely observations of other solar systems during their formation) and meteoritics -- laboratory experiments and analyses on the isotope, iron, and water content in meteorites.
The suggested combination of astrophysical and geophysical phenomena during the earliest formation phase of the Sun and the Solar System itself can explain why the inner Solar System planets are small and dry with little water by mass, while the outer Solar System planets are larger and wet with lots of water. It explains the meteorite record by forming planets in two distinct steps. The inner terrestrial protoplanets accreted early and were internally heated by strong radioactive decay; this dried them out and split the inner, dry from the outer, wet planetary population. This has several implications for the distribution and necessary formation conditions of planets like Earth in extrasolar planetary systems.
The numerical experiments performed by the interdisciplinary team showed that the relative chronologies of early onset and protracted finish of accretion in the inner Solar System, and a later onset and more rapid accretion of the outer Solar System planets can be explained by two distinct formation epochs of planetesimals, the building blocks of the planets. Recent observations of planet-forming disks showed that disk midplanes, where planets form, may have relatively low levels of turbulence. Under such conditions the interactions between the dust grains embedded in the disk gas and water around the orbital location where it transitions from gas to ice phase (the snow line) can trigger an early formation burst of planetesimals in the inner Solar System and another one later and further out.
The two distinct formation episodes of the planetesimal populations, which further accrete material from the surrounding disk and via mutual collisions, result in different geophysical modes of internal evolution for the forming protoplanets. Dr Tim Lichtenberg from the Department of Atmospheric, Oceanic and Planetary Physics at the University of Oxford and lead-author of the study notes: 'The different formation time intervals of these planetesimal populations mean that their internal heat engine from radioactive decay differed substantially. Inner Solar System planetesimals became very hot, developed internal magma oceans, quickly formed iron cores, and degassed their initial volatile content, which eventually resulted in dry planet compositions. In comparison, outer Solar System planetesimals formed later and therefore experienced substantially less internal heating and therefore limited iron core formation, and volatile release.
'The early-formed and dry inner Solar System and the later-formed and wet outer Solar System were therefore set on two different evolutionary paths very early on in their history. This opens new avenues to understand the origins of the earliest atmospheres of Earth-like planets and the place of the Solar System within the context of the exoplanetary census across the galaxy.'
This research was supported by funding from the Simons Collaboration on the Origins of Life, the Swiss National Science Foundation, and the European Research Council.

- ❖ A 'super-puff' planet like no other

Date: January 18, 2021
Source: University of Montreal



W. M. Keck Observatory in Hawaii (stock image).
Credit: © Daniel Gillies / stock.adobe.com

The core mass of the giant exoplanet WASP-107b is much lower than what was thought necessary to build up the immense gas envelope surrounding giant planets like

Jupiter and Saturn, astronomers at Université de Montréal have found.
This intriguing discovery by Ph.D. student Caroline Piaulet of UdeM's Institute for Research on Exoplanets (iREx) suggests that gas-giant planets form a lot more easily than previously believed.
Piaulet is part of the ground-breaking research team of UdeM astrophysics professor Björn Benneke that in 2019 announced the first detection of water on an exoplanet located in its star's habitable zone.
Published today in the *Astronomical Journal* with colleagues in Canada, the U.S., Germany and Japan, the new analysis of WASP-107b's internal structure "has big implications," said Benneke.
"This work addresses the very foundations of how giant planets can form and grow," he said. "It provides concrete proof that massive accretion of a gas envelope can be triggered for cores that are much less massive than previously thought."
As big as Jupiter but 10 times lighter
WASP-107b was first detected in 2017 around WASP-107, a star about 212 light years from Earth in the Virgo constellation. The planet is very close to its star -- over 16 times closer than the Earth is to the Sun. As big as Jupiter but 10 times lighter, WASP-107b is one of the least dense exoplanets known: a type that astrophysicists have dubbed "super-puff" or "cotton-candy" planets.
Piaulet and her team first used observations of WASP-107b obtained at the Keck Observatory in Hawai'i to assess its mass more accurately. They used the radial velocity method, which allows scientists to determine a planet's mass by observing the wobbling motion of its host star due to the planet's gravitational pull. They concluded that the mass of WASP-107b is about one tenth that of Jupiter, or about 30 times that of Earth.
The team then did an analysis to determine the planet's most likely internal structure. They came to a surprising conclusion: with such a low density, the planet must have a solid core of no more than four times the mass of the Earth. This means that more than 85 percent of its mass is included in the thick layer of gas that surrounds this core. By comparison, Neptune, which has a similar mass to WASP-107b, only has 5 to 15 percent of its total mass in its gas layer.
"We had a lot of questions about WASP-107b," said Piaulet. "How could a planet of such low-density form? And how did it keep its huge layer of gas from escaping, especially given the planet's close proximity to its star?
"This motivated us to do a thorough analysis to determine its formation history."
A gas giant in the making
Planets form in the disc of dust and gas that surrounds a young star called a protoplanetary disc. Classical models of gas-giant planet formation are based on Jupiter and Saturn. In these, a solid core at least 10 times more massive than the Earth is needed to accumulate a large amount of gas before the disc dissipates.
Without a massive core, gas-giant planets were not thought able to cross the critical threshold necessary to build up and retain their large gas envelopes.
How then do explain the existence of WASP-107b, which has a much less massive core? McGill University professor and iREx member Eve Lee, a world-renowned expert on super-puff planets like WASP-107b, has several hypotheses.
"For WASP-107b, the most plausible scenario is that the planet formed far away from the star, where the gas in the disc is cold enough that gas accretion can occur very quickly," she said. "The planet was later able to migrate to its current position, either through interactions with the disc or with other planets in the system."
Discovery of a second planet, WASP-107c
The Keck observations of the WASP-107 system cover a much longer period of time than previous studies have, allowing the UdeM-led research team to make an additional discovery: the existence of a second planet, WASP-107c, with a mass of about one-third that of Jupiter, considerably more than WASP-107b's.
WASP-107c is also much farther from the central star; it takes three years to complete one orbit around it, compared to only 5.7 days for WASP-107b. Also interesting: the eccentricity of this second planet is high, meaning its trajectory around its star is more oval than circular.
"WASP-107c has in some respects kept the memory of what happened in its system," said Piaulet. "Its great eccentricity hints at a rather chaotic past, with interactions between the planets which could have led to significant

displacements, like the one suspected for WASP-107b."

Several more questions

Beyond its formation history, there are still many mysteries surrounding WASP-107b. Studies of the planet's atmosphere with the Hubble Space Telescope published in 2018 revealed one surprise: it contains very little methane.

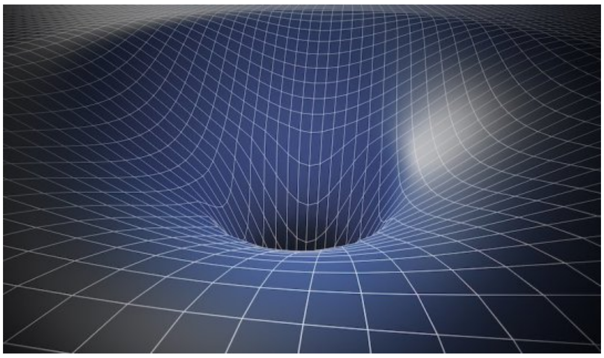
"That's strange, because for this type of planet, methane should be abundant," said Piaulet. "We're now reanalysing Hubble's observations with the new mass of the planet to see how it will affect the results, and to examine what mechanisms might explain the destruction of methane."

The young researcher plans to continue studying WASP-107b, hopefully with the James Webb Space Telescope set to launch in 2021, which will provide a much more precise idea of the composition of the planet's atmosphere.

"Exoplanets like WASP-107b that have no analogue in our Solar System allow us to better understand the mechanisms of planet formation in general and the resulting variety of exoplanets," she said. "It motivates us to study them in great detail."

- 'Galaxy-sized' observatory sees potential hints of gravitational waves

Date: January 11, 2021
Source: University of Colorado at Boulder



Curved spacetime illustration (stock image).
Credit: © vchalup / stock.adobe.com

Scientists have used a "galaxy-sized" space observatory to find possible hints of a unique signal from gravitational waves, or the powerful ripples that course through the universe and warp the fabric of space and time itself.

The new findings, which appeared recently in *The Astrophysical Journal Letters*, hail from a U.S. and Canadian project called the North American Nanohertz Observatory for Gravitational Waves (NANOGrav).

For over 13 years, NANOGrav researchers have pored over the light streaming from dozens of pulsars spread throughout the Milky Way Galaxy to try to detect a "gravitational wave background." That's what scientists call the steady flux of gravitational radiation that, according to theory, washes over Earth on a constant basis. The team hasn't yet pinpointed that target, but it's getting closer than ever before, said Joseph Simon, an astrophysicist at the University of Colorado Boulder and lead author of the new paper.

"We've found a strong signal in our dataset," said Simon, a postdoctoral researcher in the Department of Astrophysical and Planetary Sciences. "But we can't say yet that this is the gravitational wave background."

In 2017, scientists on an experiment called the Laser Interferometer Gravitational-Wave Observatory (LIGO) won the Nobel Prize in Physics for the first-ever direct detection of gravitational waves. Those waves were created when two black holes slammed into each other roughly 130 million lightyears from Earth, generating a cosmic shock that spread to our own solar system.

That event was the equivalent of a cymbal crash -- a violent and short-lived blast. The gravitational waves that Simon and his colleagues are looking for, in contrast, are more like the steady hum of conversation at a crowded cocktail party.

Detecting that background noise would be a major scientific achievement, opening a new window to the workings of the universe, he added. These waves, for example, could give scientists new tools for studying how the supermassive black holes at the centres of many galaxies merge over time.

"These enticing first hints of a gravitational wave background suggest that supermassive black holes likely do merge and that we are bobbing in a sea of gravitational waves rippling from supermassive black hole mergers in galaxies across the universe," said Julie Comerford, an associate professor of astrophysical and planetary science at CU Boulder and NANOGrav team member.

Simon will present his team's results at a virtual press conference on Monday at the 237th meeting of the American Astronomical Society.

Galactic lighthouses

Through their work on NANOGrav, Simon and Comerford are part of a high stakes, albeit collaborative, international race to find the

gravitational wave background. Their project joins two others out of Europe and Australia to make up a network called the International Pulsar Timing Array.
Simon said that, at least according to theory, merging galaxies and other cosmological events produce a steady churn of gravitational waves. They're humungous -- a single wave, Simon said, can take years or even longer to pass Earth by. For that reason, no other existing experiments can detect them directly.
"Other observatories search for gravitational waves that are on the order of seconds," Simon said. "We're looking for waves that are on the order of years or decades."
He and his colleagues had to get creative. The NANOGrav team uses telescopes on the ground not to look for gravitational waves but to observe pulsars. These collapsed stars are the lighthouses of the galaxy. They spin at incredibly fast speeds, sending streams of radiation hurtling toward Earth in a blinking pattern that remains mostly unchanged over the eons.
Simon explained that gravitational waves alter the steady pattern of light coming from pulsars, tugging or squeezing the relative distances that these rays travel through space. Scientists, in other words, might be able to spot the gravitational wave background simply by monitoring pulsars for correlated changes in the timing of when they arrive at Earth.
"These pulsars are spinning about as fast as your kitchen blender," he said. "And we're looking at deviations in their timing of just a few hundred nanoseconds."

Something there

To find that subtle signal, the NANOGrav team strives to observe as many pulsars as possible for as long as possible. To date, the group has observed 45 pulsars for at least three years and, in some cases, for well over a decade.
The hard work seems to be paying off. In their latest study, Simon and his colleagues report that they've detected a distinct signal in their data: Some common process seems to be affecting the light coming from many of the pulsars.
"We walked through each of the pulsars one by one. I think we were all expecting to find a few that were the screwy ones throwing off our data," Simon said. "But then we got through them all, and we said, 'Oh my God, there's actually something here.'"
The researchers still can't say for sure what's causing that signal. They'll need to add more pulsars to their dataset and observe them for longer periods to determine if it's actually the gravitational wave background at work.
"Being able to detect the gravitational wave background will be a huge step but that's really only step one," he said. "Step two is pinpointing what causes those waves and discovering what they can tell us about the universe."
NANOGrav is a U.S. National Science Foundation Physics Frontiers Centre. It is co-directed by Maura McLaughlin of West Virginia University and Xavier Siemens of Oregon State University.

On 1 December 2020, the 900-ton instrument platform of the Arecibo Observatory crashed into its dish, which is cradled in a natural sinkhole.

RICARDO ARDUENGO/AFP VIA GETTY IMAGES

How the famed Arecibo telescope fell—and how it might rise again

By Daniel ClеryJan. 14, 2021 , 11:52 AM

In the early morning of 10 August 2020, Sravani Vaddi, a postdoc astronomer at the Arecibo Observatory in Puerto Rico, was working from home, but her thoughts were at Arecibo's giant radio telescope. At 2 a.m., she had one precious hour to focus the 305-meter dish on NGC 7469, a distant galaxy. At its centre, two supermassive black holes wheeled around each other, following an earlier galaxy merger. Vaddi wanted to see whether having two dark hearts instead of the usual one made the galaxy shine more brightly by stirring up gases and stoking star birth. Radio emissions from the glowing gases would help her find out.

When she checked in near the end of her observations, computer servers suggested the telescope wasn't pointing at the galaxy anymore. She couldn't get an on-site telescope operator on the phone, so she gave up and went to bed.

She woke up to a full inbox. At 2:45 a.m., toward the end of her slot, an 8-centimeter-thick steel cable, one of 18 suspending a 900-ton instrument platform high above the dish, had pulled out of its socket at one end and fallen, slicing into the dish. "I was totally shocked. How could a cable break?" she says. Although she didn't know it at the time, the photons she gathered from NGC 7469 would be the last ones Arecibo would ever scoop up.

The rest of the story is now well known. A second support cable snapped 3 months later, on 6 November, and the National Science Foundation (NSF), which owns the observatory, said attempting repairs was too dangerous: Arecibo would be dismantled. On 1 December, fate took control as more cables snapped and the platform, as heavy as 2000 grand pianos, came crashing down into the dish.

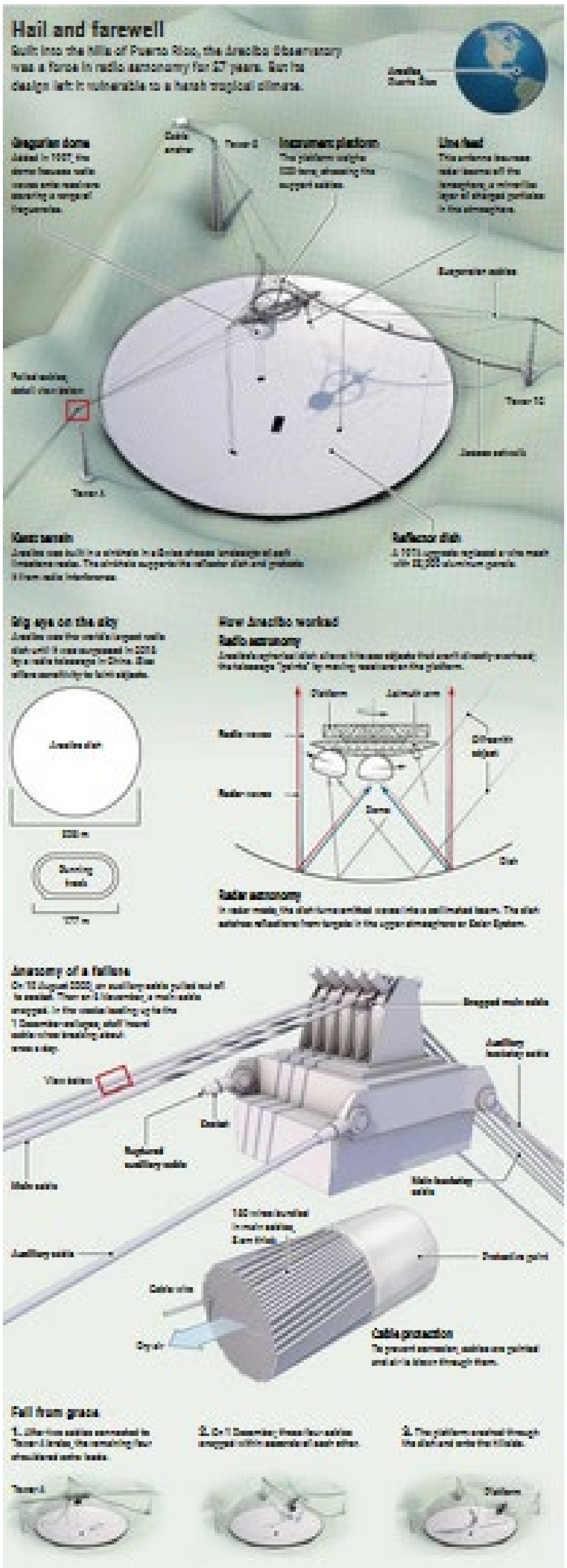
The loss dismayed scientists worldwide. Although 57 years old, Arecibo was still a scientific trailblazer. Its powerful radar could bounce radio waves off other planets and asteroids, revealing the contours of their surfaces. Other antennas could heat plasma in Earth's upper atmosphere, creating artificial aurorae for study. And for most of Arecibo's life, it was the biggest radio dish in the world, able to sense the faintest emissions, from the metronomic beats of distant stellar beacons called pulsars to the whisper of rarefied gases between galaxies.

The public, familiar with the majestic dish from films such as *Contact* and *GoldenEye*, also felt the loss. And it was a bitter blow to the people of Puerto Rico, who embraced hosting the technological marvel. Some 130 people work at the observatory, and many more derive indirect economic benefits from it. Every schoolchild on the island goes on a field trip to see the telescope, and those experiences often lead to science careers, says astrobiologist Abel Méndez of the University of Puerto Rico, Arecibo. With its fall, "Puerto Rico loses much more than any other place," he says.

Along with the grief have come sharper questions. After surviving numerous earthquakes and hurricanes, why did this scientific crown jewel collapse so unceremoniously on a calm winter morning? Some engineers and astronomers think manufacturing flaws or poor maintenance in a tropical, corrosive environment doomed the suspension cables. Others place blame at the feet of NSF's astronomy division, which for more than a decade tried to offload Arecibo so it could divert funds to operating newer telescopes. "Somehow, we lost a $300 million instrument, a magnificent, really expensive instrument, for a few million dollars," says Richard Behnke, an Arecibo staffer from 1970 to 1982 who went on to head the geospace science division at NSF. "Things should not collapse like that. It's not acceptable stewardship at all."

Meanwhile, astronomers are looking to the future. "First we mourned, then we had a wake, then we got down to work," says Joanna Rankin, an astronomer at the University of Vermont. Together with Arecibo staff, researchers last month delivered a white paper to NSF describing plans for a new $400 million telescope on the same site. Although any rebuilding effort faces major political and financial hurdles, the proposal aims for an instrument with even more dazzling capabilities than the one that was lost. "There's been a remarkable amount of commitment and energy," Rankin says.

Originally, Arecibo had little to do with astronomy. The Pentagon's Advanced Research Projects Agency funded its construction in the early 1960s as part of an effort to detect and intercept incoming Soviet missiles. Researchers thought radars might be able to spot missile trails left in the ionosphere, the upper part of the atmosphere where the Sun's radiation ionizes air molecules. But little was known about the ionosphere at the time. Arecibo's large dish, built in a natural sinkhole in Puerto Rico's karst landscape, was meant to serve as a giant radar for probing it.



(GRAPHIC) C. BICKEL/*Science*; (DATA) RHYS TAYLOR/WWW.RHYSY.NET

Upgrades after NSF took over the facility in 1969 made it alluring for more kinds of science. The original wire-mesh surface was replaced with aluminium panels that enabled observations at higher frequencies. NASA added a more powerful radar transmitter that could track Earth-threatening asteroids—and also used it to beam a message to possible civilizations among the stars. In the subsequent decades, a string of high-profile discoveries burnished the telescope's reputation: a binary pulsar system whose subtly slowing pulses provided the first indirect evidence of gravitational waves, radar maps of Venus's cloud-veiled surface that revealed evidence for volcanic repaving, and the very first planet outside our Solar System (albeit one orbiting a pulsar).

One of the telescope's quirks is that the curve of its dish is spherical rather than parabolic like most other radio telescopes. That shape enables the telescope to track objects that aren't directly overhead, even though the dish can't tilt. But it also focuses incoming rays to a line rather than a point, requiring elongated receivers. A 1997 upgrade added the igloo-shaped "Gregorian dome," which housed additional reflectors to focus the radio waves to a point where detectors and transmitters covering many frequencies could be mounted. "It became a completely different telescope and enabled it to stay on the cutting edge," says Robert Kerr, who was observatory director for two spells in the past 15 years.

The beefed-up scope won a starring role in the NANOGrav project, which in 2007 began to monitor pulsar beats for fluctuations caused by passing gravitational waves. Arecibo also aided the hunt for fast radio bursts, short and powerful blasts that have been one of radio astronomy's biggest mysteries of the past decade. In 2016, the telescope detected the first burst that repeated, showing that whatever produces the blasts is not destroyed in the process. (Highly magnetized neutron stars are the leading candidate.) "There was a new discovery every year," remembers astronomer Joan Schmelz, who was deputy director from 2015 to 2018.

Although the 1997 upgrade kept Arecibo in the vanguard, it may also have contributed to its demise. The telescope's cables were designed with a safety factor of just over two, so everyday loads on the cables would be less than half of the load that would break them. That surprises Robert Lark, a civil engineer at Cardiff University, who says that bridge cables typically have safety factors of six or more

The 110-ton Gregorian dome, added to Arecibo in 1997, boosted capabilities but the added weight may have hastened the platform's collapse. DAVID PARKER/SCIENCE SOURCE

The Gregorian dome and other new equipment added 300 tons to the platform. Although six auxiliary cables were added to bring the safety factor back to two, Kerr says it never quite got there. It was one of these auxiliary cables that failed in August. "One of the difficulties of adding or replacing cables is the accurate distribution of load," Lark says. "The new cable could have been bearing more than it should."

The end of the cable pulled free from its socket at the top of one of the platform's three support towers, says engineer Ramón Lugo, principal investigator for Arecibo at the University of Central Florida (UCF), which leads the consortium that now manages the observatory for NSF. Engineers make sockets by inserting the cable end into a cone-shaped steel cavity, splaying the cable's wires, and filling the cavity with molten metal such as zinc. The zinc adheres to the wires and forms a plug that locks them in place.

Engineers from Cornell University, which managed Arecibo from its construction until 2011, got an unexpected glimpse into one of Arecibo's sockets in the early 1980s, after an old cable was replaced and shipped to Cornell for inspection. Engineer Leigh Phoenix, who was on the team that carried out the post-mortem, says the socket appeared to be faulty. The zinc was distributed unevenly and was poorly adhered to the splayed wires. "It provided an avenue for water to get in," Phoenix says. The team also found broken and cracked wires in the socket. "It would be alarming if it had been allowed to continue," he says.

After the August failure of the auxiliary cable, UCF brought in three engineering firms to assess the situation. Their suspicion was that similar manufacturing faults in this cable's socket were to blame, Lugo says. They did not think the entire structure was at risk—even though staff were hearing individual wires break at a rate of about one per day across all of the telescope's cables. The wires were known to corrode in the tropical environment, but with 160 of them bundled into each main cable, the breakage didn't cause immediate alarm.

The lead engineering firm, Thornton Tomasetti, built a full structural model of the telescope. It showed that the four main cables running to the platform from the crippled tower, known as Tower 4, were now bearing a load equal to about 60% of their breaking strength: a safety factor of 1.67. After inspecting the structure, all three firms concluded it was stable and that the loss of another cable wouldn't cause a collapse.

Thornton Tomasetti recommended replacing all the auxiliary cables because the socket failure made all of them suspect—and because inspections showed some other cables had slipped as much as 1 centimetre from their sockets. Lugo says Arecibo staff wrote up a 500-page proposal for the repairs in 2 weeks. NSF approved the $10.5 million request, and orders were placed for new cables. Then, on 6 November, the second cable broke: a main cable, with just six visible broken wires. And this time, it did not separate from its socket: It snapped.

The mission to save the telescope was now urgent. The engineers had to reduce the load on the three main cables still attached to Tower 4, now shouldering more than 75% of their breaking load, but they couldn't risk putting people on the towers or platform. They looked at using helicopters to install extra cables or sever platform components to reduce its weight. They even considered sacrificing the entire 110 tons of the Gregorian dome, but the violent recoil of the platform after the dome was cut loose would have been "a bad thing," Lugo says. There was no good option.

One firm—Wiss, Janney, Elstner Associates—favoured stabilizing the telescope by relaxing the backstays that stretch from the towers to the ground, installing extra support cables, and removing mass from the platform before starting restoration work. But Thornton Tomasetti and the third firm, WSP, concluded that, after two cables had broken well below their design strength, none of them could be trusted. "Although it saddens us to make this recommendation, we believe the structure should be demolished in a controlled way as soon as pragmatically possible," principal engineer John Abruzzo of Thornton Tomasetti said in his report. So, at a 19 November press briefing, NSF called time on the telescope. "We understand how much Arecibo means to [the scientific] community and to Puerto Rico," said Sean Jones, head of the Directorate for Mathematical and Physical Sciences. "There is no path forward that allows us to do so safely."

On 1 December, less than 2 weeks later, Lugo, who had temporarily relocated to Puerto Rico, stopped to buy breakfast before driving up to the observatory. Just after 8 a.m., he got a call telling him the platform had collapsed. "I felt like throwing up," he says. One hour later he was on-site talking to staff who had heard and felt the crash. "There were a lot of glazed over expressions, they were all crying," he says. Cameras on a drone had caught the remaining Tower 4 cables snapping within seconds of each other while a fixed camera watched the platform fall. Arecibo's giant telescope was no more.

So why did cables that had held up the platform for decades suddenly fail so spectacularly? Decades earlier, staff noted cable wires snapping and suspected that corrosion from water was to blame. In 1976, managers tackled the problem by painting the cables to seal them off from the elements and installing fans to blow dry air through the length of the cables. Phoenix says that reduced the rate of wire breaks, but it's unclear how long those practices were maintained. Kerr says the fans weren't in use when he took over in 2007, nor was he aware of when the cables were last painted. "Someone may have dropped the ball," he says.

Lugo insists procedures were continued since UCF took over in 2018. "We were doing what was being done prior," he says. "It was not poorly maintained," Rankin agrees. "The Puerto Rico staff are incredible: They did every possible thing."

Natural disasters hastened the end, Lugo says. Hurricane Maria battered Puerto Rico in 2017. Phoenix says it was "an opportunity for trouble," because the storm's winds could have picked up seawater, whose salt makes it especially corrosive, and dumped some on the telescope. The observatory was also shaken by a series of earthquakes in December 2019 and January 2020.

Others say the NSF astronomy division's efforts to hand off the telescope didn't help. In 2006, the division convened an independent panel of astronomers for one of its "senior reviews" of existing facilities. To pay for planned new telescopes, such as the Atacama Large Millimetre/submillimetre Array in Chile and the Daniel K. Inouye Solar Telescope in Hawaii, economies were needed. Among other measures, the panel recommended closing Arecibo by 2011 unless partners were found to share operating costs. The astronomy division began to ramp down its roughly $10 million annual spending on Arecibo. NSF's atmospheric and geospace division increased its funding from $2 million to $4 million and NASA chipped in a few million dollars for tracking near-Earth asteroids. But Arecibo wasn't out of the woods.

Following an open competition, management of the observatory was transferred in 2011 from Cornell to a collaboration led by SRI International, a non-profit research institute. NSF's astronomy division still wanted more savings, however. In 2018, UCF stepped up to take over management, with support from Puerto Rico's Metropolitan University and the company Yang Enterprises, on the understanding that the astronomy division would gradually reduce its contribution to $2 million annually.

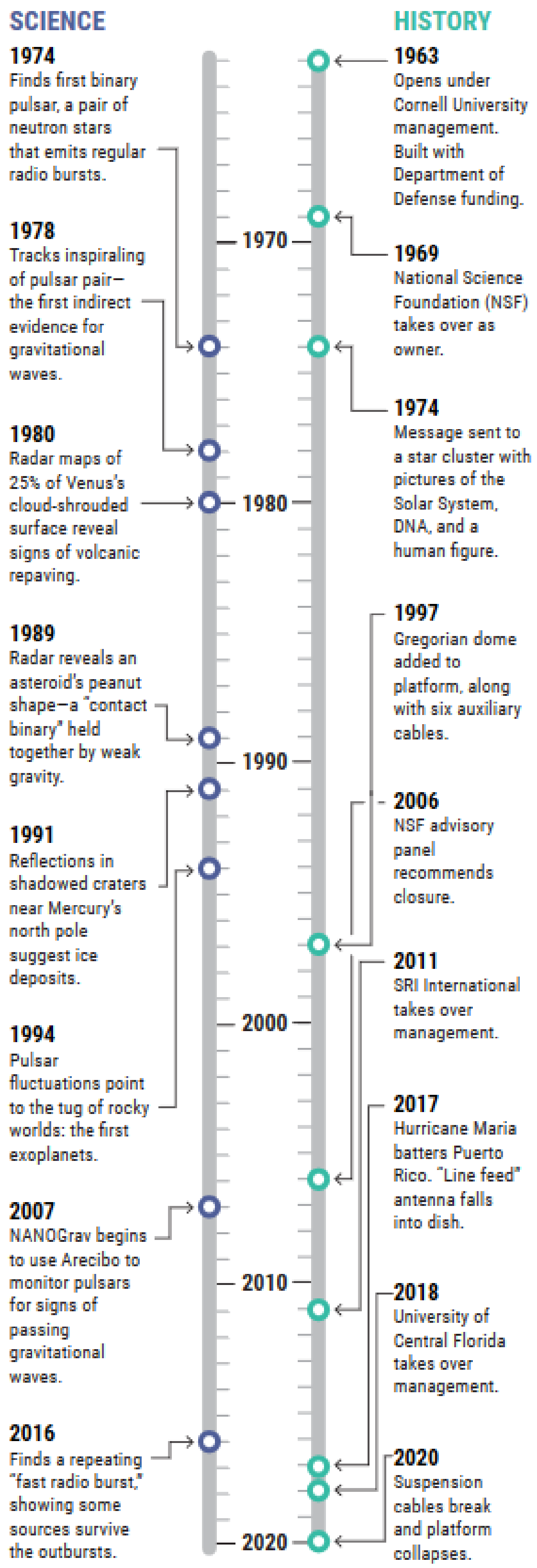
Two management changes in 7 years and the slow dwindling of funds took a toll, supporters say. “People would leave or retire when there are no raises. The best people would go elsewhere,” says planetary scientist Michael Nolan of the University of Arizona, who was Arecibo director from 2008 to 2011. And when old hands move on, something goes with them, Phoenix says. “Knowledge gets lost without that continuity.” In response to questions from *Science*, an NSF spokesperson says, “Funding from NSF covered scheduled maintenance for the facility and should not have negatively affected the observatory’s ability to maintain the 305-meter telescope.”

Although Kerr is convinced neglect was a factor, he believes the collapse had no single cause. “We drove that telescope hard. It’s an old piece of steel in the tropics, too heavy, it failed.” But he does think the 1997 upgrade, although scientifically valuable, was a mistake. “If it had not been upgraded, it would still be standing.”

After the shock of last month’s collapse wore off, observatory managers gave a group of staff and outside researchers 3 weeks to come up with a plan to replace the telescope. “We need something concrete to put in front of people,” Lugo says. “We want to develop a system that will be relevant for another 50 years.” The planners are aiming for a replacement that would surpass the capabilities of the original, be more flexible, and satisfy the needs of planetary and atmospheric scientists as well as astronomers. And they are trying to do that for less than $400 million—roughly the cost of making a Hollywood blockbuster.

Big dish, big science

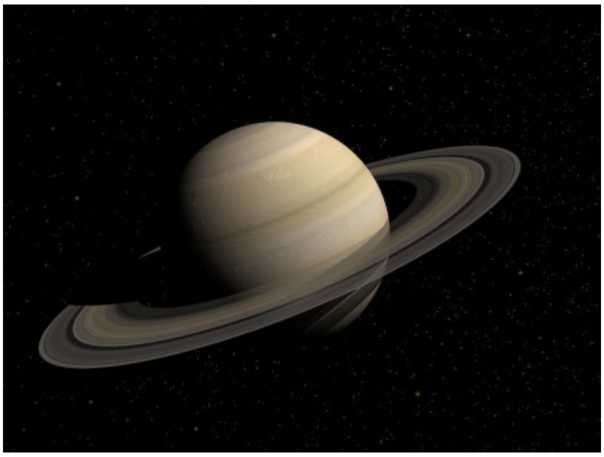
For most of its 57 years, the 305-meter-wide dish of the Arecibo Observatory was the largest in the world. Researchers used it to study Earth’s upper atmosphere, the rocks and planets of the Solar System, and more distant astrophysical objects. Here are some of its milestones.



M. ATAROD AND C. BICKEL/*SCIENCE*

- Saturn's tilt caused by its moons, researchers say

Date: January 21, 2021
Source: CNRS

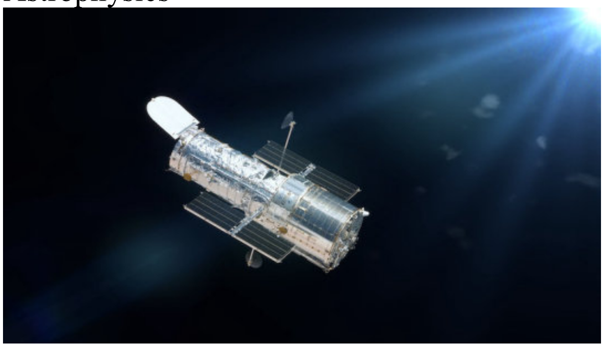


Saturn illustration (stock image).
Credit: © Dimitar Marinov / stock.adobe.com

Two scientists from CNRS and Sorbonne University working at the Institute of Celestial Mechanics and Ephemeris Calculation (Paris Observatory -- PSL/CNRS) have just shown that the influence of Saturn's satellites can explain the tilt of the rotation axis of the gas giant. Their work, published on 18 January 2021 in the journal *Nature Astronomy*, also predicts that the tilt will increase even further over the next few billion years.
Rather like David versus Goliath, it appears that Saturn's tilt may in fact be caused by its moons. This is the conclusion of recent work carried out by scientists from the CNRS, Sorbonne University and the University of Pisa, which shows that the current tilt of Saturn's rotation axis is caused by the migration of its satellites, and especially by that of its largest moon, Titan.
Recent observations have shown that Titan and the other moons are gradually moving away from Saturn much faster than astronomers had previously estimated. By incorporating this increased migration rate into their calculations, the researchers concluded that this process affects the inclination of Saturn's rotation axis: as its satellites move further away, the planet tilts more and more.
The decisive event that tilted Saturn is thought to have occurred relatively recently. For over three billion years after its formation, Saturn's rotation axis remained only slightly tilted. It was only roughly a billion years ago that the gradual motion of its satellites triggered a resonance phenomenon that continues today: Saturn's axis interacted with the path of the planet Neptune and gradually tilted until it reached the inclination of 27° observed today.
These findings call into question previous scenarios. Astronomers were already in agreement about the existence of this resonance. However, they believed that it had occurred very early on, over four billion years ago, due to a change in Neptune's orbit. Since that time, Saturn's axis was thought to have been stable. In fact, Saturn's axis is still tilting, and what we see today is merely a transitional stage in this shift. Over the next few billion years, the inclination of Saturn's axis could more than double.
The research team had already reached similar conclusions about the planet Jupiter, which is expected to undergo comparable tilting due to the migration of its four main moons and to resonance with the orbit of Uranus: over the next five billion years, the inclination of Jupiter's axis could increase from 3° to more than 30°.

- ❖ Astronomers discover first cloudless, Jupiter-like planet

This marks the second time astronomers have ever observed a cloud-free exoplanet
Date: January 22, 2021
Source: Harvard-Smithsonian Centre for Astrophysics



Hubble Space Telescope illustration (stock image).
Credit: © dottedyeti / stock.adobe.com

Astronomers at the Centre for Astrophysics | Harvard & Smithsonian have detected the first Jupiter-like planet without clouds or haze in its observable atmosphere. The findings were published this month in the *Astrophysical Journal Letters*.
Named WASP-62b, the gas giant was first detected in 2012 through the Wide-Angle Search for Planets (WASP) South survey. Its atmosphere, however, had never been closely studied until now.
"For my thesis, I have been working on exoplanet characterization," says Munazza Alam, a graduate student at the Centre for Astrophysics who led the study. "I take discovered planets and I follow up on them to characterize their atmospheres."
Known as a "hot Jupiter," WASP-62b is 575 light years away and about half the mass of our solar system's Jupiter. However, unlike

our Jupiter, which takes nearly 12 years to orbit the sun, WASP-62b completes a rotation around its star in just four-and-a-half days. This proximity to the star makes it extremely hot, hence the name "hot Jupiter."
Using the Hubble Space Telescope, Alam recorded data and observations of the planet using spectroscopy, the study of electromagnetic radiation to help detect chemical elements. Alam specifically monitored WASP-62b as it swept in front of its host star three times, making visible light observations, which can detect the presence of sodium and potassium in a planet's atmosphere.
"I'll admit that at first I wasn't too excited about this planet," Alam says. "But once I started to take a look at the data, I got excited."
While there was no evidence of potassium, sodium's presence was strikingly clear. The team was able to view the full sodium absorption lines in their data, or its complete fingerprint. Clouds or haze in the atmosphere would obscure the complete signature of sodium, Alam explains, and astronomers usually can only make out small hints of its presence.
"This is smoking gun evidence that we are seeing a clear atmosphere," she says.
Cloud-free planets are exceedingly rare; astronomers estimate that less than 7 percent of exoplanets have clear atmospheres, according to recent research. For example, the first and only other known exoplanet with a clear atmosphere was discovered in 2018. Named WASP-96b, it is classified as a hot Saturn.
Astronomers believe studying exoplanets with cloudless atmospheres can lead to a better understanding of how they were formed. Their rarity "suggests something else is going on or they formed in a different way than most planets," Alam says. Clear atmospheres also make it easier to study the chemical composition of planets, which can help identify what a planet is made of.
With the launch of the James Webb Space Telescope later this year, the team hopes to have new opportunities to study and better understand WASP-62b. The telescope's improved technologies, like higher resolution and better precision, should help them probe the atmosphere even closer to search for the presence of more elements, such as silicon.

- ❖ Testing the waters: Analysing different solid states of water on other planets and moons

Date: January 19, 2021
Source: Okayama University
Aside from regular ice, water can exist in the form of peculiar solids called clathrate hydrates, which trap small gaseous molecules. They play a large role in the evolution of atmospheres, but predicting their presence in cryogenic temperatures is difficult. In a recent study, scientists from Okayama University developed statistical mechanics theory to determine their presence in Pluto and some of Jupiter's and Saturn's satellites, providing valuable information to revise existing interpretations.
Just like on Earth, water on other planets, satellites, and even comets comes in a variety of forms depending on multiple factors such as pressure and temperature. Aside from the gaseous, liquid, and solid states we are accustomed to, water can form a different type of crystalline solid called clathrate hydrate. Although they look similar to ice, clathrate hydrates have actually small water-based cages in which smaller molecules are trapped. These trapped "guest" molecules are essential for preserving the crystalline structure of clathrate hydrates, which would otherwise "collapse" into regular ice or water.
Clathrate hydrates play a crucial role in the evolution of a planet or satellite's atmosphere; volatile gases such as methane are stored in these crystals and released slowly over geological timescales. Because of the enormous amounts of time required for clathrate hydrates to form and dissociate at cryogenic temperatures, it has proven very difficult to conduct experiments on Earth to predict their presence in other celestial bodies.
In a recent study published in *The Planetary Science Journal*, a team of scientists tackled this issue with a combination of both theory and experimental data. Lead scientist, Professor Hideki Tanaka from Okayama University, Japan, explains: "For many years, we have been developing rigorous statistical mechanics theory to estimate and predict the behaviour of clathrate hydrates. In this particular study, we focused on extending this theory to the cryogenic temperature range -- down to the 0 K limit."
A notable challenge was theoretically establishing the conditions for the formation and dissociation of clathrate hydrates under

thermodynamic equilibrium at extremely low temperatures. This was necessary to use the renowned model of water/hydrate/guest coexistence in clathrate hydrates proposed by van der Waals and Platteeuw in 1959. Tanaka, Yagasaki, and Matsumoto revised this theory to fit the cryogenic conditions that would be found outside Earth and corroborated its validity based on thermodynamic data gathered by space probes.

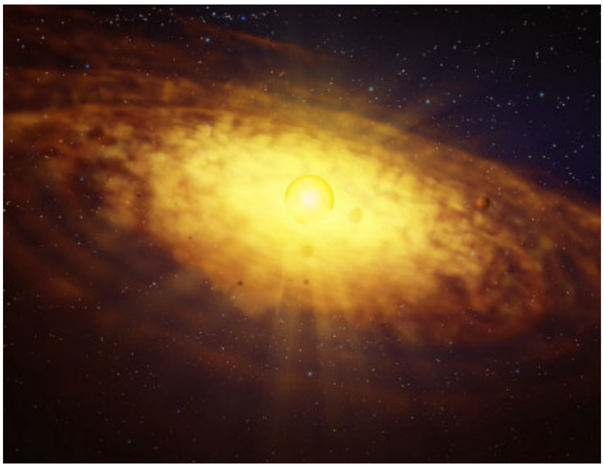
Then, the scientists used this new theory to analyse the states of water on Saturn's moon Titan, Jupiter's moons Europa and Ganymede, and Pluto. According to their model, there is a remarkable contrast in the stable forms of water found on these celestial bodies.

Whereas Europa and Ganymede contain only regular ice in contact with the thin atmosphere, all the water on the surface of Titan, and possibly Pluto, is in the form of clathrate hydrates. "It is remarkable," says Tanaka, "that one specific state of water appears exclusively in different satellite and planetary surfaces depending on temperature and pressure. In particular, the water in Titan seems to be completely in the form of methane-containing clathrate hydrates all the way up to the surface from the top of its subsurface ocean."

The extension of available theory on clathrate hydrates to cryogenic temperatures will let researchers corroborate and revise current interpretations on stable water forms in outer space and on celestial bodies. This information will be essential to understand the evolution of planetary atmospheres, unlocking another piece of the puzzle in our quest to understand the evolution of our planet and the rest of the universe.

- Much of Earth's nitrogen was locally sourced

Study shows two distinct origins of life-essential element in present-day planet
Date: January 21, 2021
Source: Rice University



Protoplanetary disk illustration (stock image).
Credit: © Mopic / stock.adobe.com

Where did Earth's nitrogen come from? Rice University scientists show one primordial source of the indispensable building block for life was close to home.

The isotopic signatures of nitrogen in iron meteorites reveal that Earth likely gathered its nitrogen not only from the region beyond Jupiter's orbit but also from the dust in the inner protoplanetary disk.

Nitrogen is a volatile element that, like carbon, hydrogen and oxygen, makes life on Earth possible. Knowing its source offers clues to not only how rocky planets formed in the inner part of our solar system but also the dynamics of far-flung protoplanetary disks.

The study by Rice graduate student and lead author Damanveer Grewal, Rice faculty member Rajdeep Dasgupta and geochemist Bernard Marty at the University of Lorraine, France, appears in *Nature Astronomy*.

Their work helps settle a prolonged debate over the origin of life-essential volatile elements in Earth and other rocky bodies in the solar system.

"Researchers have always thought that the inner part of the solar system, within Jupiter's orbit, was too hot for nitrogen and other volatile elements to condense as solids, meaning that volatile elements in the inner disk were in the gas phase," Grewal said.

Because the seeds of present-day rocky planets, also known as protoplanets, grew in the inner disk by accreting locally sourced dust, he said it appeared they did not contain nitrogen or other volatiles, necessitating their delivery from the outer solar system. An earlier study by the team suggested much of this volatile-rich material came to Earth via the collision that formed the moon.

But new evidence clearly shows only some of the planet's nitrogen came from beyond Jupiter.

In recent years, scientists have analysed non-volatile elements in meteorites, including iron meteorites that occasionally fall to Earth, to show dust in the inner and outer solar system had completely different isotopic compositions.

"This idea of separate reservoirs had only been developed for non-volatile elements," Grewal said. "We wanted to see if this is true for volatile elements as well. If so, it can be used to determine which reservoir the volatiles in present-day rocky planets came from."

Iron meteorites are remnants of the cores of protoplanets that formed at the same time as the seeds of present-day rocky planets, becoming the wild card the authors used to test their hypothesis.

The researchers found a distinct nitrogen isotopic signature in the dust that bathed the inner protoplanets within about 300,000 years of the formation of the solar system. All iron meteorites from the inner disk contained a lower concentration of the nitrogen-15 isotope, while those from the outer disk were rich in nitrogen-15.

This suggests that within the first few million years, the protoplanetary disk divided into two reservoirs, the outer rich in the nitrogen-15 isotope and the inner rich in nitrogen-14.

"Our work completely changes the current narrative," Grewal said. "We show that the volatile elements were present in the inner disk dust, probably in the form of refractory organics, from the very beginning. This means that contrary to current understanding, the seeds of the present-day rocky planets -- including Earth -- were not volatile-free."

Dasgupta said the finding is significant to those who study the potential habitability of exoplanets, a topic of great interest to him as principal investigator of CLEVER Planets, a NASA-funded collaborative project exploring how life-essential elements might come together on distant exoplanets.

"At least for our own planet, we now know the entire nitrogen budget does not come only from outer solar system materials," said Dasgupta, Rice's Maurice Ewing Professor of Earth, Environmental and Planetary Sciences.

"Even if other protoplanetary disks don't have the kind of giant planet migration resulting in the infiltration of volatile-rich materials from the outer zones, their inner rocky planets closer to the star could still acquire volatiles from their neighbouring zones," he said.

A NASA FINESST grant, a NASA Science Mission Directorate grant to support CLEVER Planets, the European Research Council, and the Lodieska Stockbridge Vaughan Fellowship at Rice supported the research.

- ❖ Exploring the solar wind with a new view of small sun structures

Date: January 19, 2021

Source: NASA/Goddard Space Flight Centre

Scientists have combined NASA data and cutting-edge image processing to gain new insight into the solar structures that create the Sun's flow of high-speed solar wind, detailed in new research published today in *The Astrophysical Journal.* This first look at relatively small features, dubbed "plumelets," could help scientists understand how and why disturbances form in the solar wind.

The Sun's magnetic influence stretches billions of miles, far past the orbit of Pluto and the planets, defined by a driving force: the solar wind. This constant outflow of solar material carries the Sun's magnetic field out into space, where it shapes the environments around Earth, other worlds, and in the reaches of deep space. Changes in the solar wind can create space weather effects that influence not only the planets, but also human and robotic explorers throughout the solar system -- and this work suggests that relatively small, previously-unexplored features close to the Sun's surface could play a crucial role in the solar wind's characteristics.

"This shows the importance of small-scale structures and processes on the Sun for understanding the large-scale solar wind and space weather system," said Vadim Uritsky, a solar scientist at the Catholic University of America and NASA's Goddard Space Flight Centre, who led the study.

Like all solar material, which is made up of a type of ionized gas called plasma, the solar wind is controlled by magnetic forces. And the magnetic forces in the Sun's atmosphere are particularly complex: The solar surface is threaded through with a constantly-changing combination of closed loops of magnetic field and open magnetic field lines that stretch out into the solar system.

It's along these open magnetic field lines that the solar wind escapes from the Sun into space. Areas of open magnetic field on the Sun can create coronal holes, patches of relatively low density that appear as dark splotches in certain ultraviolet views of the Sun. Often, embedded within these coronal holes are geysers of solar material that stream outward from the Sun for days at a time, called plumes. These solar plumes appear bright in extreme ultraviolet views of the Sun, making them easily visible to observatories like NASA's Solar Dynamics Observatory satellite and other spacecraft and instruments. As regions of particularly dense solar material in open magnetic field, plumes play a large role in creating the high-speed solar wind -- meaning that their attributes can shape the characteristics of the solar wind itself.

Using high-resolution observations from NASA's Solar Dynamics Observatory satellite, or SDO, along with an image processing technique developed for this work, Uritsky and collaborators found that these plumes are actually made up of much smaller strands of material, which they call plumelets. While the entirety of the plume stretches out across about 70,000 miles in SDO's images, the width of each plumelet strand is only a few thousand miles across, ranging from around 2,300 miles at the smallest to around 4,500 miles in width for the widest plumelets observed.

Though earlier work has hinted at structure within solar plumes, this is the first-time scientists have observed plumelets in sharp focus. The techniques used to process the images reduced the "noise" in the solar images, creating a sharper view that revealed the plumelets and their subtle changes in clear detail.

Their work, focused on a solar plume observed on July 2-3, 2016, shows that the plume's brightness comes almost entirely from the individual plumelets, without much additional fuzz between structures. This suggests that plumelets are more than just a feature within the larger system of a plume, but rather the building blocks of which plumes are made.

"People have seen structure in and at the base of plumes for a while," said Judy Karpen, one of the authors of the study and chief of the Space Weather Laboratory in the Heliophysics Science Division at NASA Goddard. "But we've found that the plume itself is a bundle of these denser, flowing plumelets, which is very different from the picture of plumes we had before."

They also found that the plumelets move individually, each oscillating on its own -- suggesting that the small-scale behaviour of these structures could be a major driver behind disruptions in the solar wind, in addition to their collective, large-scale behaviour.

Searching for plumelet signatures

The processes that create the solar wind often leave signatures in the solar wind itself -- changes in the wind's speed, composition, temperature, and magnetic field that can provide clues about the underlying physics on the Sun. Solar plumelets may also leave such fingerprints, revealing more about their exact role in the solar wind's creation, even though finding and interpreting them can be its own complex challenge.

One key source of data will be NASA's Parker Solar Probe, which has flown closer to the Sun than any other spacecraft -- reaching distances as close as 4 million miles from the solar surface by the end of its mission -- captures high-resolution measurements of the solar wind as it swings by the Sun every few months. Its observations, closer to the Sun and more detailed than those from prior missions, could reveal plumelet signatures.

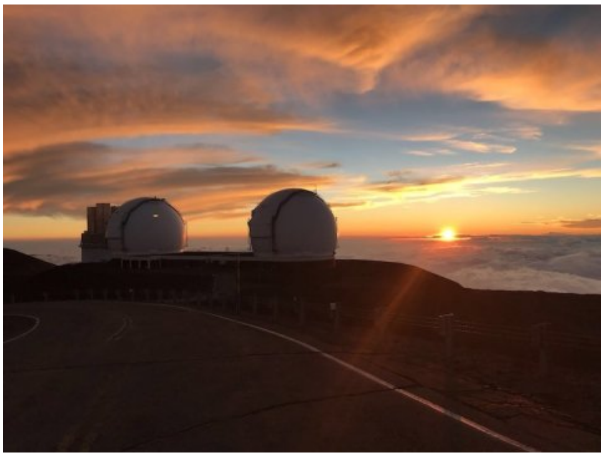
In fact, one of Parker Solar Probe's early and unexpected findings might be connected to plumelets. During its first solar flyby in November 2018, Parker Solar Probe observed sudden reversals in the magnetic field direction of the solar wind, nicknamed "switchbacks." The cause and the exact nature of the switchbacks is still a mystery to scientists, but small-scale structures like plumelets could produce similar signatures.

Finding signatures of the plumelets within the solar wind itself also depends on how well these fingerprints survive their journey away from the Sun -- or whether they would be smudged out somewhere along the millions of miles they travel from the Sun to our observatories in space.

Evaluating that question will rely on remote observatories, like ESA and NASA's Solar Orbiter, which has already taken the closest-ever images of the Sun, including a detailed view of the solar surface -- images that will only improve as the spacecraft gets closer to the Sun. NASA's upcoming PUNCH mission -- led by Craig DeForest, one of the authors on the plumelets study -- will study how the Sun's atmosphere transitions to the solar wind and could also provide answers to this question.

"PUNCH will directly observe how the Sun's atmosphere transitions to the solar wind," said Uritsky. "This will help us understand if the plumelets can survive as they propagate away from the Sun -- if can they actually be injected into the solar wind."

- A 'super-puff' planet like no other
  Date: January 18, 2021
  Source: University of Montreal



W. M. Keck Observatory in Hawaii (stock image).
Credit: © Daniel Gillies / stock.adobe.com

The core mass of the giant exoplanet WASP-107b is much lower than what was thought necessary to build up the immense gas envelope surrounding giant planets like Jupiter and Saturn, astronomers at Université de Montréal have found.

This intriguing discovery by Ph.D. student Caroline Piaulet of UdeM's Institute for Research on Exoplanets (iREx) suggests that gas-giant planets form a lot more easily than previously believed.

Piaulet is part of the ground-breaking research team of UdeM astrophysics professor Björn Benneke that in 2019 announced the first detection of water on an exoplanet located in its star's habitable zone.

Published today in the *Astronomical Journal* with colleagues in Canada, the U.S., Germany and Japan, the new analysis of WASP-107b's internal structure "has big implications," said Benneke.

"This work addresses the very foundations of how giant planets can form and grow," he said. "It provides concrete proof that massive accretion of a gas envelope can be triggered for cores that are much less massive than previously thought."

As big as Jupiter but 10 times lighter

WASP-107b was first detected in 2017 around WASP-107, a star about 212 light years from Earth in the Virgo constellation. The planet is very close to its star -- over 16 times closer than the Earth is to the Sun. As big as Jupiter but 10 times lighter, WASP-107b is one of the least dense exoplanets known: a type that astrophysicists have dubbed "super-puff" or "cotton-candy" planets.

Piaulet and her team first used observations of WASP-107b obtained at the Keck Observatory in Hawai'i to assess its mass more accurately. They used the radial velocity method, which allows scientists to determine a planet's mass by observing the wobbling motion of its host star due to the planet's gravitational pull. They concluded that the mass of WASP-107b is about one tenth that of Jupiter, or about 30 times that of Earth.

The team then did an analysis to determine the planet's most likely internal structure. They came to a surprising conclusion: with such a low density, the planet must have a solid core of no more than four times the mass of the Earth. This means that more than 85 percent of its mass is included in the thick layer of gas that surrounds this core. By comparison, Neptune, which has a similar mass to WASP-107b, only has 5 to 15 percent of its total mass in its gas layer.

"We had a lot of questions about WASP-107b," said Piaulet. "How could a planet of such low-density form? And how did it keep its huge layer of gas from escaping, especially given the planet's close proximity to its star? "This motivated us to do a thorough analysis to determine its formation history."

A gas giant in the making

Planets form in the disc of dust and gas that surrounds a young star called a protoplanetary disc. Classical models of gas-giant planet formation are based on Jupiter and Saturn. In these, a solid core at least 10 times more massive than the Earth is needed to accumulate a large amount of gas before the disc dissipates.

Without a massive core, gas-giant planets were not thought able to cross the critical threshold necessary to build up and retain their large gas envelopes.

How then do explain the existence of WASP-107b, which has a much less massive core? McGill University professor and iREx member Eve Lee, a world-renowned expert on super-puff planets like WASP-107b, has several hypotheses.

"For WASP-107b, the most plausible scenario is that the planet formed far away from the star, where the gas in the disc is cold enough that gas accretion can occur very quickly," she said. "The planet was later able to migrate to its current position, either through interactions with the disc or with other planets in the system."

Discovery of a second planet, WASP-107c

The Keck observations of the WASP-107 system cover a much longer period of time than previous studies have, allowing the UdeM-led research team to make an additional discovery: the existence of a second planet, WASP-107c, with a mass of about one-third that of Jupiter, considerably more than WASP-107b's.

WASP-107c is also much farther from the central star; it takes three years to complete one orbit around it, compared to only 5.7 days for WASP-107b. Also interesting: the eccentricity of this second planet is high, meaning its trajectory around its star is more oval than circular.

"WASP-107c has in some respects kept the memory of what happened in its system," said Piaulet. "Its great eccentricity hints at a rather chaotic past, with interactions between the planets which could have led to significant displacements, like the one suspected for WASP-107b."

Several more questions

Beyond its formation history, there are still many mysteries surrounding WASP-107b. Studies of the planet's atmosphere with the Hubble Space Telescope published in 2018 revealed one surprise: it contains very little methane.

"That's strange, because for this type of planet, methane should be abundant," said Piaulet. "We're now reanalysing Hubble's observations with the new mass of the planet to see how it will affect the results, and to examine what mechanisms might explain the destruction of methane."

The young researcher plans to continue studying WASP-107b, hopefully with the James Webb Space Telescope set to launch in 2021, which will provide a much more precise idea of the composition of the planet's atmosphere.

"Exoplanets like WASP-107b that have no analogue in our Solar System allow us to better understand the mechanisms of planet formation in general and the resulting variety of exoplanets," she said. "It motivates us to study them in great detail."

- ❖ Astronomers dissect the anatomy of planetary nebulae using Hubble Space Telescope images

Researchers shed new light on nebula formation processes

Date: January 19, 2021

Source: Rochester Institute of Technology

Images of two iconic planetary nebulae taken by the Hubble Space Telescope are revealing new information about how they develop their dramatic features. Researchers from Rochester Institute of Technology and Green Bank Observatory presented new findings about the Butterfly Nebula (NGC 6302) and the Jewel Bug Nebula (NGC 7027) at the 237th meeting of the American Astronomical Society on Friday, Jan. 15.

Hubble's Wide Field Camera 3 observed the nebulae in 2019 and early 2020 using its full, panchromatic capabilities, and the astronomers involved in the project have been using emission line images from near-ultraviolet to near-infrared light to learn more about their properties. The studies were first-of-their-kind panchromatic imaging surveys designed to understand the formation process and test models of binary-star-driven planetary nebula shaping.

"We're dissecting them," said Joel Kastner, a professor in RIT's Chester F. Carlson Centre for Imaging Science and School of Physics and Astronomy. "We're able to see the effect of the dying central star in how it's shedding and shredding its ejected material. We're able to see that material that the central star has tossed away is being dominated by ionized gas, where it's dominated by cooler dust, and even how the hot gas is being ionized, whether by the star's UV or by collisions caused by its present, fast winds."

Kastner said analysis of the new HST images of the Butterfly Nebula is confirming that the nebula was ejected only about 2,000 years ago -- an eyeblink by the standards of astronomy -- and that the S-shaped iron emission that helps give it the "wings" of gas may be even younger. Surprisingly, they found that while astronomers previously believed they had located the nebula's central star, it was actually a star not associated with the nebula that is much closer to Earth than the nebula. Kastner said he hopes that future studies with the James Webb Space Telescope could help locate the actual central star.

The team's ongoing analysis of the Jewel Bug Nebula is built on a 25-year baseline of measurements dating back to early Hubble imaging. Paula Moraga Baez, an astrophysical sciences and technology Ph.D. student from DeKalb, Ill., called the nebula "remarkable for its unusual juxtaposition of circularly symmetric, axisymmetric, and point-symmetric (bipolar) structures." Moraga noted, "The nebula also retains large masses of molecular gas and dust despite harbouring a hot central star and displaying high excitation states."

Jesse Bublitz '20 Ph.D. (astrophysical sciences and technology), now a postdoctoral researcher at Green Bank Observatory, has continued analysis of NGC 7027 with radio images from the Northern Extended Millimetre Array (NOEMA) Telescope, where he identified molecular tracers of ultraviolet and X-ray light that continue to shape the nebula. The combined observations from telescopes at other wavelengths, like Hubble, and bright molecules CO+ and HCO+ from NOEMA indicate how different regions of NGC 7027 are affected by the irradiation of its central star.

"We're very excited about these findings," said Bublitz. "We had hoped to find structure that clearly showed CO+ and HCO+ spatially coincident or entirely in distinctive regions, which we did. This is the first map of NGC 7027, or any planetary nebula, in the molecule CO+, and only the second CO+ map of any astronomical source."

In addition to Kastner, Moraga, and Bublitz, the research team involved in the HST imaging work includes Rodolfo Montez Jr. '10 Ph.D. (astrophysical sciences and technology) from Harvard-Smithsonian CfA; Bruce Balick from University of Washington; as well as Adam Frank and Eric Blackman from University of Rochester. Bublitz's international team of collaborators on radio molecular line imaging of NGC 7027 includes Kastner, Montez Jr., and astrophysicists from Spain, France, and Brazil.

- Researchers rewind the clock to calculate age and site of supernova blast

Light from supernova blast reached Earth 1,700 years ago

Date: January 15, 2021

Source: Space Telescope Science Institute

Astronomers are winding back the clock on the expanding remains of a nearby, exploded star. By using NASA's Hubble Space Telescope, they retraced the speedy shrapnel from the blast to calculate a more accurate estimate of the location and time of the stellar detonation.

The victim is a star that exploded long ago in the Small Magellanic Cloud, a satellite galaxy to our Milky Way. The doomed star left behind an expanding, gaseous corpse, a supernova remnant named 1E 0102.2-7219, which NASA's Einstein Observatory first discovered in X-rays. Like detectives, researchers sifted through archival images taken by Hubble, analysing visible-light observations made 10 years apart.

The research team, led by John Banovetz and Danny Milisavljevic of Purdue University in West Lafayette, Indiana, measured the velocities of 45 tadpole-shaped, oxygen-rich clumps of ejecta flung by the supernova blast. Ionized oxygen is an excellent tracer because it glows brightest in visible light.

To calculate an accurate explosion age, the astronomers picked the 22 fastest moving ejecta clumps, or knots. The researchers determined that these targets were the least likely to have been slowed down by passage through interstellar material. They then traced the knots' motion backward until the ejecta coalesced at one point, identifying the explosion site. Once that was known, they could calculate how long it took the speedy knots to travel from the explosion centre to their current location.

According to their estimate, light from the blast arrived at Earth 1,700 years ago, during the decline of the Roman Empire. However, the supernova would only have been visible to inhabitants of Earth's southern hemisphere. Unfortunately, there are no known records of this titanic event.

The researchers' results differ from previous observations of the supernova's blast site and age. Earlier studies, for example, arrived at explosion ages of 2,000 and 1,000 years ago. However, Banovetz and Milisavljevic say their analysis is more robust.

"A prior study compared images taken years apart with two different cameras on Hubble, the Wide Field Planetary Camera 2 and the Advanced Camera for Surveys (ACS)," Milisavljevic said. "But our study compares data taken with the same camera, the ACS, making the comparison much more robust; the knots were much easier to track using the same instrument. It's a testament to the longevity of Hubble that we could do such a clean comparison of images taken 10 years apart."

The astronomers also took advantage of the sharp ACS images in selecting which ejecta clumps to analyse. In prior studies, researchers averaged the speed of all of the gaseous debris to calculate an explosion age. However, the ACS data revealed regions where the ejecta slowed down because it was slamming into denser material shed by the star before it exploded as a supernova.

Researchers didn't include those knots in the sample. They needed the ejecta that best reflected their original velocities from the explosion, using them to determine an accurate age estimate of the supernova blast.

Hubble also clocked the speed of a suspected neutron star -- the crushed core of the doomed star -- that was ejected from the blast. Based on their estimates, the neutron star must be moving at more than 2 million miles per hour from the centre of the explosion to have arrived at its current position. The suspected neutron star was identified in observations with the European Southern Observatory's Very Large Telescope in Chile, in combination with data from NASA's Chandra X-ray Observatory.

"That is pretty fast and at the extreme end of how fast we think a neutron star can be moving, even if it got a kick from the supernova explosion," Banovetz said. "More recent investigations call into question whether the object is actually the surviving neutron star of the supernova explosion. It is potentially just a compact clump of supernova ejecta that has been lit up, and our results generally support this conclusion."

So the hunt may still be on for the neutron star. "Our study doesn't solve the mystery, but it gives an estimate of the velocity for the candidate neutron star," Banovetz said.

Banovetz will present the team's findings Jan. 14 at the American Astronomical Society's winter meeting.

The Hubble Space Telescope is a project of international cooperation between NASA and ESA (European Space Agency). NASA's Goddard Space Flight Centre in Greenbelt, Maryland, manages the telescope. The Space Telescope Science Institute (STScI) in Baltimore, Maryland, conducts Hubble science operations. STScI is operated for NASA by the Association of Universities for Research in Astronomy in Washington, D.C.

- ❖ X-Rays surrounding 'Magnificent 7' may be traces of sought-after particle

Researchers say they may have found proof of theorized axions, and possibly dark matter, around group of neutron stars

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Source: DOE/Lawrence Berkeley National Laboratory

A new study, led by a theoretical physicist at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), suggests that never-before-observed particles called axions may be the source of unexplained, high-energy X-ray emissions surrounding a group of neutron stars.

First theorized in the 1970s as part of a solution to a fundamental particle physics problem, axions are expected to be produced at the core of stars, and to convert into particles of light, called photons, in the presence of a magnetic field.

Axions may also make up dark matter -- the mysterious stuff that accounts for an estimated 85 percent of the total mass of the universe, yet we have so far only seen its gravitational effects on ordinary matter. Even if the X-ray excess turns out not to be axions or dark matter, it could still reveal new physics.

A collection of neutron stars, known as the Magnificent 7, provided an excellent test bed for the possible presence of axions, as these stars possess powerful magnetic fields, are relatively nearby -- within hundreds of light-years -- and were only expected to produce low-energy X-rays and ultraviolet light.

"They are known to be very 'boring,'" and in this case it's a good thing, said Benjamin Safdi, a Divisional Fellow in the Berkeley Lab Physics Division theory group who led a study, published Jan. 12 in the journal *Physical Review Letters*, detailing the axion explanation for the excess.

Christopher Dessert, a Berkeley Lab Physics Division affiliate, contributed heavily to the study, which also had participation by researchers at UC Berkeley, the University of Michigan, Princeton University, and the University of Minnesota.

If the neutron stars were of a type known as pulsars, they would have an active surface giving off radiation at different wavelengths. This radiation would show up across the electromagnetic spectrum, Safdi noted, and could drown out this X-ray signature that the researchers had found, or would produce

radio-frequency signals. But the Magnificent 7 are not pulsars, and no such radio signal was detected. Other common astrophysical explanations don't seem to hold up to the observations either, Safdi said.
If the X-ray excess detected around the Magnificent 7 is generated from an object or objects hiding out behind the neutron stars, that likely would have shown up in the datasets that researchers are using from two space satellites: the European Space Agency's XMM-Newton and NASA's Chandra X-ray telescopes.
Safdi and collaborators say it's still quite possible that a new, non-axion explanation arises to account for the observed X-ray excess, though they remain hopeful that such an explanation will lie outside of the Standard Model of particle physics, and that new ground- and space-based experiments will confirm the origin of the high-energy X-ray signal.
"We are pretty confident this excess exists, and very confident there's something new among this excess," Safdi said. "If we were 100% sure that what we are seeing is a new particle, that would be huge. That would be revolutionary in physics." Even if the discovery turns out not to be associated with a new particle or dark matter, he said, "It would tell us so much more about our universe, and there would be a lot to learn."
Raymond Co, a University of Minnesota postdoctoral researcher who collaborated in the study, said, "We're not claiming that we've made the discovery of the axion yet, but we're saying that the extra X-ray photons can be explained by axions. It is an exciting discovery of the excess in the X-ray photons, and it's an exciting possibility that's already consistent with our interpretation of axions."
If axions exist, they would be expected to behave much like neutrinos in a star, as both would have very slight masses and interact only very rarely and weakly with other matter. They could be produced in abundance in the interior of stars. Uncharged particles called neutrons move around within neutron stars, occasionally interacting by scattering off of one another and releasing a neutrino or possibly an axion. The neutrino-emitting process is the dominant way that neutron stars cool over time.
Like neutrinos, the axions would be able to travel outside of the star. The incredibly strong magnetic field surrounding the Magnificent 7 stars -- billions of times stronger than magnetic fields that can be produced on Earth -- could cause exiting axions to convert into light.
Neutron stars are incredibly exotic objects, and Safdi noted that a lot of modelling, data analysis, and theoretical work went into the latest study. Researchers have heavily used a bank of supercomputers known as the Lawrencium Cluster at Berkeley Lab in the latest work.
Some of this work had been conducted at the University of Michigan, where Safdi previously worked. "Without the high-performance supercomputing work at Michigan and Berkeley, none of this would have been possible," he said.
"There is a lot of data processing and data analysis that went into this. You have to model the interior of a neutron star in order to predict how many axions should be produced inside of that star."
Safdi noted that as a next step in this research, white dwarf stars would be a prime place to search for axions because they also have very strong magnetic fields, and are expected to be "X-ray-free environments."
"This starts to be pretty compelling that this is something beyond the Standard Model if we see an X-ray excess there, too," he said.
Researchers could also enlist another X-ray space telescope, called NuStar, to help solve the X-ray excess mystery.
Safdi said he is also excited about ground-based experiments such as CAST at CERN, which operates as a solar telescope to detect axions converted into X-rays by a strong magnet, and ALPS II in Germany, which would use a powerful magnetic field to cause axions to transform into particles of light on one side of a barrier as laser light strikes the other side of the barrier.
Axions have received more attention as a succession of experiments has failed to turn up signs of the WIMP (weakly interacting massive particle), another promising dark matter candidate. And the axion picture is not so straightforward -- it could actually be a family album.
There could be hundreds of axion-like particles, or ALPs, that make up dark matter, and string theory -- a candidate theory for describing the forces of the universe -- holds open the possible existence of many types of ALPs.