South Downs Mercury

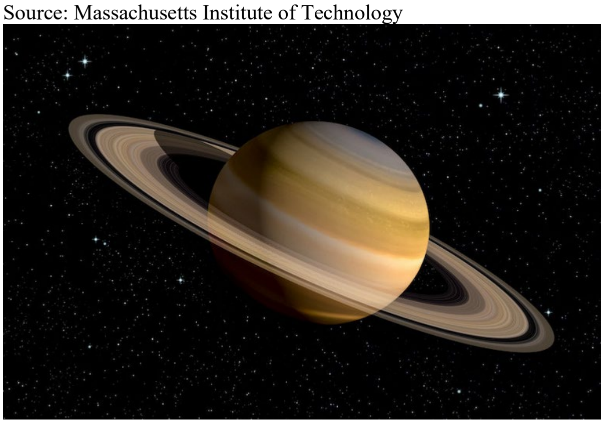
The monthly circular of South Downs Astronomical Society
Issue: 568 – October 7th 2022 Editor: Roger Burgess
Main Speaker Nicholas Evans Understanding Nothing
The meeting will also be available via Zoom

Lisa Lacey is standing down as Secretary by the end of August, we need a replacement to take over from her before she stands down

- Saturn's rings and tilt could be the product of an ancient, missing moon

A 'grazing encounter' may have smashed the moon to bits to form Saturn's rings, a new study suggests

Date: September 15, 2022
Source: Massachusetts Institute of Technology



Saturn illustration (stock image; elements furnished by NASA).
Credit: © Matthieu / stock.adobe.com

Swirling around the planet's equator, the rings of Saturn are a dead giveaway that the planet is spinning at a tilt. The belted giant rotates at a 26.7-degree angle relative to the plane in which it orbits the sun. Astronomers have long suspected that this tilt comes from gravitational interactions with its neighbour Neptune, as Saturn's tilt processes, like a spinning top, at nearly the same rate as the orbit of Neptune.

But a new modelling study by astronomers at MIT and elsewhere has found that, while the two planets may have once been in sync, Saturn has since escaped Neptune's pull. What was responsible for this planetary realignment? The team has one meticulously tested hypothesis: a missing moon.

In a study appearing in *Science*, the team proposes that Saturn, which today hosts 83 moons, once harboured at least one more, an extra satellite that they name Chrysalis. Together with its siblings, the researchers suggest, Chrysalis orbited Saturn for several billion years, pulling and tugging on the planet in a way that kept its tilt, or "obliquity," in resonance with Neptune.

But around 160 million years ago, the team estimates, Chrysalis became unstable and came too close to its planet in a grazing encounter that pulled the satellite apart. The loss of the moon was enough to remove Saturn from Neptune's grasp and leave it with the present-day tilt.

What's more, the researchers surmise, while most of Chrysalis' shattered body may have made impact with Saturn, a fraction of its fragments could have remained suspended in orbit, eventually breaking into small icy chunks to form the planet's signature rings.

The missing satellite, therefore, could explain two longstanding mysteries: Saturn's present-day tilt and the age of its rings, which were previously estimated to be about 100 million years old -- much younger than the planet itself.

"Just like a butterfly's chrysalis, this satellite was long dormant and suddenly became active, and the rings emerged," says Jack Wisdom, professor of planetary sciences at MIT and lead author of the new study.

The study's co-authors include Rola Dbouk at MIT, Burkhard Militzer of the University of California at Berkeley, William Hubbard at the University of Arizona, Francis Nimmo and Brynna Downey of the University of California at Santa Cruz, and Richard French of Wellesley College.

A moment of progress

In the early 2000s, scientists put forward the idea that Saturn's tilted axis is a result of the planet being trapped in a resonance, or gravitational association, with Neptune. But observations taken by NASA's Cassini spacecraft, which orbited Saturn from 2004 to 2017, put a new twist on the problem. Scientists found that Titan, Saturn's largest satellite, was migrating away from Saturn at a faster clip than expected, at a rate of about 11 centimetres per year. Titan's fast migration, and its gravitational pull, led scientists to conclude that the moon was likely responsible for tilting and keeping Saturn in resonance with Neptune.

But this explanation hinges on one major unknown: Saturn's moment of inertia, which is how mass is distributed in the planet's interior. Saturn's tilt could behave differently, depending on whether matter is more concentrated at its core or toward the surface.

"To make progress on the problem, we had to determine the moment of inertia of Saturn," Wisdom says.

The lost element

In their new study, Wisdom and his colleagues looked to pin down Saturn's moment of inertia using some of the last observations taken by Cassini in its "Grand Finale," a phase of the mission during which the spacecraft made an extremely close approach to precisely map the gravitational field around the entire planet. The gravitational field can be used to determine the distribution of mass in the planet.

Wisdom and his colleagues modelled the interior of Saturn and identified a distribution of mass that matched the gravitational field that Cassini observed. Surprisingly, they found that this newly identified moment of inertia placed Saturn close to, but just outside the resonance with Neptune. The planets may have once been in sync, but are no longer.

"Then we went hunting for ways of getting Saturn out of Neptune's resonance," Wisdom says.

The team first carried out simulations to evolve the orbital dynamics of Saturn and its moons backward in time, to see whether any natural instabilities among the existing satellites could have influenced the planet's tilt. This search came up empty.

So, the researchers re-examined the mathematical equations that describe a planet's precession, which is how a planet's axis of rotation changes over time. One term in this equation has contributions from all the satellites. The team reasoned that if one satellite were removed from this sum, it could affect the planet's precession.

The question was, how massive would that satellite have to be, and what dynamics would it have to undergo to take Saturn out of Neptune's resonance?

Wisdom and his colleagues ran simulations to determine the properties of a satellite, such as its mass and orbital radius, and the orbital dynamics that would be required to knock Saturn out of the resonance.

They conclude that Saturn's present tilt is the result of the resonance with Neptune and that the loss of the satellite, Chrysalis, which was about the size of Iapetus, Saturn's third-largest moon, allowed it to escape the resonance.

Sometime between 200 and 100 million years ago, Chrysalis entered a chaotic orbital zone, experienced a number of close encounters with Iapetus and Titan, and eventually came too close to Saturn, in a grazing encounter that ripped the satellite to bits, leaving a small fraction to circle the planet as a debris-strewn ring.

The loss of Chrysalis, they found, explains Saturn's precession, and its present-day tilt, as well as the late formation of its rings.

"It's a pretty good story, but like any other result, it will have to be examined by others," Wisdom says. "But it seems that this lost satellite was just a chrysalis, waiting to have its instability."

This research was supported, in part, by NASA and the National Science Foundation.

- It's a planet: New evidence of baby planet in the making

Date: September 14, 2022

Source: Harvard-Smithsonian Centre for Astrophysics

Artist's illustration of a "baby" planet forming in a protoplanetary disk. (Image credit: Centre for Astrophysics | Harvard & Smithsonian)

Astronomers agree that planets are born in protoplanetary disks -- rings of dust and gas that surround young, new-born stars. While hundreds of these disks have been spotted throughout the universe, observations of actual planetary birth and formation have proved difficult within these environments.

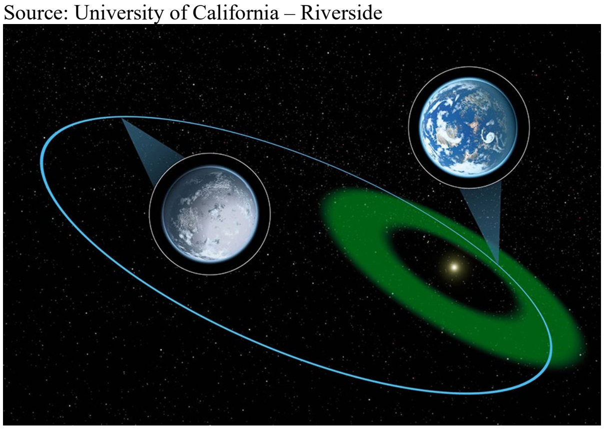
Now, astronomers at the Centre for Astrophysics | Harvard & Smithsonian have developed a new way to detect these elusive new-born planets -- and with it, "smoking gun" evidence of a small Neptune or Saturn-like planet lurking in a disk. The results are described today in *The Astrophysical Journal Letters*.

"Directly detecting young planets is very challenging and has so far only been successful in one or two cases," says Feng Long, a postdoctoral fellow at the Centre for Astrophysics who led the new study. "The planets are always too faint for us to see because they're embedded in thick layers of gas and dust."
Scientists instead must hunt for clues to infer a planet is developing beneath the dust.
"In the past few years, we've seen many structures pop up on disks that we think are caused by a planet's presence, but it could be caused by something else, too" Long says. "We need new techniques to look at and support that a planet is there."
For her study, Long decided to re-examine a protoplanetary disk known as LkCa 15. Located 518 light years away, the disk sits in the Taurus constellation on the sky. Scientists previously reported evidence for planet formation in the disk using observations with the ALMA Observatory.
Long dove into new high-resolution ALMA data on LkCa 15, obtained primarily in 2019, and discovered two faint features that had not previously been detected.
About 42 astronomical units out from the star -- or 42 times the distance Earth is from the Sun -- Long discovered a dusty ring with two separate and bright bunches of material orbiting within it. The material took the shape of a small clump and a larger arc, and were separated by 120 degrees.
Long examined the scenario with computer models to figure out what was causing the build-up of material and learned that their size and locations matched the model for the presence of a planet.
"This arc and clump are separated by about 120 degrees," she says. "That degree of separation doesn't just happen -- it's important mathematically."
Long points to positions in space known as Lagrange points, where two bodies in motion -- such as a star and orbiting planet -- produce enhanced regions of attraction around them where matter may accumulate.
"We're seeing that this material is not just floating around freely, it's stable and has a preference where it wants to be located based on physics and the objects involved," Long explains.
In this case, the arc and clump of material Long detected are located at the L_4 and L_5 Lagrange points. Hidden 60 degrees between them is a small planet causing the accumulation of dust at points L_4 and L_5.
The results show the planet is roughly the size of Neptune or Saturn, and around one to three million years old. (That's relatively young when it comes to planets.)
Directly imaging the small, new-born planet may not be possible any time soon due to technology constraints, but Long believes further ALMA observations of LkCa 15 can provide additional evidence supporting her planetary discovery.
She also hopes her new approach for detecting planets -- with material preferentially accumulating at Lagrange points -- will be utilized in the future by astronomers.
"I do hope this method can be widely adopted in the future," she says. "The only caveat is that this requires very deep data as the signal is weak."
Long recently completed her postdoctoral fellowship at the Centre for Astrophysics and will join the University of Arizona as a NASA Hubble Fellow this September.
Co-authors on the study are Sean Andrews, Chunhua Qi, David Wilner and Karin Oberg of the CfA; Shangjia Zhang and Zhaohuan Zhu of the University of Nevada; Myriam Benisty of the University of Grenoble; Stefano Facchini of the University of Milan; Andrea Isella of Rice University; Jaehan Bae of the University of Florida; Jane Huang of the University of Michigan and Ryan Loomis of the National Radio Astronomy Observatory.
The team used high resolution ALMA observations taken with Band 6 (1.3mm) and Band 7 (0.88mm) receivers.

- Could more of Earth's surface host life?

Jupiter's orbit shape plays key, overlooked role on Earth

Date: September 9, 2022
Source: University of California – Riverside



A habitable zone, shown in green here, is defined as the region around a star where liquid water, an essential ingredient for life as we know it, could potentially be present. Image courtesy: NASA/JPL-Caltech.

Of all known planets, Earth is as friendly to life as any planet could possibly be -- or is it? If Jupiter's orbit changes, a new study shows Earth could be more hospitable than it is today.

When a planet has a perfectly circular orbit around its star, the distance between the star and the planet never changes. Most planets, however, have "eccentric" orbits around their stars, meaning the orbit is oval-shaped. When the planet gets closer to its star, it receives more heat, affecting the climate.

Using detailed models based on data from the solar system as it is known today, UC Riverside researchers created an alternative solar system. In this theoretical system, they found that if gigantic Jupiter's orbit were to become more eccentric, it would in turn induce big changes in the shape of Earth's orbit.

"If Jupiter's position remained the same, but the shape of its orbit changed, it could actually increase this planet's habitability," said Pam Vervoort, UCR Earth and planetary scientist and lead study author.

Between zero and 100 degrees Celsius, the Earth's surface is habitable for multiple known life forms. If Jupiter pushed Earth's orbit to become more eccentric, parts of the Earth would sometimes get closer to the sun. Parts of the Earth's surface that are now sub-freezing would get warmer, increasing temperatures in the habitable range.

This result, now published in the *Astronomical Journal*, upends two long-held scientific assumptions about our solar system.

"Many are convinced that Earth is the epitome of a habitable planet and that any change in Jupiter's orbit, being the massive planet it is, could only be bad for Earth," Vervoort said. "We show that both assumptions are wrong."

The researchers are interested in applying this finding to the search for habitable planets around other stars, called exoplanets.

"The first thing people look for in an exoplanet search is the habitable zone, the distance between a star and a planet to see if there's enough energy for liquid water on the planet's surface," said Stephen Kane, UCR astrophysicist and study co-author.

During its orbit, different parts of a planet receive more or fewer direct rays, resulting in the planet having seasons. Parts of the planet may be pleasant during one season, and extremely hot or cold in another.

"Having water on its surface a very simple first metric, and it doesn't account for the shape of a planet's orbit, or seasonal variations a planet might experience," Kane said.

Existing telescopes are capable of measuring a planet's orbit. However, there are additional factors that could affect habitability, such as the degree to which a planet is tilted toward or away from a star. The part of the planet tilted away from the star would get less energy, causing it to be colder.

This same study found that if Jupiter were positioned much closer to the sun, it would induce extreme tilting on Earth, which would make large sections of the Earth's surface sub-freezing.

It is more difficult to measure tilt, or a planet's mass, so the researchers would like to work toward methods that help them estimate those factors as well.

Ultimately, the movement of a giant planet is important in the quest to make predictions about the habitability of planets in other systems as well as the quest to understand its influence in this solar system.

"It's important to understand the impact that Jupiter has had on Earth's climate through time, how its effect on our orbit has changed us in the past, and how it might change us once again in the future," Kane said.

- Astronomers detect hot gas bubble swirling around the Milky Way's supermassive black hole

Date: September 22, 2022
Source: ESO

Using the Atacama Large Millimetre/submillimetre Array (ALMA), astronomers have spotted signs of a 'hot spot' orbiting Sagittarius A*, the black hole at the centre of our galaxy. The finding helps us better understand the enigmatic and dynamic environment of our supermassive black hole.

"We think we're looking at a hot bubble of gas zipping around Sagittarius A* on an orbit similar in size to that of the planet Mercury, but making a full loop in just around 70 minutes. This requires a mind blowing velocity of about 30% of the speed of light!" says Maciek Wielgus of the Max Planck Institute for Radio Astronomy in Bonn, Germany, who led the study published today in *Astronomy & Astrophysics*.

The observations were made with ALMA in the Chilean Andes -- a radio telescope co-owned by the European Southern Observatory (ESO) -- during a campaign by the Event Horizon Telescope (EHT) Collaboration to image black holes. In April 2017 the EHT linked together eight existing radio telescopes worldwide, including ALMA, resulting in the recently released first ever image of Sagittarius A*. To calibrate the EHT data, Wielgus and his colleagues, who are members of the EHT Collaboration, used ALMA data recorded simultaneously with the EHT observations of Sagittarius A*. To the team's surprise, there were more clues to the nature of the black hole hidden in the ALMA-only measurements.

By chance, some of the observations were done shortly after a burst or flare of X-ray energy was emitted from the centre of our galaxy, which was spotted by NASA's Chandra Space Telescope. These kinds of flares, previously observed with X-ray and infrared telescopes, are thought to be associated with so-called 'hot spots', hot gas bubbles that orbit very fast and close to the black hole.

"What is really new and interesting is that such flares were so far only clearly present in X-ray and infrared observations of Sagittarius A*. Here we see for the first time a very strong indication that orbiting hot spots are also present in radio observations," says Wielgus, who is also affiliated with the Nicolaus Copernicus Astronomical Centre, Poland and the Black Hole Initiative at Harvard University, USA.

"Perhaps these hot spots detected at infrared wavelengths are a manifestation of the same physical phenomenon: as infrared-emitting hot spots cool down, they become visible at longer wavelengths, like the ones observed by ALMA and the EHT," adds Jesse Vos, a PhD student at Radboud University, the Netherlands, who was also involved in this study.

The flares were long thought to originate from magnetic interactions in the very hot gas orbiting very close to Sagittarius A*, and the new findings support this idea. "Now we find strong evidence for a magnetic origin of these flares and our observations give us a clue about the geometry of the process. The new data are extremely helpful for building a theoretical interpretation of these events," says co-author Monika Mo?cibrodzka from Radboud University.

ALMA allows astronomers to study polarised radio emission from Sagittarius A*, which can be used to unveil the black hole's magnetic field. The team used these observations together with theoretical models to learn more about the formation of the hot spot and the environment it is embedded in, including the magnetic field around Sagittarius A*. Their research provides stronger constraints on the shape of this magnetic field than previous observations, helping astronomers uncover the nature of our black hole and its surroundings.

The observations confirm some of the previous discoveries made by the GRAVITY instrument at ESO's Very Large Telescope (VLT), which observes in the infrared. The data from GRAVITY and ALMA both suggest the flare originates in a clump of gas swirling around the black hole at about 30% of the speed of light in a clockwise direction in the sky, with the orbit of the hot spot being nearly face-on.

"In the future we should be able to track hot spots across frequencies using coordinated multiwavelength observations with both GRAVITY and ALMA -- the success of such an endeavour would be a true milestone for our understanding of the physics of flares in the Galactic centre," says Ivan Marti-Vidal of the University of València in Spain, co-author of the study.

The team is also hoping to be able to directly observe the orbiting gas clumps with the EHT, to probe ever closer to the black hole and learn more about it. "*Hopefully, one day, we will be comfortable saying that we 'know' what is going on in Sagittarius A**," Wielgus concludes.

More information

This research was presented in the paper "Orbital motion near Sagittarius A* -- Constraints from polarimetric ALMA observations" to appear in *Astronomy & Astrophysics*.

The team is composed of M. Wielgus (Max-Planck-Institut für Radioastronomie, Germany [MPIfR]; Nicolaus Copernicus Astronomical Centre, Polish Academy of Sciences, Poland;

Black Hole Initiative at Harvard University, USA [BHI]), M. Moscibrodzka (Department of Astrophysics, Radboud University, The Netherlands [Radboud]), J. Vos (Radboud), Z. Gelles (Centre for Astrophysics | Harvard & Smithsonian, USA and BHI), I. Martí-Vidal (Universitat de València, Spain), J. Farah (Las Cumbres Observatory, USA; University of California, Santa Barbara, USA), N. Marchili (Italian ALMA Regional Centre, INAF-Istituto di Radioastronomia, Italy and MPIfR), C. Goddi (Dipartimento di Fisica, Università degli Studi di Cagliari, Italy and Universidade de São Paulo, Brazil), and H. Messias (Joint ALMA Observatory, Chile).

The Atacama Large Millimetre/submillimetre Array (ALMA), an international astronomy facility, is a partnership of ESO, the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile. ALMA is funded by ESO on behalf of its Member States, by NSF in cooperation with the National Research Council of Canada (NRC) and the Ministry of Science and Technology (MOST) and by NINS in cooperation with the Academia Sinica (AS) in Taiwan and the Korea Astronomy and Space Science Institute (KASI). ALMA construction and operations are led by ESO on behalf of its Member States; by the National Radio Astronomy Observatory (NRAO), managed by Associated Universities, Inc. (AUI), on behalf of North America; and by the National Astronomical Observatory of Japan (NAOJ) on behalf of East Asia. The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.

The European Southern Observatory (ESO) enables scientists worldwide to discover the secrets of the Universe for the benefit of all. We design, build and operate world-class observatories on the ground -- which astronomers use to tackle exciting questions and spread the fascination of astronomy -- and promote international collaboration in astronomy. Established as an intergovernmental organisation in 1962, today ESO is supported by 16 Member States (Austria, Belgium, the Czech Republic, Denmark, France, Finland, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland and the United Kingdom), along with the host state of Chile and with Australia as a Strategic Partner. ESO's headquarters and its visitor centre and planetarium, the ESO Supernova, are located close to Munich in Germany, while the Chilean Atacama Desert, a marvellous place with unique conditions to observe the sky, hosts our telescopes. ESO operates three observing sites: La Silla, Paranal and Chajnantor. At Paranal, ESO operates the Very Large Telescope and its Very Large Telescope Interferometer, as well as two survey telescopes, VISTA working in the infrared and the visible-light VLT Survey Telescope. Also at Paranal ESO will host and operate the Cherenkov Telescope Array South, the world's largest and most sensitive gamma-ray observatory. Together with international partners, ESO operates APEX and ALMA on Chajnantor, two facilities that observe the skies in the millimetre and submillimetre range. At Cerro Armazones, near Paranal, we are building "the world's biggest eye on the sky" -- ESO's Extremely Large Telescope. From our offices in Santiago, Chile we support our operations in the country and engage with Chilean partners and society.

- Newly formed craters located on Mars

These craters hold interesting clues about the planet's atmosphere and interior, including how it formed and evolved over time

Date: September 21, 2022
Source: University of Maryland

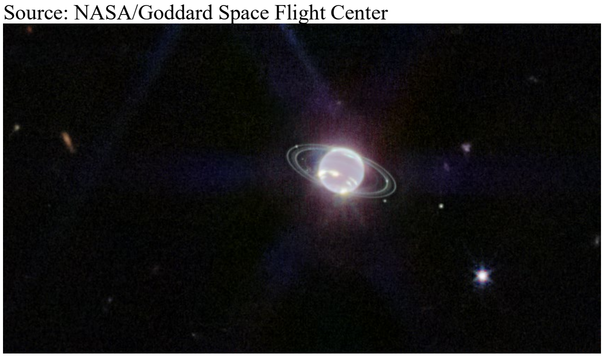
A Hubble space telescope image of Mars. Photograph: Nasa/ESA/PA

An international team of researchers with NASA's InSight mission located four new craters created by impacts on the surface of Mars. Using data from a seismometer and visuals acquired from the Mars Reconnaissance Orbiter, the team successfully calculated and confirmed the impact locations. This is the first time that researchers have been able to capture the dynamics of an impact on Mars. The researchers' discoveries were published

September 19, 2022 in the journal *Nature Geoscience.*
"Meteoroids and other projectiles in space can change the atmosphere and surface of any planet through impact," said University of Maryland Geology Associate Professor Nicholas Schmerr, a co-author of the paper. "We've seen this on Earth, where these objects can hurtle through the atmosphere, hit the ground and leave behind a crater. But before this, we've never been able to capture the dynamics of an impact on Mars, where there's a much thinner atmosphere."
As space projectiles enter the planetary atmosphere and impact the ground, the projectiles trigger acoustic waves (sound waves that travel through fluid or gas) and seismic waves (waves that travel through a solid medium). Schmerr and his InSight colleagues used these waves, measured by the SEIS (Seismic Experiment for Interior Structure) instrument on InSight, to estimate the approximate locations of resulting impact sites, observing the unique physics that dictated the projectiles' movements. The team then matched their approximations to visuals provided by high-resolution cameras, confirming the sites and accuracy of the team's modelling.
These findings demonstrate how planetary seismology (the study of quakes and related events like volcanic eruptions) can be used to identify sources of seismic activity.
According to Schmerr, this ability may help researchers measure how often new impacts occur in the inner solar system, where both Mars and Earth reside -- an observation essential to understanding the population of near-Earth objects like asteroids or rock fragments that may pose a danger to Earth.
Additionally, using images to determine the precise location of these impacts makes their associated acoustic and seismic waves invaluable for studying the Martian atmosphere and interior. With a better understanding of mars quake locations, scientists will be able to gather essential information about the planet, such as the size and solidity of its core or its heating processes. Geophysicists like Schmerr anticipate that new advances in planetary seismology will allow them to better investigate underlying tectonic activities and other sources of seismic activity within Mars.
The findings ultimately bring researchers another step closer to understanding planetary formation and evolution.
"Studying how impacts work on Mars is like opening a window into the fundamental processes of how terrestrial planets form," Schmerr said. "All inner solar system planets share this commonality, including Earth."
NASA's InSight is a robotic lander designed to study the interior structure of Mars. Active since 2018, the lander is expected to continue the InSight mission until its ability to gather solar power is fully depleted.
Video: https://youtu.be/sRfOL-9tUn8

- New Webb image captures clearest view of Neptune's rings in decades

Date: September 21, 2022
Source: NASA/Goddard Space Flight Center



What do we see in Webb's latest image of the ice giant Neptune? Webb captured seven of Neptune's 14 known moons: Galatea, Naiad, Thalassa, Despina, Proteus, Larissa, and Triton. Neptune's large and unusual moon,
Credits: NASA, ESA, CSA, STScI

NASA's James Webb Space Telescope shows off its capabilities closer to home with its first image of Neptune. Not only has Webb captured the clearest view of this distant planet's rings in more than 30 years, but its cameras reveal the ice giant in a whole new light.
Most striking in Webb's new image is the crisp view of the planet's rings -- some of which have not been detected since NASA's Voyager 2 became the first spacecraft to observe Neptune during its flyby in 1989. In addition to several bright, narrow rings, the Webb image clearly shows Neptune's fainter dust bands.
"It has been three decades since we last saw these faint, dusty rings, and this is the first time we've seen them in the infrared," notes Heidi Hammel, a Neptune system expert and interdisciplinary scientist for Webb. Webb's extremely stable and precise image quality permits these very faint rings to be detected so close to Neptune.

Neptune has fascinated researchers since its discovery in 1846. Located 30 times farther from the Sun than Earth, Neptune orbits in the remote, dark region of the outer solar system. At that extreme distance, the Sun is so small and faint that high noon on Neptune is similar to a dim twilight on Earth.

This planet is characterized as an ice giant due to the chemical make-up of its interior. Compared to the gas giants, Jupiter and Saturn, Neptune is much richer in elements heavier than hydrogen and helium. This is readily apparent in Neptune's signature blue appearance in Hubble Space Telescope images at visible wavelengths, caused by small amounts of gaseous methane.

Webb's Near-Infrared Camera (NIRCam) images objects in the near-infrared range from 0.6 to 5 microns, so Neptune does not appear blue to Webb. In fact, the methane gas so strongly absorbs red and infrared light that the planet is quite dark at these near-infrared wavelengths, except where high-altitude clouds are present. Such methane-ice clouds are prominent as bright streaks and spots, which reflect sunlight before it is absorbed by methane gas. Images from other observatories, including the Hubble Space Telescope and the W.M. Keck Observatory, have recorded these rapidly evolving cloud features over the years.

More subtly, a thin line of brightness circling the planet's equator could be a visual signature of global atmospheric circulation that powers Neptune's winds and storms. The atmosphere descends and warms at the equator, and thus glows at infrared wavelengths more than the surrounding, cooler gases.

Neptune's 164-year orbit means its northern pole, at the top of this image, is just out of view for astronomers, but the Webb images hint at an intriguing brightness in that area. A previously-known vortex at the southern pole is evident in Webb's view, but for the first time Webb has revealed a continuous band of high-latitude clouds surrounding it.

Webb also captured seven of Neptune's 14 known moons. Dominating this Webb portrait of Neptune is a very bright point of light sporting the signature diffraction spikes seen in many of Webb's images, but this is not a star. Rather, this is Neptune's large and unusual moon, Triton.

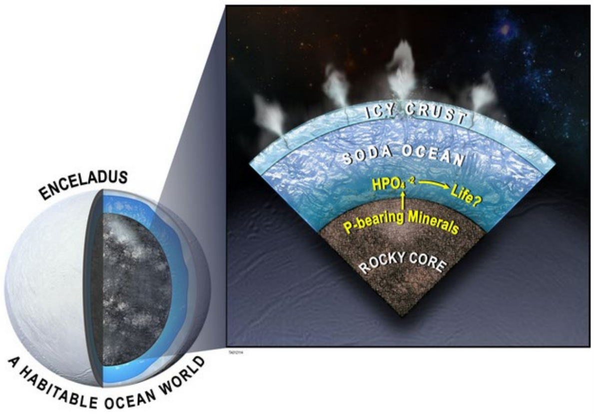
Covered in a frozen sheen of condensed nitrogen, Triton reflects an average of 70 percent of the sunlight that hits it. It far outshines Neptune in this image because the planet's atmosphere is darkened by methane absorption at these near-infrared wavelengths. Triton orbits Neptune in an unusual backward (retrograde) orbit, leading astronomers to speculate that this moon was originally a Kuiper belt object that was gravitationally captured by Neptune. Additional Webb studies of both Triton and Neptune are planned in the coming year.

The James Webb Space Telescope is the world's premier space science observatory. Webb will solve mysteries in our solar system, look beyond to distant worlds around other stars, and probe the mysterious structures and origins of our universe and our place in it. Webb is an international program led by NASA with its partners, ESA (European Space Agency) and the Canadian Space Agency.

- ❖ Scientist helps identify new evidence for habitability in Enceladus's ocean

Saturn moon's subsurface ocean is likely rich in phosphorus, a key component for life

Date: September 19, 2022
Source: Southwest Research Institute



The search for extra-terrestrial life just got more interesting as a team of scientists including Southwest Research Institute's Dr. Christopher Glein has discovered new evidence for a key building block for life in the subsurface ocean of Saturn's moon Enceladus. New modelling indicates that Enceladus's ocean should be relatively rich in dissolved phosphorus, an essential ingredient for life.

"Enceladus is one of the prime targets in humanity's search for life in our solar system," said Glein, a leading expert in extra-terrestrial oceanography. He is a co-author of a paper in the *Proceedings of the National Academy of Sciences* (*PNAS*) describing this research. "In the years since NASA's Cassini spacecraft visited the Saturn system, we have been

repeatedly blown away by the discoveries made possible by the collected data."
The Cassini spacecraft discovered Enceladus's subsurface liquid water and analysed samples as plumes of ice grains and water vapor erupted into space from cracks in the moon's icy surface.
"What we have learned is that the plume contains almost all the basic requirements of life as we know it," Glein said. "While the bio essential element phosphorus has yet to be identified directly, our team discovered evidence for its availability in the ocean beneath the moon's icy crust."
One of the most profound discoveries in planetary science over the past 25 years is that worlds with oceans beneath a surface layer of ice are common in our solar system. Such worlds include the icy satellites of the giant planets, such as Europa, Titan and Enceladus, as well as more distant bodies like Pluto. Worlds like Earth with surface oceans must reside within a narrow range of distances from their host stars to maintain the temperatures that support surface liquid water. Interior water ocean worlds, however, can occur over a much wider range of distances, greatly expanding the number of habitable worlds likely to exist across the galaxy.
"The quest for extra-terrestrial habitability in the solar system has shifted focus, as we now look for the building blocks for life, including organic molecules, ammonia, sulphur-bearing compounds as well as the chemical energy needed to support life," Glein said.
"Phosphorus presents an interesting case because previous work suggested that it might be scarce in the ocean of Enceladus, which would dim the prospects for life."
Phosphorus in the form of phosphates is vital for all life on Earth. It is essential for the creation of DNA and RNA, energy-carrying molecules, cell membranes, bones and teeth in people and animals, and even the sea's microbiome of plankton.
Team members performed thermodynamic and kinetic modelling that simulates the geochemistry of phosphorus based on insights from Cassini about the ocean-seafloor system on Enceladus. In the course of their research, they developed the most detailed geochemical model to date of how seafloor minerals dissolve into Enceladus's ocean and predicted that phosphate minerals would be unusually soluble there.
"The underlying geochemistry has an elegant simplicity that makes the presence of dissolved phosphorus inevitable, reaching levels close to or even higher than those in modern Earth seawater," Glein said. "What this means for astrobiology is that we can be more confident than before that the ocean of Enceladus is habitable."
According to Glein, the next step is clear: "We need to get back to Enceladus to see if a habitable ocean is actually inhabited."

- Geologist proposes the number of ancient Martian lakes might have been dramatically underestimated by scientists

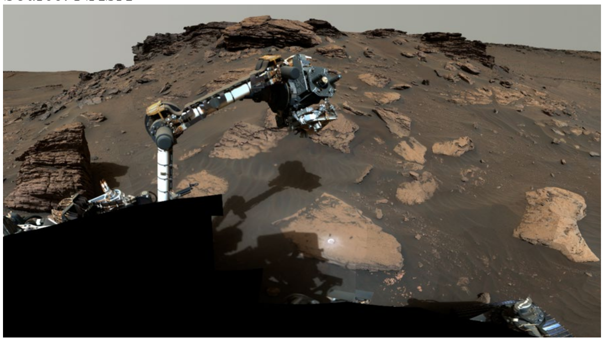
Date: September 19, 2022
Source: The University of Hong Kong

Lakes are bodies of water fed by rainfall, snowmelt, rivers and groundwater, through which, Earth is teeming with life. Lakes also contain critical geologic records of past climates. Though Mars is a frozen desert today, scientists have shown that Mars contains evidence of ancient lakes that existed billions of years ago, which could contain evidence for ancient life and climate conditions on the red planet. Through a meta-analysis of years of satellite data that shows evidence for lakes on Mars, Dr Joseph Michalski, a geologist in the Department of Earth Sciences, The University of Hong Kong (HKU) proposed that scientists might have dramatically underestimated the number of ancient Martian lakes that once existed. Michalski and the international team recently published their results in *Nature Astronomy*, which describe a global analysis of ancient Martian lakes. "We know of approximately 500 ancient lakes deposited on Mars, but nearly all the lakes we know about are larger than 100 km^2," explains Michalski. "But on Earth, 70% of the lakes are smaller than this size, occurring in cold environments where glaciers have retreated. These small-sized lakes are difficult to identify on Mars by satellite remote sensing, but many small lakes probably did exist. It is likely that at least

70% of Martian lakes have yet to be discovered." Scientists monitor these small lakes on Earth in order to understand climate change. The missing small lakes on Mars might also contain critical information about past climates.
The recent paper also reports that most known Martian lakes date to a period 3,500 to 4,000 million years ago, but each of the lakes might have lasted only a geologically short time (10,000 to 100,000 years) during this time span. This means that ancient Mars was probably mostly cold and dry as well, but it warmed episodically for short periods of time. Michalski adds, "Because of the lower gravity on Mars and the pervasive, fine-grained soil, lakes on Mars would have been very murky and might not have allowed light to penetrate very deeply, which could present a challenge to photosynthetic life, if it existed."
Lakes contain water, nutrients and energy sources for possible microbial life, including light for photosynthesis. Therefore, lakes are the top targets for Astro biological exploration by Mars Rovers such as NASA's Perseverance rover now on Mars. But Michalski warns, "Not all lakes are created equal. In other words, some Martian lakes would be more interesting for microbial life than others because some of the lakes were large, deep, long-lived and had a wide range of environments such as hydrothermal systems that could have been conducive to the formation of simple life." From this point of view, it might make sense to target large, ancient, environmentally diverse lakes for future exploration.
"Earth is host to many environments that can serve as analogues to other planets. From the harsh terrain of Svalbard to the depths of Mono Lake -- we can determine how to design tools for detecting life elsewhere right here at home. Most of those tools are aimed at detecting the remains and residues of microbial life," said Dr David BAKER, an ecologist at HKU School of Biological Sciences who is well-informed about the Earth's microbial systems in lakes.
China successfully landed its first lander, Zhurong, on Mars in May this year. Zhurong is currently roving the plains of Utopia Planitia, exploring mineralogical and chemical clues to recent climate change. China is also planning a sample return mission likely to occur at the end of this decade, which could target one of the interesting lake deposits.
Dr Joseph Michalski is an Associate Professor in the Department of Earth Sciences and Deputy Director of the Laboratory for Space Research at HKU. He worked with colleagues from Canada, USA, and the UK on the research, which is funded by the Research Grants Council in Hong Kong.

- NASA's Perseverance rover investigates geologically rich Mars terrain

Date: September 16, 2022
Source: NASA



NASA’s Perseverance rover puts its robotic arm to work around a rocky outcrop called “Skinner Ridge” in Mars’ Jezero Crater. Composed of multiple images, this mosaic shows layered sedimentary rocks in the face of a cliff in the delta, as well as one of the locations where the rover abraded a circular patch to analyse a rock’s composition.
Credits: NASA/JPL-Caltech/ASU/MSSS

NASA's Perseverance rover is well into its second science campaign, collecting rock-core samples from features within an area long considered by scientists to be a top prospect for finding signs of ancient microbial life on Mars. The rover has collected four samples from an ancient river delta in the Red Planet's Jezero Crater since July 7, bringing the total count of scientifically compelling rock samples to 12.
"We picked the Jezero Crater for Perseverance to explore because we thought it had the best chance of providing scientifically excellent samples -- and now we know we sent the rover to the right location," said Thomas Zurbuchen, NASA's associate administrator for science in Washington. "These first two science campaigns have yielded an amazing diversity of samples to bring back to Earth by the Mars Sample Return campaign."
Twenty-eight miles (45 kilometres) wide, Jezero Crater hosts a delta -- an ancient fan-shaped feature that formed about 3.5 billion years ago at the convergence of a Martian river and a lake. Perseverance is currently

investigating the delta's sedimentary rocks, formed when particles of various sizes settled in the once-watery environment. During its first science campaign, the rover explored the crater's floor, finding igneous rock, which forms deep underground from magma or during volcanic activity at the surface.
"The delta, with its diverse sedimentary rocks, contrasts beautifully with the igneous rocks -- formed from crystallization of magma -- discovered on the crater floor," said Perseverance project scientist Ken Farley of Caltech in Pasadena, California. "This juxtaposition provides us with a rich understanding of the geologic history after the crater formed and a diverse sample suite. For example, we found a sandstone that carries grains and rock fragments created far from Jezero Crater -- and a mudstone that includes intriguing organic compounds."
"Wildcat Ridge" is the name given to a rock about 3 feet (1 meter) wide that likely formed billions of years ago as mud and fine sand settled in an evaporating saltwater lake. On July 20, the rover abraded some of the surface of Wildcat Ridge so it could analyse the area with the instrument called Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals, or SHERLOC. SHERLOC's analysis indicates the samples feature a class of organic molecules that are spatially correlated with those of sulphate minerals. Sulphate minerals found in layers of sedimentary rock can yield significant information about the aqueous environments in which they formed.

What Is Organic Matter?

Organic molecules consist of a wide variety of compounds made primarily of carbon and usually include hydrogen and oxygen atoms. They can also contain other elements, such as nitrogen, phosphorus, and sulphur. While there are chemical processes that produce these molecules that don't require life, some of these compounds are the chemical building blocks of life. The presence of these specific molecules is considered to be a potential biosignature -- a substance or structure that could be evidence of past life but may also have been produced without the presence of life.
In 2013, NASA's Curiosity Mars rover found evidence of organic matter in rock-powder samples, and Perseverance has detected organics in Jezero Crater before. But unlike that previous discovery, this latest detection was made in an area where, in the distant past, sediment and salts were deposited into a lake under conditions in which life could potentially have existed. In its analysis of Wildcat Ridge, the SHERLOC instrument registered the most abundant organic detections on the mission to date.
"In the distant past, the sand, mud, and salts that now make up the Wildcat Ridge sample were deposited under conditions where life could potentially have thrived," said Farley. "The fact the organic matter was found in such a sedimentary rock -- known for preserving fossils of ancient life here on Earth -- is important. However, as capable as our instruments aboard Perseverance are, further conclusions regarding what is contained in the Wildcat Ridge sample will have to wait until it's returned to Earth for in-depth study as part of the agency's Mars Sample Return campaign."
The first step in the NASA-ESA (European Space Agency) Mars Sample Return campaign began when Perseverance cored its first rock sample in September 2021. Along with its rock-core samples, the rover has collected one atmospheric sample and two witness tubes, all of which are stored in the rover's belly.
The geologic diversity of the samples already carried in the rover is so good that the rover team is looking into depositing select tubes near the base of the delta in about two months. After depositing the cache, the rover will continue its delta explorations.
"I've studied Martian habitability and geology for much of my career and know first-hand the incredible scientific value of returning a carefully collected set of Mars rocks to Earth," said Laurie Leshin, director of NASA's Jet Propulsion Laboratory in Southern California. "That we are weeks from deploying Perseverance's fascinating samples and mere years from bringing them to Earth so scientists can study them in exquisite detail is truly phenomenal. We will learn so much."

More About the Mission

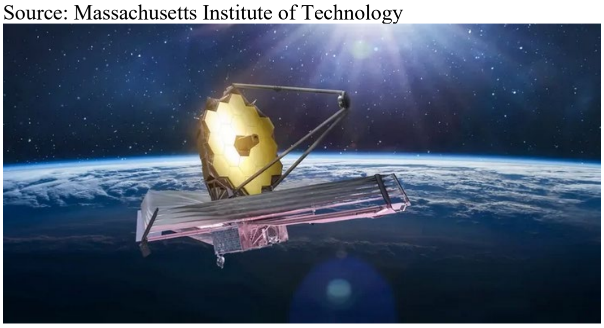
A key objective for Perseverance's mission on Mars is astrobiology, including caching samples that may contain signs of ancient microbial life. The rover will characterize the planet's geology and past climate, pave the way for human exploration of the Red Planet, and be the first mission to collect and cache Martian rock and regolith.

Subsequent NASA missions, in cooperation with ESA, would send spacecraft to Mars to collect these sealed samples from the surface and return them to Earth for in-depth analysis.
The Mars 2020 Perseverance mission is part of NASA's Moon to Mars exploration approach, which includes Artemis missions to the Moon that will help prepare for human exploration of the Red Planet.
JPL, which is managed for NASA by Caltech, built and manages operations of the Perseverance rover.
For more about Perseverance:
https://mars.nasa.gov/mars2020/

- ❖ Astronomer’s risk misinterpreting planetary signals in James Webb data

Refining current opacity models will be key to unearthing details of exoplanet properties -- and signs of life -- in data from the powerful new telescope

Date: September 15, 2022
Source: Massachusetts Institute of Technology



NASA's James Webb Space Telescope is revealing the universe with spectacular, unprecedented clarity. The observatory's ultrasharp infrared vision has cut through the cosmic dust to illuminate some of the earliest structures in the universe, along with previously obscured stellar nurseries and spinning galaxies lying hundreds of millions of light years away.
In addition to seeing farther into the universe than ever before, Webb will capture the most comprehensive view of objects in our own galaxy -- namely, some of the 5,000 planets that have been discovered in the Milky Way. Astronomers are harnessing the telescope's light-parsing precision to decode the atmospheres surrounding some of these nearby worlds. The properties of their atmospheres could give clues to how a planet formed and whether it harbours signs of life.
But a new MIT study suggests that the tools astronomers typically use to decode light-based signals may not be good enough to accurately interpret the new telescope's data. Specifically, opacity models -- the tools that model how light interacts with matter as a function of the matter's properties -- may need significant retuning in order to match the precision of Webb's data, the researchers say.
If these models are not refined? The researchers predict that properties of planetary atmospheres, such as their temperature, pressure, and elemental composition, could be off by an order of magnitude.
"There is a scientifically significant difference between a compound like water being present at 5 percent versus 25 percent, which current models cannot differentiate," says study co-leader Julien de Wit, assistant professor in MIT's Department of Earth, Atmospheric, and Planetary Sciences (EAPS).
"Currently, the model we use to decrypt spectral information is not up to par with the precision and quality of data we have from the James Webb telescope," adds EAPS graduate student Prajwal Niraula. "We need to up our game and tackle together the opacity problem."
De Wit, Niraula, and their colleagues have published their study in *Nature Astronomy*. Co-authors include spectroscopy experts Iouli Gordon, Robert Hargreaves, Clara Sousa-Silva, and Roman Kochanov of the Harvard-Smithsonian Center for Astrophysics.

Levelling up

Opacity is a measure of how easily photons pass through a material. Photons of certain wavelengths can pass straight through a material, be absorbed, or be reflected back out depending on whether and how they interact with certain molecules within a material. This interaction also depends on a material's temperature and pressure.
An opacity model works on the basis of various assumptions of how light interacts with matter. Astronomers use opacity models to derive certain properties of a material, given the spectrum of light that the material emits. In the context of exoplanets, an opacity model can decode the type and abundance of chemicals in a planet's atmosphere, based on the light from the planet that a telescope captures.
De Wit says that the current state-of-the-art opacity model, which he likens to a classical language translation tool, has done a decent job of decoding spectral data taken by instruments such as those on the Hubble Space Telescope.
"So far, this Rosetta Stone has been doing OK," de Wit says. "But now that we're going

to the next level with Webb's precision, our translation process will prevent us from catching important subtleties, such as those making the difference between a planet being habitable or not."

Light, perturbed

He and his colleagues make this point in their study, in which they put the most commonly used opacity model to the test. The team looked to see what atmospheric properties the model would derive if it were tweaked to assume certain limitations in our understanding of how light and matter interact. The researchers created eight such "perturbed" models. They then fed each model, including the real version, "synthetic spectra" -- patterns of light that were simulated by the group and similar to the precision that the James Webb telescope would see.

They found that, based on the same light spectra, each perturbed model produced wide-ranging predictions for the properties of a planet's atmosphere. Based on their analysis, the team concludes that, if existing opacity models are applied to light spectra taken by the Webb telescope, they will hit an "accuracy wall." That is, they won't be sensitive enough to tell whether a planet has an atmospheric temperature of 300 Kelvin or 600 Kelvin, or whether a certain gas takes up 5 percent or 25 percent of an atmospheric layer.

"That difference matters in order for us to constrain planetary formation mechanisms and reliably identify biosignatures," Niraula says.

The team also found that every model also produced a "good fit" with the data, meaning, even though a perturbed model produced a chemical composition that the researchers knew to be incorrect, it also generated a light spectrum from that chemical composition that was close enough to, or "fit" with the original spectrum.

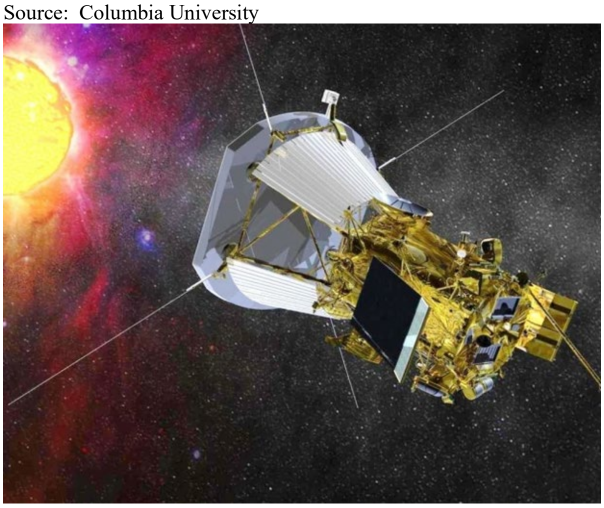
"We found that there are enough parameters to tweak, even with a wrong model, to still get a good fit, meaning you wouldn't know that your model is wrong and what it's telling you is wrong," de Wit explains.

He and his colleagues raise some ideas for how to improve existing opacity models, including the need for more laboratory measurements and theoretical calculations to refine the models' assumptions of how light and various molecules interact, as well as collaborations across disciplines, and in particular, between astronomy and spectroscopy.

"There is so much that could be done if we knew perfectly how light and matter interact," Niraula says. "We know that well enough around the Earth's conditions, but as soon as we move to different types of atmospheres, things change, and that's a lot of data, with increasing quality, that we risk misinterpreting."

- Where do high-energy particles that endanger satellites, astronauts and airplanes come from?

Date: September 13, 2022
Source: Columbia University



NASA Parker Solar Probe Plus named to honor Pioneering Physicist Eugene Parker. The Johns Hopkins University Applied Physics Lab.

For decades, scientists have been trying to solve a vexing problem about the weather in outer space: At unpredictable times, high-energy particles bombard the earth and objects outside the earth's atmosphere with radiation that can endanger the lives of astronauts and destroy satellites' electronic equipment. These flare-ups can even trigger showers of radiation strong enough to reach passengers in airplanes flying over the North Pole. Despite scientists' best efforts, a clear pattern of how and when flare-ups will occur has remained enduringly difficult to identify.

This week, in a paper in *The Astrophysical Journal Letters*, authors Luca Comisso and Lorenzo Sironi of Columbia's Department of Astronomy and the Astrophysics Laboratory, have for the first time used supercomputers to simulate when and how high-energy particles are born in turbulent environments like that on the atmosphere of the sun. This new research

paves the way for more accurate predictions of when dangerous bursts of these particles will occur.
"This exciting new research will allow us to better predict the origin of solar energetic particles and improve forecasting models of space weather events, a key goal of NASA and other space agencies and governments around the globe," Comisso said. Within the next couple of years, he added, NASA's Parker Solar Probe, the closest spacecraft to the sun, may be able to validate the paper's findings by directly observing the predicted distribution of high-energy particles that are generated in the sun's outer atmosphere.
In their paper, "Ion and Electron Acceleration in Fully Kinetic Plasma Turbulence," Comisso and Sironi demonstrate that magnetic fields in the outer atmosphere of the sun can accelerate ions and electrons up to velocities close to the speed of light. The sun and other stars' outer atmosphere consist of particles in a plasma state, a highly turbulent state distinct from liquid, gas, and solid states. Scientists have long believed that the sun's plasma generates high-energy particles. But particles in plasma move so erratically and unpredictably that they have until now not been able to fully demonstrate how and when this occurs.
Using supercomputers at Columbia, NASA, and the National Energy Research Scientific Computing Center, Comisso and Sironi created computer simulations that show the exact movements of electrons and ions in the sun's plasma. These simulations mimic the atmospheric conditions on the sun, and provide the most extensive data gathered to-date on how and when high-energy particles will form.
The research provides answers to questions that scientists have been investigating for at least 70 years: In 1949, the physicist Enrico Fermi began to investigate magnetic fields in outer space as a potential source of the high-energy particles (which he called cosmic rays) that were observed entering the earth's atmosphere. Since then, scientists have suspected that the sun's plasma is a major source of these particles, but definitively proving it has been difficult.
Comisso and Sironi's research, which was conducted with support from NASA and the National Science Foundation, has implications far beyond our own solar system. The vast majority of the observable matter in the universe is in a plasma state. Understanding how some of the particles that constitute plasma can be accelerated to high-energy levels is an important new research area since energetic particles are routinely observed not just around the sun but also in other environments across the universe, including the surroundings of black holes and neutron stars.
While Comisso and Sironi's new paper focuses on the sun, further simulations could be run in other contexts to understand how and when distant stars, black holes, and other entities in the universe will generate their own bursts of energy.
"Our results centre on the sun but can also be seen as a starting point to better understanding how high-energy particles are produced in more distant stars and around black holes," Comisso said. "We've only scratched the surface of what supercomputer simulations can tell us about how these particles are born across the universe."

- Astronomy: Is over-eating to blame for bulges in Milky Way bar?

Date: September 9, 2022
Source: National Institutes of Natural Sciences

A new simulation conducted on the world's most powerful supercomputer dedicated to astronomy has produced a testable scenario to explain the appearance of the bar of the Milky Way. Comparing this scenario to data from current and future space telescopes will help clarify the evolution of our home Galaxy.
Astronomy is revealing the structure of the Milky Way Galaxy in which we live in increasing detail. We know that it is a disk galaxy, with two- or four- armed spirals, with a straight bar in the middle connecting the spirals. Now, we also know that the inner part of the bar has a "peanut-shaped bulge," places where the bar is thicker, sticking out above and below the mid plane of the Milky Way Galaxy and a "nuclear bulge," which is disky and located in the central part of the Milky

Way. Some other galaxies, but not all, exhibit similar two-type bulges.

Like dieters who suddenly find bulges sticking out, astronomers asked the question, "How did the two-type bulges form?" To answer this question a team led by Junichi Baba at the National Astronomical Observatory of Japan (NAOJ) simulated one possible scenario for a Milky-Way-like galaxy on "ATERUI II" at NAOJ, the world's most powerful supercomputer dedicated to astronomy. The team's simulation is the most complete and accurate to date, including not only the stars in the galaxy, but also the gas. It also incorporates the birth of new stars from the gas and the deaths of stars as supernovae.

The formation of a bar helps to channel gas into the central part of the galaxy, where it triggers the formation of new stars. So it might be reasonable to assume that the nuclear bugle in the galaxy is created from new stars born there. But the simulations show that there are almost no new stars in the bar outside the nuclear bulge, because the bar is so effective at channelling gas towards the centre. This means that pigging-out on gas is not the reason that a peanut-shaped bulge develops in the bar. Instead, the team finds that gravitational interactions can drive some of the stars into orbits which take them above and below the mid plane.

The most exciting part is that the simulation provides a testable scenario. Because the peanut-shaped bulge acquires no new stars, all of its stars must predate the formation of the bar. At the same time, the bar channels gas to the central region where it creates many new stars. So almost all of the stars in the nuclear bulge will have been born after the bar formed. This means that the stars in the peanut-shaped bulge will be older than the stars in the nuclear bulge, with a clear break between the ages. This break corresponds to the time when the bar formed.

Data from the European Space Agency's Gaia probe and Japan's future JASMINE satellite will allow us to determine the motions and ages of the stars and test this scenario. If astronomers can detect a difference between the ages of the stars in peanut-shaped and nuclear bulges, it will not only prove that overeating is not to blame for the peanut-shaped bulge, it will tell us the age of the bar in the Milky Way Galaxy.

Video: https://youtu.be/Shucn3HIlow

- ❖ Physicists invoke the cosmological collider to explain why matter, and not antimatter, dominates the universe

Date: September 8, 2022
Source: University of California – Riverside

Early in its history, shortly after the Big Bang, the universe was filled with equal amounts of matter and "antimatter" -- particles that are matter counterparts but with opposite charge. But then, as space expanded, the universe cooled. Today's universe is full of galaxies and stars which are made of matter. Where did the antimatter go, and how did matter come to dominate the universe? This cosmic origin of matter continues to puzzle scientists.

Physicists at the University of California, Riverside, and Tsinghua University in China have now opened a new pathway for probing the cosmic origin of matter by invoking the "cosmological collider."

Not just any collider

High energy colliders, such as the Large Hadron Collider, have been built to produce very heavy subatomic elementary particles that may reveal new physics. But some new physics, such as that explaining dark matter and the origin of matter, can involve much heavier particles, requiring much higher energy than what a human-made collider can provide. It turns out the early cosmos could have served as such a super-collider.

Yanou Cui, an associate professor of physics and astronomy at UCR, explained that it is widely believed that cosmic inflation, an era when the universe expanded at an exponentially accelerating rate, preceded the Big Bang.

"Cosmic inflation provided a highly energetic environment, enabling the production of heavy new particles as well as their interactions," Cui said. "The inflationary universe behaved just like a cosmological collider, except that the energy was up to 10 billion times larger than any human-made collider."

According to Cui, microscopic structures created by energetic events during inflation got stretched as the universe expanded, resulting in regions of varying density in an otherwise homogeneous universe. Subsequently, these microscopic structures seeded the large-scale structure of our universe, manifested today as the distribution of galaxies across the sky. Cui explained that new subatomic particle physics may be revealed by studying the imprint of the

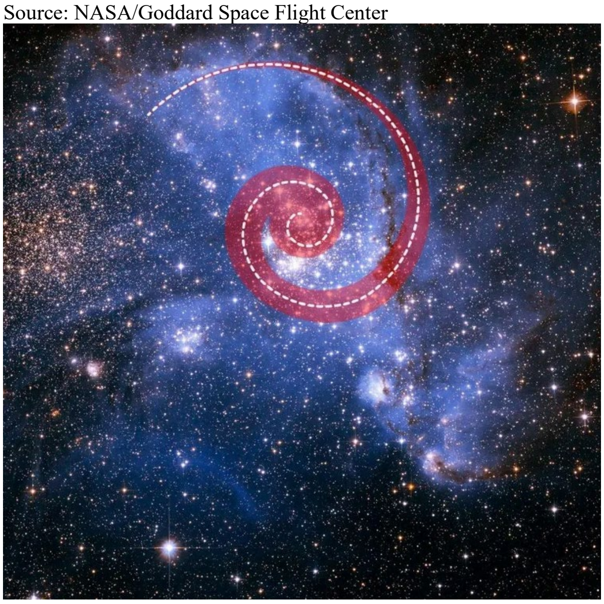
cosmological collider in the cosmos' contents today, such as galaxies and the cosmic microwave background.
Cui and Zhong-Zhi Xianyu, an assistant professor of physics at Tsinghua University, report in the journal *Physical Review Letters* that by applying the physics of the cosmological collider and using precision data for measuring the structure of our universe from upcoming experiments such as SPHEREx and 21 cm line tomography, the mystery of the cosmic origin of matter may be unravelled.
"The fact that our current-day universe is dominated by matter remains among the most perplexing, longstanding mysteries in modern physics," Cui said. "A subtle imbalance or asymmetry between matter and antimatter in the early universe is required to achieve today's matter dominance but cannot be realized within the known framework of fundamental physics."

Leptogenesis to the rescue

Cui and Xianyu propose testing leptogenesis, a well-known mechanism that explains the origin of the baryon -- visible gas and stars -- asymmetry in our universe. Had the universe begun with equal amounts of matter and antimatter, they would have annihilated each other into photon radiation, leaving nothing. Since matter far exceeds antimatter today, asymmetry is required to explain the imbalance.
"Leptogenesis is among the most compelling mechanisms generating the matter-antimatter asymmetry," Cui said. "It involves a new fundamental particle, the right-handed neutrino. It was long thought, however, that testing leptogenesis is next to impossible because the mass of the right-handed neutrino is typically many orders of magnitudes beyond the reach of the highest energy collider ever built, the Large Hadron Collider."
The new work proposes to test leptogenesis by decoding the detailed statistical properties of the spatial distribution of objects in the cosmic structure observed today, reminiscent of the microscopic physics during cosmic inflation. The cosmological collider effect, the researchers argue, enables the production of the super-heavy right-handed neutrino during the inflationary epoch.
"Specifically, we demonstrate that essential conditions for the asymmetry generation, including the interactions and masses of the right-handed neutrino, which is the key player here, can leave distinctive fingerprints in the statistics of the spatial distribution of galaxies or cosmic microwave background and can be precisely measured," Cui said. "The astrophysical observations anticipated in the coming years can potentially detect such signals and unravel the cosmic origin of matter."
Cui was supported in the research by a grant from the U.S. Department of Energy.

- ❖ Hubble finds spiralling stars, providing window into early universe

Researchers find the spiral may be feeding star formation in a nearby stellar nursery
Date: September 8, 2022
Source: NASA/Goddard Space Flight Center



Stars are the machines that sculpt the universe, yet scientists don't fully know how they form. To understand the frenzied 'baby boom' of star birth that occurred early in the universe's history, researchers turned to the Small Magellanic Cloud, a satellite galaxy of the Milky Way. This nearby galaxy has a simpler chemical composition than the Milky Way, making it similar to the galaxies found in the younger universe, when heavier elements were scarcer. This allows it to serve as a proxy for the early universe.
Two separate studies -- the first with the Hubble Space Telescope, and the second with the European Southern Observatory's Very Large Telescope -- recently came to the same conclusion. Using different methods, the independent teams found young stars spiralling into the centre of a massive star cluster called NGC 346 in the Small Magellanic Cloud. This river-like motion of gas and stars is an efficient way to fuel star

birth, researchers say. The teams' results show that the process of star formation in the Small Magellanic Cloud is similar to that in our own Milky Way.
Nature likes spirals -- from the whirlpool of a hurricane, to pinwheel-shaped protoplanetary disks around new-born stars, to the vast realms of spiral galaxies across our universe. Now astronomers are bemused to find young stars that are spiralling into the centre of a massive cluster of stars in the Small Magellanic Cloud, a satellite galaxy of the Milky Way.
The outer arm of the spiral in this huge, oddly shaped stellar nursery called NGC 346 may be feeding star formation in a river-like motion of gas and stars. This is an efficient way to fuel star birth, researchers say.
The Small Magellanic Cloud has a simpler chemical composition than the Milky Way, making it similar to the galaxies found in the younger universe, when heavier elements were scarcer. Because of this, the stars in the Small Magellanic Cloud burn hotter and so run out of their fuel faster than in our Milky Way.
Though a proxy for the early universe, at 200,000 light-years away the Small Magellanic Cloud is also one of our closest galactic neighbours.
Learning how stars form in the Small Magellanic Cloud offers a new twist on how a firestorm of star birth may have occurred early in the universe's history, when it was undergoing a "baby boom" about 2 to 3 billion years after the big bang (the universe is now 13.8 billion years old).
The new results find that the process of star formation there is similar to that in our own Milky Way.
Only 150 light-years in diameter, NGC 346 boasts the mass of 50,000 Suns. Its intriguing shape and rapid star formation rate has puzzled astronomers. It took the combined power of NASA's Hubble Space Telescope and the European Southern Observatory's Very Large Telescope (VLT) to unravel the behaviour of this mysterious-looking stellar nesting ground.
"Stars are the machines that sculpt the universe. We would not have life without stars, and yet we don't fully understand how they form," explained study leader Elena Sabbi of the Space Telescope Science Institute in Baltimore. "We have several models that make predictions, and some of these predictions are contradictory. We want to determine what is regulating the process of star formation, because these are the laws that we need to also understand what we see in the early universe."
Researchers determined the motion of the stars in NGC 346 in two different ways. Using Hubble, Sabbi and her team measured the changes of the stars' positions over 11 years. The stars in this region are moving at an average velocity of 2,000 miles per hour, which means that in 11 years they move 200 million miles. This is about 2 times the distance between the Sun and the Earth.
But this cluster is relatively far away, inside a neighbouring galaxy. This means the amount of observed motion is very small and therefore difficult to measure. These extraordinarily precise observations were possible only because of Hubble's exquisite resolution and high sensitivity. Also, Hubble's three-decade-long history of observations provides a baseline for astronomers to follow minute celestial motions over time.
The second team, led by Peter Zeidler of AURA/STScI for the European Space Agency, used the ground-based VLT's Multi Unit Spectroscopic Explorer (MUSE) instrument to measure radial velocity, which determines whether an object is approaching or receding from an observer.
"What was really amazing is that we used two completely different methods with different facilities and basically came to the same conclusion, independent of each other," said Zeidler. "With Hubble, you can see the stars, but with MUSE we can also see the gas motion in the third dimension, and it confirms the theory that everything is spiralling inwards."
But why a spiral?
"A spiral is really the good, natural way to feed star formation from the outside toward the centre of the cluster," explained Zeidler. "It's the most efficient way that stars and gas fuelling more star formation can move towards the centre."
Half of the Hubble data for this study of NGC 346 is archival. The first observations were taken 11 years ago. They were recently repeated to trace the motion of the stars over time. Given the telescope's longevity, the Hubble data archive now contains more than 32 years of astronomical data powering unprecedented, long-term studies.

"The Hubble archive is really a gold mine," said Sabbi. "There are so many interesting star-forming regions that Hubble has observed over the years. Given that Hubble is performing so well, we can actually repeat these observations. This can really advance our understanding of star formation."
Video: https://youtu.be/KGK8UThH_nw