South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk Claire Bradshaw "Astrophotography - from sky to screen"

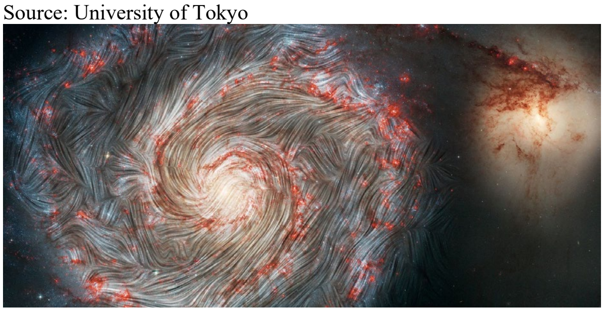
I have been interested in space and astronomy most of my life, gaining my first set of binoculars as a child followed by a Tasco reflector telescope. From these early days, interruptions came with University, marriage etc and it wasn't until 2012 that I obtained my first real telescope - an eq3 Skywatcher 150p gifted from a friend's lottery winnings! After that things took off, using webcams to image planets and a DSLR to shoot deep space. I then leapt into dedicated astro-camera imaging and things moved on from there. I love doing talks, having my work on display in galleries and trying to get the next best shot, learning more as I go. I am also part of a five-woman strong team creating a forthcoming book on Women in STEM, due for release in 2024.

Please support a raffle we are organizing this month.

❖ Our surprising magnetic galaxy

The first 3D map of magnetic fields in our galaxy explains star-forming regions

Date: January 11, 2024
Source: University of Tokyo



Magnetic fields mapped within the Whirlpool Galaxy. Credit: NASA, SOFIA science team, ESA, STScI

A team of astronomers including those from the University of Tokyo created the first-ever map of magnetic field structures within a spiral arm of our Milky Way galaxy. Previous studies on galactic magnetic fields only gave a very general picture, but the new study reveals that magnetic fields in the spiral arms of our galaxy break away from this general picture significantly and are tilted away from the galactic average by a high degree. The findings suggest magnetic fields strongly impact star-forming regions which means they played a part in the creation of our own solar system.

It might come as a surprise to some that magnetic fields can exist on scales larger than a planet. Most of our daily experience with magnetic fields involves either sticking things to our refrigerator, or perhaps using a compass to point north. The latter shows the existence of magnetic fields generated by our planet. Our sun also creates a vast magnetic field, and this can affect phenomena like solar flares. But magnetic fields that span the galaxy are almost too large to comprehend, and yet they likely have a role in the formation of stars and planets.

"Until now, all observations of magnetic fields within the Milky Way led to a very limited model that was uniform all over and largely matched the disc shape of the galaxy itself," said Assistant Professor Yasuo Doi from the Department of Earth Science and Astronomy. "Thanks in part to telescope facilities at Hiroshima University capable of measuring polarized light to help us ascertain magnetic signatures, and the Gaia satellite launched by the European Space Agency in 2013, which specialized in measuring the distances to stars, we are able to build a better model with finer details in three dimensions. We focused on a specific area, the Sagittarius arm of our spiral galaxy (we are in the neighbouring Orion arm) and found the dominant magnetic field there breaks away from the plane of the galaxy significantly." Previous models and observations could only imagine a smooth and largely homogeneous magnetic field in our galaxy; whereas the new data show that although magnetic field lines in the spiral arms do roughly align with the galaxy at large, at small scales the lines are actually spread out across a range of distances due to various astrophysical phenomena such as supernovae and stellar winds. The galactic magnetic fields are also incredibly weak, around 100,000 times weaker than Earth's

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own magnetic field. Despite this, however, over long-time spans, gas and dust in interstellar space are accelerated by these fields which explains the presence of some stellar nurseries -- star-forming regions -- that cannot be explained by gravity alone. This finding implies further mapping of the magnetic fields within our galaxy could help better explain the nature and evolution of the Milky Way and other galaxies too.

"I am personally intrigued by the foundational process of star formation, pivotal to the creation of life, including ourselves, and I aim to grasp this phenomenon in its entirety with time," said Doi. "We aim to further our observations and build better models of galactic magnetic field structures. This endeavour aims to provide observational insights into the accumulation of gas fuelling active star formation within our galaxy and its historical development."

- **Earth-sized planet discovered in 'our solar backyard'**

'It's a useful planet because it may be like an early Earth'

Date: January 14, 2024
Source: University of Wisconsin-Madison

Image: @Kapook2981 | iStock

A team of astronomers has discovered a planet closer and younger than any other Earth-sized world yet identified. It's a remarkably hot world whose proximity to our own planet and to a star like our sun mark it as a unique opportunity to study how planets evolve.

The new planet was described in a new study published this week by The Astronomical Journal. Melinda Soares-Furtado, a NASA Hubble Fellow at the University of Wisconsin-Madison who will begin work as an astronomy professor at the university in the fall, and recent UW-Madison graduate Benjamin Capistrant, now a graduate student at the University of Florida, co-led the study with co-authors from around the world.

"It's a useful planet because it may be like an early Earth," says Soares-Furtado.

Here is what scientists know about the planet:

- The planet is known as HD 63433d and it's the third planet found in orbit around a star called HD 63433.
- HD 63433d is so close to its star, it completes a trip all the way around every 4.2 days.
- "Even though it's really close-orbiting, we can use follow-up data to search for evidence of outgassing and atmospheric loss that could be important constraints on how terrestrial worlds evolve," Soares-Furtado says. "But that's where the similarities end -- and end *dramatically*."
- Based on its orbit, the astronomers are relatively certain HD 63433d is tidally locked, which means one side is perpetually facing its star.
- That side can reach a brutal 2,300 degrees Fahrenheit and may flow with lava, while the opposite side is forever dark.

What you should know about the planet's star:

- HD 63433 is roughly the same size and star type as our sun, but (at about 400 million years old) it's not even one-tenth our sun's age.
- The star is about 73 light years away from our own sun and part of the group of stars moving together that make up the constellation Ursa Major, which includes the Big Dipper.
- "On a dark night in Madison," Soares-Furtado says, "you could see [HD 63433] through a good pair of binoculars."

How the scientists found the planet:

- The study's authors are collaborating on a planet-hunting project called THYME. In 2020, they used data from NASA's Transiting Exoplanet Survey Satellite to identify two mini-Neptune-sized planets orbiting HD 63433.
- Since then, TESS took four more looks at the star, compiling enough data for the researchers to detect HD 63433d crossing between the star and the satellite.

What comes next:

- The researchers, including UW-Madison study co-authors graduate student Andrew C. Nine, undergraduate Alyssa Jankowski and Juliette Becker, a UW-Madison astronomy professor, think there is plenty to learn from HD 63433d.

- The planet is uniquely situated for further study. Its peppy young star is visible from both the Northern and Southern hemispheres, increasing the number of instruments, like the South African Large Telescope or WIYN Observatory in Arizona (both of which UW-Madison helped design and build) that can be trained on the system.
- And the star is orders of magnitude closer than many Soares-Furtado has studied, possibly affording opportunities to develop new methods to study gasses escaping from the planet's interior or measure its magnetic field.

"This is our solar backyard, and that's kind of exciting," Soares-Furtado says. "What sort of information can a star this close, with such a crowded system around it, give away? How will it help us as we move on to look for planets among the maybe 100 other, similar stars in this young group it's part of?"

This research was supported in part by grants from NASA (HST-HF2-51493.001-A, 21-ASTRO21-0068 and XRP 80NSSC21K0393) and the National Science Foundation (AST-2143763, PHY-2210452 and 1745302).

❖ NASA's Webb finds signs of possible aurorae on isolated brown dwarf

Date: January 9, 2024
Source: NASA/Goddard Space Flight Centre

This artist concept portrays the brown dwarf W1935, which is located 47 light-years from Earth. Astronomers using NASA's James Webb Space Telescope found infrared emission from methane coming from W1935. This is an unexpected discovery because the brown dwarf is cold and lacks a host star; therefore, there is no obvious source of energy to heat its upper atmosphere and make the methane glow. The team speculates that the methane emission may be due to processes generating aurorae, shown here in red.
NASA, ESA, CSA, and L. Hustak (STScI)

Astronomers using NASA's James Webb Space Telescope have found a brown dwarf (an object more massive than Jupiter but smaller than a star) with infrared emission from methane, likely due to energy in its upper atmosphere. This is an unexpected discovery because the brown dwarf, W1935, is cold and lacks a host star; therefore, there is no obvious source for the upper atmosphere energy. The team speculates that the methane emission may be due to processes generating aurorae.

These findings are being presented at the 243rd meeting of the American Astronomical Society in New Orleans.

To help explain the mystery of the infrared emission from methane, the team turned to our solar system. Methane in emission is a common feature in gas giants like Jupiter and Saturn. The upper-atmosphere heating that powers this emission is linked to aurorae.

On Earth, aurorae are created when energetic particles blown into space from the Sun are captured by Earth's magnetic field. They cascade down into our atmosphere along magnetic field lines near Earth's poles, colliding with gas molecules and creating eerie, dancing curtains of light. Jupiter and Saturn have similar auroral processes that involve interacting with the solar wind, but they also get auroral contributions from nearby active moons like Io (for Jupiter) and Enceladus (for Saturn).

For isolated brown dwarfs like W1935, the absence of a stellar wind to contribute to the auroral process and explain the extra energy in the upper atmosphere required for the methane emission is a mystery. The team surmises that either unaccounted internal processes like the atmospheric phenomena of Jupiter and Saturn, or external interactions with either interstellar plasma or a nearby active moon, may help account for the emission.

A Detective Story

The aurorae's discovery played out like a detective story. A team led by Jackie Faherty, an astronomer at the American Museum of Natural History in New York, was awarded time with the Webb telescope to investigate 12 cold brown dwarfs. Among those were W1935 -- an object that was discovered by citizen scientist Dan Caselden, who worked with the Backyard Worlds zooniverse project -- and W2220, an object that was discovered using NASA's Wide Field Infrared Survey

Explorer. Webb revealed in exquisite detail that W1935 and W2220 appeared to be near clones of each other in composition. They also shared similar brightness, temperatures, and spectral features of water, ammonia, carbon monoxide, and carbon dioxide. The striking exception was that W1935 showed emission from methane, as opposed to the anticipated absorption feature that was observed toward W2220. This was seen at a distinct infrared wavelength to which Webb is uniquely sensitive.

"We expected to see methane because methane is all over these brown dwarfs. But instead of absorbing light, we saw just the opposite: The methane was glowing. My first thought was, what the heck? Why is methane emission coming out of this object?" said Faherty.

The team used computer models to infer what might be behind the emission. The modelling work showed that W2220 had an expected distribution of energy throughout the atmosphere, getting cooler with increasing altitude. W1935, on the other hand, had a surprising result. The best model favoured a temperature inversion, where the atmosphere got warmer with increasing altitude. "This temperature inversion is really puzzling," said Ben Burningham, a co-author from the University of Hertfordshire in England and lead modeler on the work. "We have seen this kind of phenomenon in planets with a nearby star that can heat the stratosphere, but seeing it in an object with no obvious external heat source is wild."

Clues from our Solar System

For clues, the team looked in our own backyard, to the planets of our solar system. The gas giant planets can serve as proxies for what is seen going on more than 40 light-years away in the atmosphere of W1935.

The team realized that temperature inversions are prominent in planets like Jupiter and Saturn. There is still ongoing work to understand the causes of their stratospheric heating, but leading theories for the solar system involve external heating by aurorae and internal energy transport from deeper in the atmosphere (with the former a leading explanation).

Brown Dwarf Aurora Candidates in Context

This is not the first time an aurora has been used to explain a brown dwarf observation. Astronomers have detected radio emission coming from several warmer brown dwarfs and invoked aurorae as the most likely explanation. Searches were conducted with ground-based telescopes like the Keck Observatory for infrared signatures from these radio-emitting brown dwarfs to further characterize the phenomenon, but were inconclusive.

W1935 is the first auroral candidate outside the solar system with the signature of methane emission. It's also the coldest auroral candidate outside our solar system, with an effective temperature of about 400 degrees Fahrenheit (200 degrees Celsius), about 600 degrees Fahrenheit warmer than Jupiter.

In our solar system the solar wind is a primary contributor to auroral processes, with active moons like Io and Enceladus playing a role for planets like Jupiter and Saturn, respectively. W1935 lacks a companion star entirely, so a stellar wind cannot contribute to the phenomenon. It is yet to be seen whether an active moon might play a role in the methane emission on W1935.

"With W1935, we now have a spectacular extension of a solar system phenomenon without any stellar irradiation to help in the explanation." Faherty noted. "With Webb, we can really 'open the hood' on the chemistry and unpack how similar or different the auroral process may be beyond our solar system," she added.

- **Records of cometary dust hitting the asteroid Ryugu**

Date: January 23, 2024
Source: Tohoku University

Ryugu is a near-Earth asteroid that gained significant attention when the Japanese Hayabusa2 mission collected samples and returned them to Earth. These samples have proven to offer a treasure trove of insights into the solar systems, including the possible role of asteroids in delivering organic molecules to earth.

Now, a team of scientists have performed an intensive investigation of Ryugu samples, discovering evidence that points to cometary

organic matter being transported from space to the near-Earth region.
The team included Megumi Matsumoto, an assistant professor from the Earth Science Department at Tohoku University Graduate School of Science. Details of their findings were published in the journal *Science Advances* on January 19, 2024.
Asteroid Ryugu has no protective atmospheres, and its surface layer is directly exposed to space. Small interplanetary dust in space can hit the asteroid surface, causing changes to the composition of the asteroid surface materials.
Matsumoto and her colleagues revealed that the sample surfaces contain small 'melt splashes,' ranging in size from 5 to 20 micrometres. These melt splashes were created when micrometeoroids of cometary dust bombarded Ryugu.
"Our 3D CT imaging and chemical analyses showed that the melt splashes consist mainly of silicate glasses with voids and small inclusions of spherical iron sulphides," says Matsumoto. "The chemical compositions of the melt splashes suggest that Ryugu's hydrous silicates mixed with cometary dust."
The mixing and melting of Ryugu's surface materials and cometary dust during impact induced heating and rapid cooling formed the melt splashes. The voids correspond to the water vapor released from the Ryugu's hydrous silicates and subsequently captured in the melt splashes.
Analysis also revealed small carbonaceous materials with abundant nano-pores and iron sulphide inclusions in the melt splashes. The carbonaceous materials are texturally similar to primitive organic matter in cometary dust, though they lack nitrogen and oxygen, making them chemically different from organic matter.
"We propose that the carbonaceous materials formed from cometary organic matter via the evaporation of volatiles, such as nitrogen and oxygen, during the impact-induced heating. This suggests that cometary matter was transported to the near-Earth region from the outer solar system," adds Matsumoto. "This organic matter might be the small seeds of life once delivered from space to Earth."
Looking ahead, the team hopes to examine Ryugu samples to find more melt splashes that will provide further insights into the influx of primitive space materials into Earth.

- ❖ **Lightest black hole or heaviest neutron star? MeerKAT uncovers a mysterious object in Milky Way**

Date: January 18, 2024
Source: University of Manchester

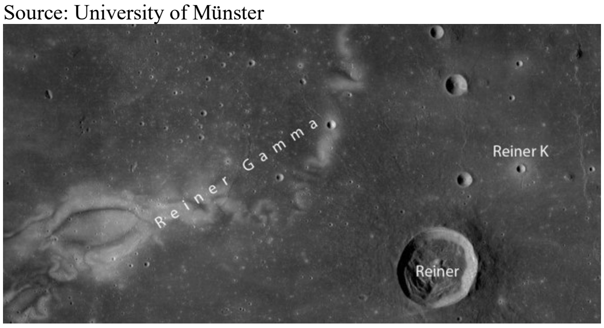
An international team of astronomers have found a new and unknown object in the Milky Way that is heavier than the heaviest neutron stars known and yet simultaneously lighter than the lightest black holes known.
Using the MeerKAT Radio Telescope, astronomers from a number of institutions including The University of Manchester and the Max Planck Institute for Radio Astronomy in Germany found an object in orbit around a rapidly spinning millisecond pulsar located around 40,000 light years away in a dense group of stars known as a globular cluster.
Using the clock-like ticks from the millisecond pulsar they showed that the massive object lies in the so-called black hole mass gap.
It could be the first discovery of the much-coveted radio pulsar -- black hole binary; a stellar pairing that could allow new tests of Einstein's general relativity and open doors to the study of black holes.
The results are published today in the journal *Science.*
UK project lead Ben Stappers, Professor of Astrophysics at The University of Manchester, said: "Either possibility for the nature of the companion is exciting. A pulsar-black hole system will be an important target for testing theories of gravity and a heavy neutron star will provide new insights in nuclear physics at very high densities."
When a neutron star -- the ultra-dense remains of dead star -- acquire too much mass, usually by consuming or colliding with another star, they will collapse. What they become after they collapse is the cause of much speculation, but it is believed that they could become black holes -- objects so gravitationally attractive that even light cannot escape them.

Astronomers believe that the total mass required for a neutron star to collapse is 2.2 times the mass of the sun. Theory, backed by observation, tells us that the lightest black holes created by these stars are much larger, at about five times more massive than the Sun, giving rise to what is known as the 'black hole mass gap'.
The nature of compact objects in this mass gap is unknown and detailed study has so far proved challenging. The discovery of the object may help finally understand these objects.
Prof Stappers, added: "The ability of the extremely sensitive MeerKAT telescope to reveal and study these objects is a enabling a great step forward and provides us with a glimpse of what will be possible with the Square Kilometre Array."
The discovery of the object was made while observing a large cluster of stars known as NGC 1851 located in the southern constellation of Columba, using the MeerKAT telescope.
The globular cluster NGC 1851 is a dense collection of old stars that are much more tightly packed than the stars in the rest of the Galaxy. Here, it is so crowded that the stars can interact with each other, disrupting orbits and in the most extreme cases colliding.
The astronomers, part of the international Transients and Pulsars with MeerKAT (TRAPUM) collaboration, believe that it is one such collision between two neutron stars that is proposed to have created the massive object that now orbits the radio pulsar.
The team were able to detect faint pulses from one of the stars, identifying it as a radio pulsar -- a type of neutron star that spins rapidly and shines beams of radio light into the Universe like a cosmic lighthouse.
The pulsar spins more than 170 times a second, with every rotation producing a rhythmic pulse, like the ticking of a clock.
The ticking of these pulses is incredibly regular and by observing how the times of the tick’s change, using a technique called pulsar timing, they were able to make extremely precise measurements of its orbital motion.
Ewan Barr from Max Planck Institute for Radio Astronomy, who led the study with his colleague Arunima Dutta, explained: "Think of it like being able to drop an almost perfect stopwatch into orbit around a star almost 40,000 light years away and then being able to time those orbits with microsecond precision."
The regular timing also allowed a very precise measurement of the system's location, showing that the object in orbit with the pulsar was no regular star but an extremely dense remnant of a collapsed star.
Observations also showed that the companion has a mass that was simultaneously bigger than that of any known neutron star and yet smaller than that of any known black hole, placing it squarely in the black-hole mass gap.
While the team cannot conclusively say whether they have discovered the most massive neutron star known, the lightest black hole known or even some new exotic star variant, what is certain is that they have uncovered a unique laboratory for probing the properties of matter under the most extreme conditions in the Universe.
Arunima Dutta concludes: "We're not done with this system yet.
"Uncovering the true nature of the companion will a turning point in our understanding of neutron stars, black holes, and whatever else might be lurking in the black hole mass gap."

❖ Moon rocks with unique dust found

Research team studies interaction of dust with boulders and discovers potentially anomalous rocks

Date: January 18, 2024
Source: University of Münster



The meter-high rocks discovered in the work are located near the Reiner K crater in the "Reiner Gamma" region, which has a magnetic anomaly.

Our Earth's Moon is almost completely covered in dust. Unlike on Earth, this dust is not smoothed by wind and weather, but is sharp-edged and also electrostatically charged. This dust has been studied since the Apollo era at the end of the 1960s. Now, an international research team led by Dr. Ottaviano Rüsch from the University of Münster has for the first time discovered anomalous meter-sized rocks on the lunar surface that are covered in dust and presumably exhibit unique properties -- such as magnetic anomalies. The scientists' most important finding is that only very few boulders on the Moon have a layer of dust with very special reflective properties. For example, the dust on these newly discovered boulders reflects sunlight differently than on previously known rocks. These new findings help scientists to understand the processes that form and change the lunar crust. The results of the study have been published in the *Journal of Geophysical Research -- Planets*.

It is known that there are magnetic anomalies on the lunar surface, particularly near a region called Reiner Gamma. However, the question of whether rocks can be magnetic has never been investigated. "Current knowledge of the Moon's magnetic properties is very limited, so these new rocks will shed light on the history of the Moon and its magnetic core," says Ottaviano Rüsch from the 'Institut für Planetologie', categorizing the discovery. "For the first time, we have investigated the interactions of dust with rocks in the Reiner Gamma region -- more precisely, the variations in the reflective properties of these rocks. For example, we can deduce to what extent and in which direction the sunlight is reflected by these large rocks." The images were taken by NASA's Lunar Reconnaissance Orbiter spacecraft, which orbits the Moon.

The research team was originally interested in cracked rocks. They first used artificial intelligence to search through around one million images for fractured rocks -- these images were also taken by the Lunar Reconnaissance Orbiter. "Modern data processing methods allow us to gain completely new insights into global contexts -- at the same time, we keep finding unknown objects in this way, such as the anomalous rocks that we are investigating in this new study," says Valentin Bickel from the Centre for Space and Habitability at the University of Bern. The search algorithm identified around 130,000 interesting rocks, half of which were scrutinized by the scientists.

"We recognized a boulder with distinctive dark areas on just one image. This rock was very different from all the others, as it scatters less light back towards the sun than other rocks. We suspect that this is due to the particular dust structure, such as the density and grain size of the dust," Ottaviano Rüsch explains. "Normally, lunar dust is very porous and reflects a lot of light back in the direction of illumination. However, when the dust is compacted, the overall brightness usually increases. This is not the case with the observed dust-covered rocks," adds Marcel Hess from TU Dortmund University. This is a fascinating discovery -- however, the scientists are still in the early stages of understanding this dust and its interactions with the rock. In the coming weeks and months, the scientists want to further investigate the processes that lead to the interactions between dust and rocks and to the formation of the special dust structure. These processes include, for example, the lifting of the dust due to electrostatic charging or the interaction of the solar wind with local magnetic fields.

In addition to numerous other international unmanned space missions to the Moon, NASA will be sending an automatic rover, a mobile robot, to the Reiner Gamma region in the coming years to find similar types of boulders with special dust. Even if it is still a dream of the future, a better understanding of dust movement can help with the planning of human settlements on the Moon, for example. After all, we know from the experience of the Apollo astronauts that dust poses many problems, such as the contamination of habitats (e.g., space stations) and technical equipment.

- **Origin of intense light in supermassive black holes and tidal disruption events revealed**

Date: January 18, 2024
Source: The Hebrew University of Jerusalem

Anew study by Hebrew University is a significant breakthrough in understanding Tidal Disruption Events (TDEs) involving supermassive black holes. The new simulations, for the first time ever, accurately replicate the entire sequence of a TDE from stellar disruption to the peak luminosity of the resulting flare. This study has unveiled a previously unknown type of shockwave within TDEs, settling a longstanding debate about the energy source of the brightest phases in these events. It confirms that shock dissipation powers the brightest weeks of a TDE flare, opening doors for future studies to

utilize TDE observations as a means to measure essential properties of black holes and potentially test Einstein's predictions in extreme gravitational environments.
The mysteries of supermassive black holes have long captivated astronomers, offering a glimpse into the deepest corners of our universe. Now, a new study led by Dr. Elad Steinberg and Dr. Nicholas C. Stone at the Racah Institute of Physics, The Hebrew University, sheds new light on these enigmatic cosmic entities.
Supermassive black holes, ranging from millions to billions of times the mass of our Sun, have remained elusive despite their pivotal role in shaping galaxies. Their extreme gravitational pull warps spacetime, creating an environment that defies conventional understanding and presents a challenge for observational astronomers.
Enter Tidal Disruption Events (TDEs), a dramatic phenomenon that occurs when ill-fated stars venture too close to a black hole's event horizon, and are torn apart into thin streams of plasma. As this plasma returns towards the black hole, a series of shockwaves heat it up, leading to an extraordinary display of luminosity -- a flare that surpasses the collective brightness of an entire galaxy for weeks or even months.
The study conducted by Steinberg and Stone represents a significant leap forward in understanding these cosmic events. For the first time, their simulations have recreated a realistic TDE, capturing the complete sequence from the initial star disruption to the peak of the ensuing luminous flare, all made possible by pioneering radiation-hydrodynamics simulation software developed by Steinberg at The Hebrew University.
This research has uncovered a previously unexplored type of shockwave within TDEs, revealing that these events dissipate their energy at a faster rate than previously understood. By clarifying this aspect, the study resolves a long-standing theoretical debate, confirming that the brightest phases of a TDE flare are powered by shock dissipation -- a revelation that sets the stage for comprehensive exploration by observational astronomers.
These findings pave the way for translating TDE observations into precise measurements of crucial black hole properties, including mass and spin. Moreover, these cosmic occurrences could serve as a litmus test for validating Einstein's predictions in extreme gravitational environments.
Steinberg and Stone's study not only unravels the intricate dynamics of TDEs but also opens a new chapter in our quest to comprehend the fundamental workings of supermassive black holes. Their simulations mark a crucial step towards harnessing these celestial events as invaluable tools for deciphering the cosmic mysteries lurking at the heart of galaxies.

- ❖ **The metalens meets the stars**

Large, all-glass metalens images sun, moon and nebulae

Date: January 17, 2024
Source: Harvard John A. Paulson School of Engineering and Applied Sciences

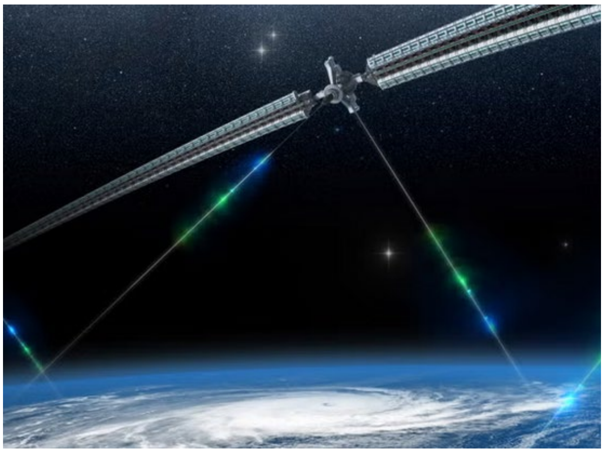
Image of the Moon taken by the metalens from the roof of the Science Centre in Cambridge. (Credit: Capasso Lab/Harvard SEAS)
Download Image

Metalenses have been used to image microscopic features of tissue and resolve details smaller than a wavelength of light. Now they are going bigger.
Researchers at the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) have developed a 10-centimeter-diameter glass metalens that can image the sun, the moon and distant nebulae with high resolution. It is the first all-glass, large-scale metalens in the visible wavelength that can be mass produced using conventional CMOS fabrication technology.
The research is published in *ACS Nano*.
"The ability to accurately control the size of tens of billions of nanopillars over an unprecedentedly large flat lens using state-of-the-art semiconductor foundry processes is a nanofabrication feat that opens exciting new opportunities for space science and technology," said Federico Capasso, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering at SEAS and senior author of the paper.

Most flat metalenses, which use millions of pillar-like nanostructures to focus light, are about the size of a piece of glitter. In 2019, Capasso and his team developed a centimetre-scale metalens using a technique called deep-ultraviolet (DUV) projection lithography, which projects and forms a nanostructure pattern that can be directly etched into the glass wafer**,** eliminating the time-consuming writing and deposition processes that were required for previous metalenses.
DUV projection lithography is commonly used to pattern fine lines and shapes in silicon chips for smartphones and computers. Joon-Suh Park, a former graduate student at SEAS and current postdoctoral fellow in Capasso's team, demonstrated that the technique could not only be used to mass produce metalenses but also increase their size for applications in virtual and augmented reality.
But making the metalens even larger for applications in astronomy and free-space optical communications posed an engineering problem.
"There is a major limitation with the lithography tool because these tools are used to make computer chips, so chip size is restricted to no more than 20 to 30 millimetres," said Park, co-first author of the paper. "In order to make a 100-millimeter diameter lens, we needed to find a way around this limitation."
Park and the team developed a technique to stitch together several patterns of nanopillars using the DUV projection lithography tool. By dividing the lens into 25 sections but using only the 7 sections of a quadrant considering the rotational symmetry, the researchers showed that DUV projection lithography could pattern 18.7 billion designed nanostructures onto a 10-centimeter circular area in a matter of minutes. The team also developed a vertical glass etching technique that allows the creation of high-aspect ratio, smooth-sidewall nanopillars etched into glass.
"Using the same DUV projection lithography, one could produce large-diameter, aberration-correcting meta-optics or even larger lenses on larger glass diameter wafers as the corresponding CMOS foundry tools become increasingly available in the industry," said Soon Wei Daniel Lim, a postdoctoral fellow at SEAS and co-first author of the paper.
Lim played a lead role in the full simulation and characterization of all the possible fabrication errors that could arise during mass-manufacturing processes and how they could impact the optical performance of metalenses.
After addressing possible manufacturing challenges, the researchers demonstrated the power of the metalens in imaging celestial objects.
Mounting the metalens on a tripod with a colour filter and camera sensor, Park and the team took to the roof of Harvard's Science Centre. There, they imaged the Sun, the moon and the North America nebula, a dim nebula in the constellation Cygnus about 2,590 light years away.
"We were able to get very detailed images of the Sun, the moon and the nebula that are comparable to images taken by conventional lenses" said Arman Amirzhan, a graduate student in the Capasso Lab and co-author of the paper.
Using only the metalens, the researchers were able to image the same cluster of sunspots as a NASA image taken that same day.
The team also demonstrated that the lens could survive exposure to extreme heat, extreme cold and the intense vibrations that would occur during a space launch without any damage or loss in optical performance.
Because of its size and monolithic glass composition, the lens could also be used for long-range telecommunications and directed energy transport applications.
The research is co-authored by Hyukmo Kang, Karlene Karrfalt, Daewook Kim, Joel Leger, Augustine Urbas, Marcus Ossiander and Zhaoyi Li. It was supported by the Defense Advanced Research Projects Agency (DARPA) Grant No. HR00111810001 and the Air Force Office of Scientific Research under Award No. FA9550-22-1-0312.

- **Space solar power project ends first in-space mission with successes and lessons**

Date: January 17, 2024
Source: California Institute of Technology


An illustration of how solar energy could be beamed to Earth via satellites
(iStock/ Getty Images)

One year ago, Caltech's Space Solar Power Demonstrator (SSPD-1) launched into space to demonstrate and test three technological innovations that are among those necessary to make space solar power a reality.

The spaceborne testbed demonstrated the ability to beam power wirelessly in space; it measured the efficiency, durability, and function of a variety of different types of solar cells in space; and gave a real-world trial of the design of a lightweight deployable structure to deliver and hold the aforementioned solar cells and power transmitters.

Now, with SSPD-1's mission in space concluded, engineers on Earth are celebrating the testbed's successes and learning important lessons that will help chart the future of space solar power.

"Solar power beamed from space at commercial rates, lighting the globe, is still a future prospect. But this critical mission demonstrated that it should be an achievable future," says Caltech President Thomas F. Rosenbaum, the Sonja and William Davidow Presidential Chair and professor of physics.

SSPD-1 represents a major milestone in a project that has been underway for more than a decade, garnering international attention as a tangible and high-profile step forward for a technology being pursued by multiple nations. It was launched on January 3, 2023, aboard a Momentus Vigoride spacecraft as part of the Caltech Space Solar Power Project (SSPP), led by professors Harry Atwater, Ali Hajimiri, and Sergio Pellegrino. It consists of three main experiments, each testing a different technology:

- DOLCE (Deployable on-Orbit ultraLight Composite Experiment): a structure measuring 1.8 meters by 1.8 meters that demonstrates the novel architecture, packaging scheme, and deployment mechanisms of the scalable modular spacecraft that will eventually make up a kilometre-scale constellation to serve as a power station.
- ALBA: a collection of 32 different types of photovoltaic (PV) cells to enable an assessment of the types of cells that can withstand punishing space environments.
- MAPLE (Microwave Array for Power-transfer Low-orbit Experiment): an array of flexible, lightweight microwave-power transmitters based on custom integrated circuits with precise timing control to focus power selectively on two different receivers to demonstrate wireless power transmission at distance in space.

"It's not that we don't have solar panels in space already. Solar panels are used to power the International Space Station, for example," says Atwater, Otis Booth Leadership Chair of Division of Engineering and Applied Science; Howard Hughes Professor of Applied Physics and Materials Science; director of the Liquid Sunlight Alliance; and one of the principal investigators of SSPP. "But to launch and deploy large enough arrays to provide meaningful power to Earth, SSPP has to design and create solar power energy transfer systems that are ultra-lightweight, cheap, flexible, and deployable."

DOLCE: Deploying the Structure

Though all of the experiments aboard SSPD-1 were ultimately successful, not everything went according to plan. For the scientists and engineers leading this effort, however, that was exactly the point. The authentic test environment for SSPD-1 provided an opportunity to evaluate each of the components and the insights gleaned will have a profound impact on future space solar power array designs.

For example, during the deployment of DOLCE -- which was intended to be a three- to four-day process -- one of the wires connecting the diagonal booms to the corners of the structure, which allowed it to unfurl, became snagged. This stalled the deployment and damaged the connection between one of the booms and the structure.

With the clock ticking, the team used cameras on DOLCE as well as a full-scale working model of DOLCE in Pellegrino's lab to identify and try to solve the problem. They established that the damaged system would deploy better when warmed directly by the Sun and also by solar energy reflected off Earth.

Once the diagonal booms had been deployed and the structure was fully uncoiled, a new complication arose: Part of the structure became jammed under the deployment mechanism, something that had never been seen in laboratory testing. Using images from the DOLCE cameras, the team was able to reproduce this kind of jamming in the lab and developed a strategy to fix it. Ultimately, Pellegrino and his team completed the deployment through a motion of DOLCE's actuators that vibrated the whole structure and worked the jam free. Lessons from the experience, Pellegrino says, will inform the next deployment mechanism.

"The space test has demonstrated the robustness of the basic concept, which has allowed us to achieve a successful deployment in spite of two anomalies," says Pellegrino, Joyce and Kent Kresa Professor of Aerospace and Civil Engineering and co-director of SSPP. "The troubleshooting process has given us many new insights and has sharply focused us on the connection between our modular structure and the diagonal booms. We have developed new ways to counter the effects of self-weight in ultralight deployable structures."

ALBA: Harvesting Solar Energy

Meanwhile, the photovoltaic performance of three entirely new classes of ultralight research-grade solar cells, none of which had ever been tested in orbit before, were measured over the course of more than 240 days of operation by the ALBA team, led by Atwater. Some of the solar cells were custom-fabricated using facilities in the SSPP labs and the Kavli Nanoscience Institute (KNI) at Caltech, which gave the team a reliable and fast way to get small cutting-edge devices quickly ready for flight. In future work, the team plans to test large-area cells made using highly scalable inexpensive manufacturing methods that can dramatically reduce both the mass and the cost of these space solar cells.

Space solar cells presently available commercially are typically 100 times more expensive than the solar cells and modules widely deployed on Earth. This is because their manufacture employs an expensive step called epitaxial growth, in which crystalline films are grown in a specific orientation on a substrate. The SSPP solar cell team achieved low-cost nonepitaxial space cells by using cheap and scalable production processes like those used to make today's silicon solar cells. These processes employ high-performance compound semiconductor materials such as gallium arsenide that are typically used to make high-efficiency space cells today.

The team also tested perovskite cells, which have captured the attention of solar manufacturers because they are cheap and flexible, and luminescent solar concentrators with the potential to be deployed in large flexible polymer sheets.

Over ALBA's lifespan, the team collected enough data to be able to observe changes in the operation of individual cells in response to space weather events like solar flares and geomagnetic activity. They found, for example, tremendous variability in the performance of the perovskite cells, whereas the low-cost gallium arsenide cells consistently performed well overall.

"SSPP gave us a unique opportunity to take solar cells directly from the lab at Caltech into orbit, accelerating the in-space testing that would normally have taken years to be done. This kind of approach has dramatically shortened the innovation-cycle time for space solar technology," says Atwater.

MAPLE: Wireless Power Transfer in Space

Finally, as announced in June, MAPLE demonstrated its ability to transmit power wirelessly in space and to direct a beam to Earth -- a first in the field. MAPLE experiments continued for eight months after the initial demonstrations, and in this subsequent work, the team pushed MAPLE to its limits to expose and understand its potential weaknesses so that lessons learned could be applied to future design.

The team compared the performance of the array early in the mission with its performance at the end of the mission, when MAPLE was intentionally stressed. A drop in the total transmitted power was observed. Back in the lab on Earth, the group reproduced the power drop, attributing it to the degradation of a few individual transmitting elements in the array as well as some complex electrical-thermal interactions in the system.

"These observations have already led to revisions in the design of various elements of MAPLE to maximize its performance over extended periods of time," says Hajimiri, Bren Professor of Electrical Engineering and Medical Engineering and co-director of SSPP. "Testing in space with SSPD-1 has given us more visibility into our blind spots and more confidence in our abilities."

SSPP: Moving Forward

SSPP began after philanthropist Donald Bren, chairman of Irvine Company and a life member of the Caltech community, first learned about the potential for space-based solar energy manufacturing as a young man in an article in *Popular Science* magazine. Intrigued by the potential for space solar power, Bren approached Caltech's then-president Jean-Lou Chameau in 2011 to discuss the creation of a space-based solar power research project. In the years to follow, Bren and his wife, Brigitte Bren, a Caltech trustee, agreed to make a series of donations (yielding a total commitment of over $100 million) through the Donald Bren Foundation to fund the project and to endow a number of Caltech professorships.

"The hard work and dedication of the brilliant scientists at Caltech have advanced our dream of providing the world with abundant, reliable, and affordable power for the benefit of all humankind," Donald Bren says.

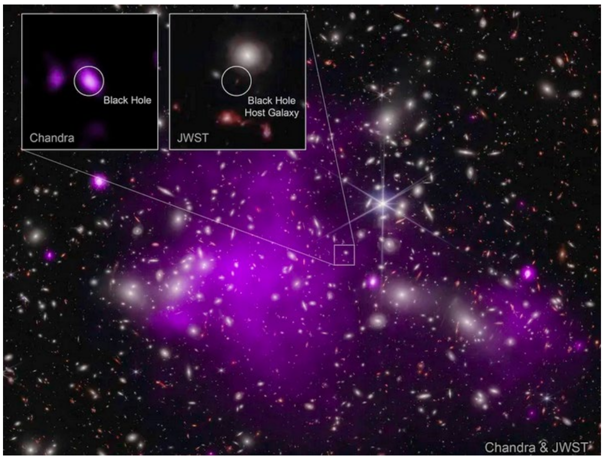
In addition to the support received from the Brens, Northrop Grumman Corporation provided Caltech with $12.5 million between 2014 and 2017 through a sponsored research agreement that aided technology development and advanced the project's science.

With SSPD-1 winding down its mission, the testbed stopped communications with Earth on November 11. The Vigoride-5 vehicle that hosted SSPD-1 will remain in orbit to support continued testing and demonstration of the vehicle's Microwave Electrothermal Thruster engines that use distilled water as a propellant. It will ultimately deorbit and disintegrate in Earth's atmosphere.

Meanwhile, the SSPP team continues work in the lab, studying the feedback from SSPD-1 to identify the next set of fundamental research challenges for the project to tackle.

- ❖ **Astronomers detect oldest black hole ever observed**

Date: January 17, 2024
Source: University of Cambridge



The galaxy cluster Abell 2744, which lies in front of the galaxy containing the newly discovered black hole X-ray: NASA / CXC / SAO / Ákos Bogdán; Infrared: NASA / ESA / CSA / STScI; Image Processing: NASA / CXC / SAO / L. Frattare & K. Arcand

Researchers have discovered the oldest black hole ever observed, dating from the dawn of the universe, and found that it is 'eating' its host galaxy to death.

The international team, led by the University of Cambridge, used the NASA/ESA/CSA James Webb Space Telescope (JWST) to detect the black hole, which dates from 400 million years after the big bang, more than 13 billion years ago. The results, which lead author Professor Roberto Maiolino says are "a giant leap forward," are reported in the journal *Nature*.

That this surprisingly massive black hole -- a few million times the mass of our Sun -- even exists so early in the universe challenges our assumptions about how black holes form and grow. Astronomers believe that the supermassive black holes found at the centre of galaxies like the Milky Way grew to their current size over billions of years. But the size of this newly-discovered black hole suggests that they might form in other ways: they might be 'born big' or they can eat matter at a rate that's five times higher than had been thought possible.

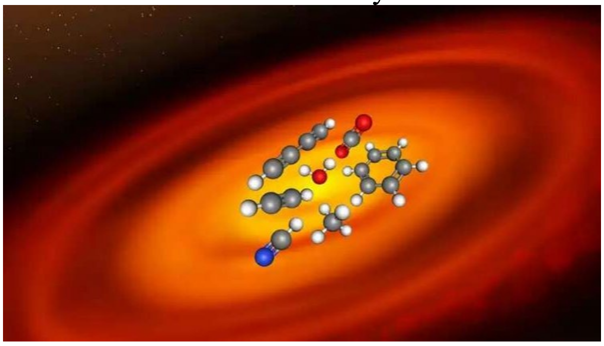
According to standard models, supermassive black holes form from the remnants of dead stars, which collapse and may form a black hole about a hundred times the mass of the Sun. If it grew in an expected way, this newly-detected black hole would take about a billion years to grow to its observed size. However, the universe was not yet a billion years old when this black hole was detected.

"It's very early in the universe to see a black hole this massive, so we've got to consider other ways they might form," said Maiolino, from Cambridge's Cavendish Laboratory and Kavli Institute of Cosmology. "Very early galaxies were extremely gas-rich, so they

would have been like a buffet for black holes."
Like all black holes, this young black hole is devouring material from its host galaxy to fuel its growth. Yet, this ancient black hole is found to gobble matter much more vigorously than its siblings at later epochs.
The young host galaxy, called GN-z11, glows from such an energetic black hole at its centre. Black holes cannot be directly observed, but instead they are detected by the tell-tale glow of a swirling accretion disc, which forms near the edges of a black hole. The gas in the accretion disc becomes extremely hot and starts to glow and radiate energy in the ultraviolet range. This strong glow is how astronomers are able to detect black holes.
GN-z11 is a compact galaxy, about one hundred times smaller than the Milky Way, but the black hole is likely harming its development. When black holes consume too much gas, it pushes the gas away like an ultra-fast wind. This 'wind' could stop the process of star formation, slowly killing the galaxy, but it will also kill the black hole itself, as it would also cut off the black hole's source of 'food'.
Maiolino says that the gigantic leap forward provided by JWST makes this the most exciting time in his career. "It's a new era: the giant leap in sensitivity, especially in the infrared, is like upgrading from Galileo's telescope to a modern telescope overnight," he said. "Before Webb came online, I thought maybe the universe isn't so interesting when you go beyond what we could see with the Hubble Space Telescope. But that hasn't been the case at all: the universe has been quite generous in what it's showing us, and this is just the beginning."
Maiolino says that the sensitivity of JWST means that even older black holes may be found in the coming months and years. Maiolino and his team are hoping to use future observations from JWST to try to find smaller 'seeds' of black holes, which may help them untangle the different ways that black holes might form: whether they start out large or they grow fast.
The research was supported in part by the European Research Council, the Royal Society, and the Science and Technology Facilities Council (STFC), part of UK Research and Innovation (UKRI).
Study delivers detailed photos of galaxies' inner structures

- **JWST data reveals how dust, gas assemble to form galactic disks**

Date: January 17, 2024
Source: Ohio State University



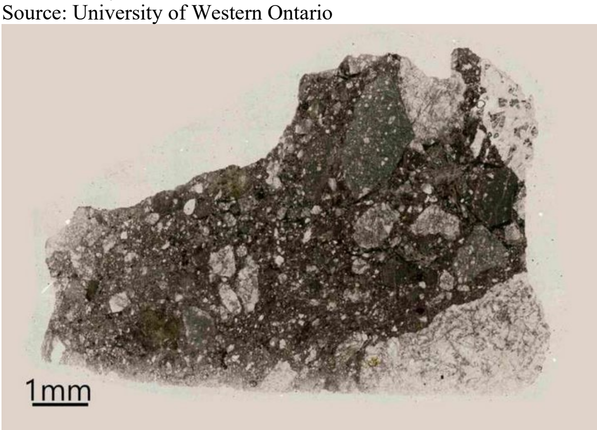
For the first time, high-resolution images captured by the James Webb Space Telescope are offering powerful insights into the complex dust patterns of nearby star-forming galaxies.

One of the most fundamental building blocks in the universe, cosmic dust is a vital ingredient to the growth of a galaxy. When scattered, these tiny grains help plant the seeds for the creation of stars and planets alike -- yet only recently, through rapid leaps in technology, have astronomers begun to shine a brighter light on their intricate physics.
Led by scientists at The Ohio State University, an international team of astronomers used data collected by the James Webb Space Telescope's Mid-Infrared Instrument to create stunning visuals of 19 spiral galaxies located relatively close to the Milky Way. By examining infrared light -- wavelengths invisible to the naked eye -- these incredibly precise images reveal how dust fertilizes the universe after being heated by both massive young stars and surrounding interstellar space radiation.
"Using this brand-new data, we're able to see the distribution of dust emission and determine what the interstellar material in the disks of these galaxies looks like," said Debosmita Pathak, lead author of the study and a graduate student in astronomy at Ohio State.
The images were taken from the PHANGS-JWST Cycle 1 Treasury, a survey collaboration that uses high-powered telescopes to better understand galactic evolution. In this study, they used data collected from the first year of Webb observations to create probability distribution function (PDF) measurements that chart the galaxies' dust emissions in the mid-infrared. They found that the disks of galaxies in the mid-infrared show both a normal distribution of gas (represented in the study's PDF charts as a high peak) and a high distribution (appearing as a gentle slope). While the

regions where star-forming nurseries reside look noticeably different, the shape and width of the distribution of diffuse gas in these galaxies stayed consistent.
"Dynamically, they've all got very different things going on in the centres," said Pathak. "But once you take the centres out of the picture, the disks of these galaxies look very similar to each other."
The study, published recently in *The Astronomical Journal*, suggests that because the patterns of infrared light emitted by these observed galaxies seem to be uniform, the density of the gas inside galactic disks follows a specific pattern even when shaped by very different galactic environments. "Because this dust traces out the fuel for future generations of stars," Pathak said, "the similarity we see among galaxies hints that some aspects of star and planet formation may be universal across galaxies."
By illuminating another clue about the mysteries of our universe, these galactic snapshots also provide an opportunity for humans to take a look in the cosmic mirror, Pathak said.
"It's hard for us to get a global perspective of the Milky Way," said Pathak. "This study tells us that if you looked at it as an outsider, you would see something similar to what we saw for a bunch of other nearby galaxies."
Moreover, deepening our current understanding of the structure of nearby galaxies could lead to a better grasp of astrophysics, including how various objects in the universe fit together.
Ultimately, once more data becomes available after the next few JWST cycles, the team plans to redo much of the work with an even larger and richer sample size.
"You can't observe all galaxies in the universe at such high resolutions, so it helps to be able to make quantitative statements about them in general, because that allows us to extrapolate about more and more galaxies in the future," said Pathak.
This study was supported by the National Science Foundation, the Alexander von Humboldt Foundation, the Heising-Simons Foundation, the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Simons Foundation. Other Ohio State co-authors were Adam K. Leroy, Todd A. Thompson and Laura A. Lopez.

❖ Discovery changes understanding of water's history on the Moon

Date: January 16, 2024
Source: University of Western Ontario



The lunar meteorite sample Tara Hayden investigated and successfully discovered the water-bearing mineral apatite. Credit: Tara Hayden

New research from a Western University postdoctoral fellow shows the early lunar crust which makes up the surface of the Moon was considerably enriched in water more than 4 billion years ago, counter to previously held understanding. The discovery is outlined in a study published today in the journal *Nature Astronomy.*
Working with a meteorite she classified as one that came from the Moon while a graduate student at The Open University (U.K.), Tara Hayden identified, for the first time, the mineral apatite (the most common phosphate) in a sample of early lunar crust.
The research offers exciting new evidence that the Moon's early crust contained more water than was originally thought, opening new doors into the study of lunar history.
"The discovery of apatite in the Moon's early crust for the first time is incredibly exciting -- as we can finally start to piece together this unknown stage of lunar history. We find the Moon's early crust was richer in water than we expected, and its volatile stable isotopes reveal an even more complex history than we knew before," said Hayden, currently working as a cosmochemist with planetary geologist Gordon "Oz" Osinski in Western's department of Earth sciences.
"Lunar meteorites are revealing new, exciting parts of the Moon's evolution and expanding our knowledge beyond the samples collected during the Apollo missions. As the new stage of lunar exploration begins, I am eager to see what we will learn from the lunar far side," said Hayden.
The Apollo samples were first assumed to be 'volatile-poor' upon their return from the Moon, leading to the wide-known description of the Moon as 'bone dry.'

In 2008, Alberto Saal and other researchers discovered the presence of significant amounts of water and other volatiles in glass beads from the Apollo sample collection. This set forth fifteen years of re-analysis of the Apollo samples while newly found lunar meteorites have revealed the Moon had much more water across its surface.

"We know most about the history of water on the Moon from the Apollo samples, but those samples are thought to only represent about five per cent of the entire Moon surface," said Hayden. "Until we get more samples back in the upcoming Artemis missions, the only other samples from the surface we have are meteorites."

Hayden made the discovery at The Open University during her PhD studies while verifying a rock sample for a collector as a lunar meteorite. Beyond its identification, the sample proved to be holding a key piece of data about water on the Moon.

"I was so lucky the meteorite not only came from the Moon but remarkably, featured chemistry so vital to our understanding about lunar water-bearing minerals," said Hayden.

This work was focused primarily on the mineral apatite, which contains volatile elements in its mineral structure. Apatite was found in all lunar rock types except glass beads and ferroan anorthosites, the latter representing the Moon's early crust. The Ferroan Anorthosite group is known to be incredibly old (4.5-4.3 billion years old) and is the only rock type known to have formed directly from the Lunar Magma Ocean -- when the Moon was almost entirely molten. The discovery of apatite in this rock type has allowed for the direct examination of this unknown stage in lunar evolution for the first time.

"Unravelling the history of water in the earliest-formed lunar crust approximately 4.5 billion years ago is important for improving our understanding of the origin of water in the Solar System. Ancient rock samples from the Moon in the form of lunar meteorites provide an excellent opportunity for undertaking such investigations," said Mahesh Anand, professor of planetary science and exploration at The Open University and Hayden's formal lead supervisor.

Future Artemis missions

Hayden says the timing of the discovery is perfect as the NASA Artemis missions are preparing for launch and researchers, including her current supervisor, are developing programming and targets for the astronauts.

"It has been long believed the lunar surface has been dried out for thousands and even millions of years, but maybe there might be more water available than we thought on the surface of the Moon and we just need to find a way to extract it," said Hayden.

Osinski is equally excited for the potential opportunities of this new discovery.

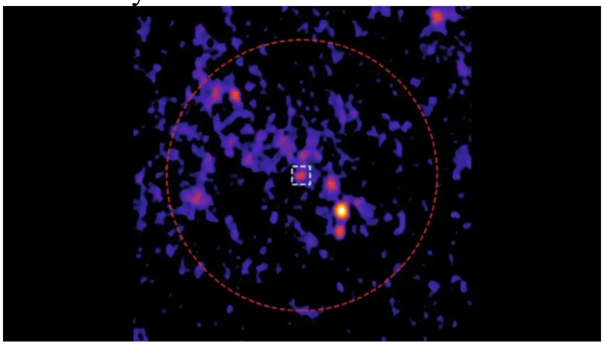
Last year, Osinski was selected for the NASA geology team that is developing the surface science plan for the first crewed lunar landing mission in more than 50 years. He will join his colleagues in mission control's science backroom at NASA's Johnson Space Centre in Houston providing support throughout the Artemis III mission.

"Tara's discoveries are super exciting and will feed into our sampling strategy for the Artemis III mission where we hope to identify and sample some of the earliest crust on the Moon," said Osinski.

Osinski also serves as principal investigator and scientific lead on Canada's first lunar rover, which is being designed and built by Canadensys Aerospace.

- **Astronomers produce most sensitive radio image ever of ancient star cluster**

Date: January 16, 2024
Source: International Centre for Radio Astronomy Research



A team of astronomers identified a new radio source (white square) in the centre of globular cluster 47 Tucanae (red circle). Paduano et al.

A global team of astronomers have created the most sensitive radio image ever of a globular cluster, an ancient ball of tightly-packed stars. The image is of the second brightest globular cluster in the night sky -- known as 47 Tucanae -- and was produced by a team led by the Curtin University node of the International Centre for Radio Astronomy Research (ICRAR) in Western Australia.

The scientists also detected a previously undiscovered radio signal from the centre of the cluster.
The research was published overnight in *The Astrophysical Journal*.
Astronomer Dr Arash Bahramian, from ICRAR's Curtin University node, says star clusters are an ancient relic of the early Universe.
"Globular clusters are very old, giant balls of stars that we see around the Milky Way," he said. "They're incredibly dense, with tens of thousands to millions of stars packed together in a sphere.
"Our image is of 47 Tucanae, one of the most massive globular clusters in the galaxy. It has over a million stars and a very bright, very dense core."
Dr Bahramian said the ultra-sensitive image was created from more than 450 hours of observations on CSIRO's Australia Telescope Compact Array (ATCA), on Gomeroi Country.
It is the deepest, most sensitive radio image ever compiled by any Australian radio telescope.
Dr Bahramian said 47 Tucanae can be seen with the naked eye and was first catalogued in the 1700s.
But he said imaging it in such great detail allowed astronomers to discover an incredibly faint radio signal at the centre of the cluster that had not been detected before.
Lead author Dr Alessandro Paduano, from ICRAR's Curtin University node, said the detection of the signal was an exciting discovery and could be attributed to one of two possibilities.
"The first is that 47 Tucanae could contain a black hole with a mass somewhere between the supermassive black holes found in the centres of galaxies and the stellar black holes created by collapsed stars," he said.
"While intermediate-mass black holes are thought to exist in globular clusters, there hasn't been a clear detection of one yet.
"If this signal turns out to be a black hole, it would be a highly significant discovery and the first ever radio detection of one inside a cluster."
The second possible source of the signal is a pulsar -- a rotating neutron star that emits radio waves.
"A pulsar this close to a cluster centre is also a scientifically interesting discovery, as it could be used to search for a central black hole that is yet to be detected." Dr Paduano said.
Co-author Dr Tim Galvin, a research scientist with CSIRO, said the project once again demonstrated the ongoing importance of ATCA.
"This project has stretched our software to its limits, in terms of both data management and processing, and it has been really exciting to see the wealth of science that these techniques have enabled."
"Alessandro's research represents a culmination of years of research and technological advancements, and ATCA's ultra-deep image of 47 Tucanae represents just the beginning of the discoveries that are yet to come."
The ultra-sensitive image produced is what researchers can expect from the SKA radio telescopes, currently being built in Australia and South Africa by the SKA Observatory (SKAO).
Once complete, the SKA telescopes will be the two largest radio telescope arrays in the world, transforming our understanding of the Universe and tackling some of the most fundamental scientific questions of our time.
Dr Bahramian said researchers are continually finding new and innovative ways to get the best out of the radio telescopes they use.
"We managed to achieve close to SKA-quality science with the current generation of radio telescopes, combining hundreds of hours of observations to reveal the faintest details," he said.
"It gives us a glimpse of the exciting capabilities the next generation of radio telescopes will achieve when they come online."
The technique used for the ultra-sensitive image could help future radio telescopes, such as the SKA, to detect some of the faintest objects in the Universe.