# South Downs Mercury

**The monthly circular of South Downs Astronomical Society**
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**Main Talk Trevor Pitt This talk will follow the life of Arthur C Clarke**

For the Raffle this month we have an Arena 114mm Refractor Telescope

This talk will follow the life of Arthur C Clarke, born 1917, from his early collections of science fiction through becoming the chair of the interplanetary society to his varied collections of science fiction and science fact writings. In terms of space, Arthur is best known for conceptualising the communication satellites in geosynchronous orbit (sometimes called the Clarke orbit) and promoting the global view of space exploration

- Astronomers witness the birth of a very distant cluster of galaxies from the early Universe

Date: March 30, 2023
Source: ESO

Using the Atacama Large Millimetre/submillimetre Array (ALMA), of which ESO is a partner, astronomers have discovered a large reservoir of hot gas in the still-forming galaxy cluster around the Spiderweb galaxy -- the most distant detection of such hot gas yet. Galaxy clusters are some of the largest objects known in the Universe and this result, published today in *Nature*, further reveals just how early these structures begin to form.
Galaxy clusters, as the name suggests, host a large number of galaxies -- sometimes even thousands. They also contain a vast "intracluster medium" (ICM) of gas that permeates the space between the galaxies in the cluster. This gas in fact considerably outweighs the galaxies themselves. Much of the physics of galaxy clusters is well understood; however, observations of the earliest phases of formation of the ICM remain scarce.
Previously, the ICM had only been studied in fully-formed nearby galaxy clusters. Detecting the ICM in distant protoclusters -- that is, still-forming galaxy clusters -- would allow astronomers to catch these clusters in the early stages of formation. A team led by Luca Di Mascolo, first author of the study and researcher at the University of Trieste, Italy, were keen to detect the ICM in a protocluster from the early stages of the Universe.
Galaxy clusters are so massive that they can bring together gas that heats up as it falls towards the cluster. "Cosmological simulations have predicted the presence of hot gas in protoclusters for over a decade, but observational confirmations has been missing," explains Elena Rasia, researcher at the Italian National Institute for Astrophysics (INAF) in Trieste, Italy, and co-author of the study. "Pursuing such key observational confirmation led us to carefully select one of the most promising candidates protoclusters." That was the Spiderweb protocluster, located at an epoch when the Universe was only 3 billion years old. Despite being the most intensively studied protocluster, the presence of the ICM has remained elusive. Finding a large reservoir of hot gas in the Spiderweb protocluster would indicate that the system is on its way to becoming a proper, long-lasting galaxy cluster rather than dispersing.
Di Mascolo's team detected the ICM of the Spiderweb protocluster through what's known as the thermal Sunyaev-Zeldovich (SZ) effect. This effect happens when light from the cosmic microwave background -- the relic radiation from the Big Bang -- passes through the ICM. When this light interacts with the fast-moving electrons in the hot gas it gains a bit of energy and its colour, or wavelength,

changes slightly. "At the right wavelengths, the SZ effect thus appears as a shadowing effect of a galaxy cluster on the cosmic microwave background," explains Di Mascolo.

By measuring these shadows on the cosmic microwave background, astronomers can therefore infer the existence of the hot gas, estimate its mass and map its shape. "Thanks to its unparalleled resolution and sensitivity, ALMA is the only facility currently capable of performing such a measurement for the distant progenitors of massive clusters," says Di Mascolo.

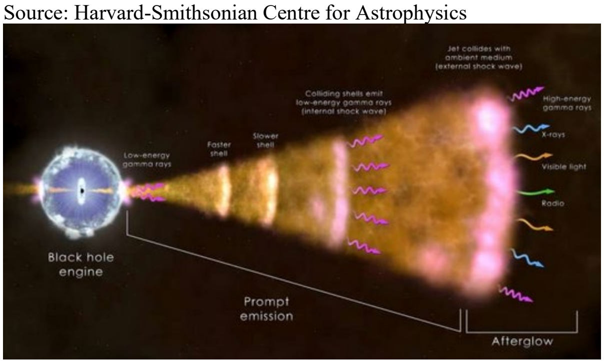
They determined that the Spiderweb protocluster contains a vast reservoir of hot gas at a temperature of a few tens of millions of degrees Celsius. Previously, cold gas had been detected in this protocluster, but the mass of the hot gas found in this new study outweighs it by thousands of times. This finding shows that the Spiderweb protocluster is indeed expected to turn into a massive galaxy cluster in around 10 billion years, growing its mass by at least a factor of ten.

Tony Mroczkowski, co-author of the paper and researcher at ESO, explains that "this system exhibits huge contrasts. The hot thermal component will destroy much of the cold component as the system evolves, and we are witnessing a delicate transition." He concludes that "it provides observational confirmation of long-standing theoretical predictions about the formation of the largest gravitationally bound objects in the Universe."

These results help to set the groundwork for synergies between ALMA and ESO's upcoming Extremely Large Telescope (ELT ), which "will revolutionise the study of structures like the Spiderweb," says Mario Nonino, a co-author of the study and researcher at the Astronomical Observatory of Trieste. The ELT and its state-of-the-art instruments, such as HARMONI and MICADO, will be able to peer into protoclusters and tell us about the galaxies in them in great detail. Together with ALMA's capabilities to trace the forming ICM, this will provide a crucial glimpse into the assembly of some of the largest structures in the early Universe.

- Brightest gamma-ray burst ever observed reveals new mysteries of cosmic explosions

Date: March 28, 2023
Source: Harvard-Smithsonian Centre for Astrophysics




This illustration shows the ingredients of a long gamma-ray burst, the most common type. The core of a massive star (left) has collapsed, forming a black hole that sends a jet of particles moving through the collapsing star and out into space at nearly the speed of light. Radiation across the spectrum arises from hot ionized gas (plasma) in the vicinity of the new-born black hole, collisions among shells of fast-moving gas within the jet (internal shock waves), and from the leading edge of the jet as it sweeps up and interacts with its surroundings (external shock). Credit: NASA's Goddard Space Flight Centre

On October 9, 2022, an intense pulse of gamma-ray radiation swept through our solar system, overwhelming gamma-ray detectors on numerous orbiting satellites, and sending astronomers on a chase to study the event using the most powerful telescopes in the world.

The new source, dubbed GRB 221009A for its discovery date, turned out to be the brightest gamma-ray burst (GRB) ever recorded.

In a new study that appears today in the *Astrophysical Journal Letters*, observations of GRB 221009A spanning from radio waves to gamma-rays, including critical millimetre-wave observations with the Centre for Astrophysics | Harvard & Smithsonian's Submillimetre Array (SMA) in Hawaii, shed new light on the decades-long quest to understand the origin of these extreme cosmic explosions.

The gamma-ray emission from GRB 221009A lasted over 300 seconds. Astronomers think that such "long-duration" GRBs are the birth cry of a black hole, formed as the core of a massive and rapidly spinning star collapses under its own weight. The new-born black hole launches powerful jets of plasma at near the speed of light, which pierce through the collapsing star and shine in gamma-rays.

With GRB 221009A being the brightest burst ever recorded, a real mystery lay in what would come after the initial burst of gamma-rays. "As the jets slam into gas surrounding the dying star, they produce a bright `afterglow' of light across the entire

spectrum," says Tanmoy Laskar, assistant professor of physics and astronomy at the University of Utah, and lead author of the study. "The afterglow fades quite rapidly, which means we have to be quick and nimble in capturing the light before it disappears, taking its secrets with it."
As part of a campaign to use the world's best radio and millimetre telescopes to study the afterglow of GRB 221009A, astronomers Edo Berger and Yvette Cendes of the Centre for Astrophysics (CfA) rapidly gathered data with the SMA.
"This burst, being so bright, provided a unique opportunity to explore the detailed behaviour and evolution of an afterglow with unprecedented detail -- we did not want to miss it!" says Edo Berger, professor of astronomy at Harvard University and the CfA. "I have been studying these events for more than twenty years, and this one was as exciting as the first GRB I ever observed."
"Thanks to its rapid-response capability, we were able to quickly turn the SMA to the location of GRB 221009A," says SMA project scientist and CfA researcher Garrett Keating. "The team was excited to see just how bright the afterglow of this GRB was, which we were able to continue to monitor for more than 10 days as it faded."
After analysing and combining the data from the SMA and other telescopes all over the world, the astronomers were flummoxed: the millimetre and radio wave measurements were much brighter than expected based on the visible and X-ray light.
"This is one of the most detailed datasets we have ever collected, and it is clear that the millimetre and radio data just don't behave as expected," says CfA research associate Yvette Cendes. "A few GRBs in the past have shown a brief excess of millimetre and radio emission that is thought to be the signature of a shockwave in the jet itself, but in GRB 221009A the excess emission behaves quite differently than in these past cases."
She adds, "It is likely that we have discovered a completely new mechanism to produce excess millimetre and radio waves."
One possibility, says Cendes, is that the powerful jet produced by GRB 221009A is more complex than in most GRBs. "It is possible that the visible and X-ray light are produced by one portion of the jet, while the early millimetre and radio waves are produced by a different component."
"Luckily, this afterglow is so bright that we will continue to study its radio emission for months and maybe years to come," adds Berger. "With this much longer time span we hope to decipher the mysterious origin of the early excess emission."
Independent of the exact details of this particular GRB, the ability to respond rapidly to GRBs and similar events with millimetre-wave telescopes is an essential new capability for astronomers.
"A key lesson from this GRB is that without fast-acting radio and millimetre telescopes, such as the SMA, we would miss out on potential discoveries about the most extreme explosions in the universe," says Berger. "We never know in advance when such events will occur, so we have to be as responsive as possible if we're going to take advantage of these gifts from the cosmos."

- Redness of Neptunium asteroids sheds light on early Solar System

Date: March 28, 2023
Source: Royal Astronomical Society

This is an artist's concept of a craggy piece of solar system debris that belongs to a class of bodies called trans-Neptunium objects (TNOs). Most TNOs are small and faint, making them difficult to spot. Generally, they are more than 100 million times fainter than objects visible to the unaided eye. The newfound TNOs range from 40 to 100 kilometres across. In this illustration, the distant Sun is reduced to a bright star at a distance of about 5 billion kilometres.
Credit
Artwork Credit: NASA, ESA, and G. Bacon (STScI). Science Credit: NASA, ESA, and C. Fuentes (Harvard-Smithsonian Centre for Astrophysics)
Licence type


Asteroids sharing their orbits with the planet Neptune have been observed to exist in a broad spectrum of red colour, implying the existence of two populations of asteroids in the region, according to a new study by an international team of researchers. The research is published in the journal *Monthly Notices of the Royal Astronomical Society: Letters*.
The team of scientists from the USA, California, France, the Netherlands, Chile and Hawaii observed 18 asteroids sharing the orbit of Neptune, known as Neptunium Trojans.

They are between 50 and 100 km in size and are located at a distance of around 4.5 billion kilometres from the Sun. Asteroids orbiting this far away are faint and so are challenging for astronomers to study. Before the new work, only about a dozen Neptunium Trojans had been studied, requiring the use of some of the largest telescopes on Earth.
The new data were gathered over the course of two years using the WASP wide field camera on the Palomar Observatory telescope in California, the GMOS cameras on the Gemini North and South telescopes in Hawaii and Chile, and the LRIS camera on the Keck Telescope in Hawaii.
Of the 18 observed Neptunium Trojans, several were much redder than most asteroids, and compared with other asteroids in this group looked at in previous studies. Redder asteroids are expected to have formed much further from the Sun; one population of these is known as the Cold Classical trans-Neptunium objects found beyond the orbit of Pluto, at around 6 billion kilometres from the Sun. The newly observed Neptunium Trojans are also unlike asteroids located in the orbit of Jupiter, which are typically more neutral in colour.
The redness of the asteroids implies that they contain a higher proportion of more volatile ices such as ammonia and methanol. These are extremely sensitive to heat, and can rapidly transform into gas if the temperature rises, so are more stable at large distances from the Sun.
The location of the asteroids at the same orbital distance as Neptune also implies that they are stable on timescales comparable to the age of the Solar System. They effectively act as a time-capsule, recording the initial conditions of the Solar System.
The presence of redder asteroids among the Neptunium Trojans suggests the existence of a transition zone between more neutral coloured and redder objects. The redder Neptunium asteroids may have formed beyond this transition boundary before being captured into the orbit of Neptune. The Neptunium Trojans would have been captured into the same orbit as the planet Neptune as the ice giant planet migrated from the inner solar system to where it is now, some 4.5 billion kilometres from the Sun.
Lead author Dr Bryce Bolin of the NASA Goddard Space Flight Centre said, "In our new work we have more than doubled the sample of Neptunium Trojans studied with large telescopes. It's exciting to find the first evidence of redder asteroids in this group."
"Because we have a larger sample of Neptunium Trojans with measured colours, we can now start to see major differences between asteroid groups. Our observations also show that the Neptunium Trojans are also different in colour compared to asteroid groups even further from the Sun. A possible explanation may be that the processing of the surfaces of asteroids by the Sun's heat may have different effects for asteroids at varying solar distances."

- JWST confirms giant planet atmospheres vary widely

Date: March 27, 2023
Source: Cornell University
An international team of astronomers has found the atmospheric compositions of giant planets out in the galaxy do not fit our own solar system trend.
Using NASA's James Webb Space Telescope (JWST), the researchers discovered that the atmosphere of exoplanet HD149026b, a 'hot Jupiter' orbiting a star comparable to our sun, is super-abundant in the heavier elements carbon and oxygen -- far above what scientists would expect for a planet of its mass.
These findings, published in "High atmospheric metal enrichment for a Saturn-mass planet" in *Nature* on March 27, provide insight into planet formation.
"It appears that every giant planet is different, and we're starting to see those differences thanks to JWST," said Jonathan Lunine, professor in the physical sciences at Cornell University and co-author of the study.
The giant planets of our solar system exhibit a nearly perfect correlation between both overall composition and atmospheric composition and mass, said Jacob Bean, professor of astronomy and astrophysics at the University of Chicago and lead author of the paper. Extrasolar planets show a much greater diversity of overall compositions, but scientists didn't know how varied their atmospheric compositions are, until this analysis of HD149026b -- also known as Smertrios.
Smertrios is super-enriched compared to its mass, Lunine said: "It's the mass of Saturn, but its atmosphere seems to have as much as 27 times the number of heavy elements

relative to its hydrogen and helium that we find in Saturn."
This ratio, called metallicity -- even though it includes many elements that are not metals -- is useful for comparing a planet to its home star, or other planets in its system, Lunine said. Smertrios is the only planet known in this particular planetary system.
Another key measurement is the ratio of carbon to oxygen in a planet's atmosphere, which reveals the "recipe" of original solids in a planetary system, Lunine said. For Smertrios, it's about 0.84 -- higher than in our solar system. In our sun, it's a bit more than one carbon for every two oxygen atoms (0.55).
While an abundance of carbon might seem favourable for chances of life, a high carbon to oxygen ratio actually means less water on a planet or in a planetary system -- a problem for life as we know it.
Smertrios is an interesting first case of atmospheric composition for this particular study, said Lunine, who has plans in place to observe five more giant exoplanets in the coming year using JWST. Many more observations are needed before astronomers can discover any patterns among giant planets or in systems with multiple giant planets or terrestrial planets to the compositional diversity astronomers are beginning to document.
"The origin of this diversity is a fundamental mystery in our understanding of planet formation," Bean said. "Our hope is that further atmospheric observations of extrasolar planets with JWST will quantify this diversity better and yield constraints on more complex trends that might exist."
The study was supported by NASA and the University of Chicago.

- Temperature of a rocky exoplanet measured

Date: March 27, 2023
Source: NASA/Goddard Space Flight Centre

*The exoplanet TRAPPIST-1 b in the artist's image. Source: NASA, ESA, CSA, J. Olmsted (STScI)*

An international team of researchers has used NASA's James Webb Space Telescope to measure the temperature of the rocky exoplanet TRAPPIST-1 b. The measurement is based on the planet's thermal emission: heat energy given off in the form of infrared light detected by Webb's Mid-Infrared Instrument (MIRI). The result indicates that the planet's dayside has a temperature of about 500 kelvins (roughly 450 degrees Fahrenheit) and suggests that it has no significant atmosphere.
This is the first detection of *any* form of light emitted by an exoplanet as small and as cool as the rocky planets in our own solar system. The result marks an important step in determining whether planets orbiting small active stars like TRAPPIST-1 can sustain atmospheres needed to support life. It also bodes well for Webb's ability to characterize temperate, Earth-sized exoplanets using MIRI.
"These observations really take advantage of Webb's mid-infrared capability," said Thomas Greene, an astrophysicist at NASA's Ames Research Centre and lead author on the study published today in the journal *Nature*. "No previous telescopes have had the sensitivity to measure such dim mid-infrared light."

**Rocky Planets Orbiting Ultracool Red Dwarfs**

In early 2017, astronomers reported the discovery of seven rocky planets orbiting an ultracool red dwarf star (or M dwarf) 40 light-years from Earth. What is remarkable about the planets is their similarity in size and mass to the inner, rocky planets of our own solar system. Although they all orbit much closer to their star than any of our planets orbit the Sun - all could fit comfortably within the orbit of Mercury - they receive comparable amounts of energy from their tiny star.
TRAPPIST-1 b, the innermost planet, has an orbital distance about one hundredth that of Earth's and receives about four times the amount of energy that Earth gets from the Sun. Although it is not within the system's habitable zone, observations of the planet can provide important information about its sibling planets, as well as those of other M-dwarf systems.
"There are ten times as many of these stars in the Milky Way as there are stars like the Sun, and they are twice as likely to have rocky planets as stars like the Sun," explained Greene. "But they are also very active - they are very bright when they're young, and they

give off flares and X-rays that can wipe out an atmosphere."

Co-author Elsa Ducrot from the French Alternative Energies and Atomic Energy Commission (CEA) in France, who was on the team that conducted earlier studies of the TRAPPIST-1 system, added, "It's easier to characterize terrestrial planets around smaller, cooler stars. If we want to understand habitability around M stars, the TRAPPIST-1 system is a great laboratory. These are the best targets we have for looking at the atmospheres of rocky planets."

**Detecting an Atmosphere (or not)**

Previous observations of TRAPPIST-1 b with the Hubble and Spitzer space telescopes found no evidence for a puffy atmosphere, but were not able to rule out a dense one.

One way to reduce the uncertainty is to measure the planet's temperature. "This planet is tidally locked, with one side facing the star at all times and the other in permanent darkness," said Pierre-Olivier Lagage from CEA, a co-author on the paper. "If it has an atmosphere to circulate and redistribute the heat, the dayside will be cooler than if there is no atmosphere."

The team used a technique called secondary eclipse photometry, in which MIRI measured the change in brightness from the system as the planet moved behind the star. Although TRAPPIST-1 b is not hot enough to give off its own visible light, it does have an infrared glow. By subtracting the brightness of the star on its own (during the secondary eclipse) from the brightness of the star and planet combined, they were able to successfully calculate how much infrared light is being given off by the planet.

**Measuring Minuscule Changes in Brightness**

Webb's detection of a secondary eclipse is itself a major milestone. With the star more than 1,000 times brighter than the planet, the change in brightness is less than 0.1%.

"There was also some fear that we'd miss the eclipse. The planets all tug on each other, so the orbits are not perfect," said Taylor Bell, the post-doctoral researcher at the Bay Area Environmental Research Institute who analysed the data. "But it was just amazing: The time of the eclipse that we saw in the data matched the predicted time within a couple of minutes."

The team analysed data from five separate secondary eclipse observations. "We compared the results to computer models showing what the temperature should be in different scenarios," explained Ducrot. "The results are almost perfectly consistent with a blackbody made of bare rock and no atmosphere to circulate the heat. We also didn't see any signs of light being absorbed by carbon dioxide, which would be apparent in these measurements."

This research was conducted as part of Webb Guaranteed Time Observation (GTO) program 1177, which is one of eight programs from Webb's first year of science designed to help fully characterize the TRAPPIST-1 system. Additional secondary eclipse observations of TRAPPIST-1 b are currently in progress, and now that they know how good the data can be, the team hopes to eventually capture a full phase curve showing the change in brightness over the entire orbit. This will allow them to see how the temperature changes from the day to the nightside and confirm if the planet has an atmosphere or not.

"There was one target that I dreamed of having," said Lagage, who worked on the development of the MIRI instrument for more than two decades. "And it was this one. This is the first time we can detect the emission from a rocky, temperate planet. It's a really important step in the story of discovering exoplanets."

- ❖ Artificial intelligence discovers secret equation for 'weighing' galaxy clusters

Date: March 23, 2023
Source: Simons Foundation

This image taken by NASA's Hubble Space Telescope shows a spiral galaxy (bottom left) in front of a large galaxy cluster. New research leveraged an artificial tool to estimate the masses of galaxy clusters more accurately. ESA/Hubble & NASA

Astrophysicists at the Institute for Advanced Study, the Flatiron Institute and their colleagues have leveraged artificial intelligence to uncover a better way to estimate the mass of colossal clusters of galaxies. The AI discovered that by just adding a simple term to an existing equation, scientists can produce far better mass estimates than they previously had.
The improved estimates will enable scientists to calculate the fundamental properties of the universe more accurately, the astrophysicists reported March 17, 2023, in the *Proceedings of the National Academy of Sciences*.
"It's such a simple thing; that's the beauty of this," says study co-author Francisco Villaescusa-Navarro, a research scientist at the Flatiron Institute's Centre for Computational Astrophysics (CCA) in New York City. "Even though it's so simple, nobody before found this term. People have been working on this for decades, and still they were not able to find this."
The work was led by Digvijay Wadekar of the Institute for Advanced Study in Princeton, New Jersey, along with researchers from the CCA, Princeton University, Cornell University and the Centre for Astrophysics | Harvard & Smithsonian.
Understanding the universe requires knowing where and how much *stuff* there is. Galaxy clusters are the most massive objects in the universe: A single cluster can contain anything from hundreds to thousands of galaxies, along with plasma, hot gas and dark matter. The cluster's gravity holds these components together. Understanding such galaxy clusters is crucial to pinning down the origin and continuing evolution of the universe.
Perhaps the most crucial quantity determining the properties of a galaxy cluster is its total mass. But measuring this quantity is difficult -- galaxies cannot be 'weighed' by placing them on a scale. The problem is further complicated because the dark matter that makes up much of a cluster's mass is invisible. Instead, scientists deduce the mass of a cluster from other observable quantities.
In the early 1970s, Rashid Sunyaev, current distinguished visiting professor at the Institute for Advanced Study's School of Natural Sciences, and his collaborator Yakov B. Zel'dovich developed a new way to estimate galaxy cluster masses. Their method relies on the fact that as gravity squashes matter together, the matter's electrons push back. That electron pressure alters how the electrons interact with particles of light called photons. As photons left over from the Big Bang's afterglow hit the squeezed material, the interaction creates new photons. The properties of those photons depend on how strongly gravity is compressing the material, which in turn depends on the galaxy cluster's heft. By measuring the photons, astrophysicists can estimate the cluster's mass. However, this 'integrated electron pressure' is not a perfect proxy for mass, because the changes in the photon properties vary depending on the galaxy cluster. Wadekar and his colleagues thought an artificial intelligence tool called 'symbolic regression' might find a better approach. The tool essentially tries out different combinations of mathematical operators -- such as addition and subtraction -- with various variables, to see what equation best matches the data.
Wadekar and his collaborators 'fed' their AI program a state-of-the-art universe simulation containing many galaxy clusters. Next, their program, written by CCA research fellow Miles Cranmer, searched for and identified additional variables that might make the mass estimates more accurate.
AI is useful for identifying new parameter combinations that human analysts might overlook. For example, while it is easy for human analysts to identify two significant parameters in a dataset, AI can better parse

through high volumes, often revealing unexpected influencing factors.
"Right now, a lot of the machine-learning community focuses on deep neural networks," Wadekar explained. "These are very powerful, but the drawback is that they are almost like a black box. We cannot understand what goes on in them. In physics, if something is giving good results, we want to know why it is doing so. Symbolic regression is beneficial because it searches a given dataset and generates simple mathematical expressions in the form of simple equations that you can understand. It provides an easily interpretable model."
The researchers' symbolic regression program handed them a new equation, which was able to better predict the mass of the galaxy cluster by adding a single new term to the existing equation. Wadekar and his collaborators then worked backward from this AI-generated equation and found a physical explanation. They realized that gas concentration correlates with the regions of galaxy clusters where mass inferences are less reliable, such as the cores of galaxies where supermassive black holes lurk. Their new equation improved mass inferences by downplaying the importance of those complex cores in the calculations. In a sense, the galaxy cluster is like a spherical doughnut. The new equation extracts the jelly at the centre of the doughnut that can introduce larger errors, and instead concentrates on the doughy outskirts for more reliable mass inferences.
The researchers tested the AI-discovered equation on thousands of simulated universes from the CCA's CAMELS suite. They found that the equation reduced the variability in galaxy cluster mass estimates by around 20 to 30 percent for large clusters compared with the currently used equation.
The new equation can provide observational astronomers engaged in upcoming galaxy cluster surveys with better insights into the mass of the objects they observe. "There are quite a few surveys targeting galaxy clusters [that] are planned in the near future," Wadekar noted. "Examples include the Simons Observatory, the Stage 4 CMB experiment and an X-ray survey called eROSITA. The new equations can help us in maximizing the scientific return from these surveys."
Wadekar also hopes that this publication will be just the tip of the iceberg when it comes to using symbolic regression in astrophysics. "We think that symbolic regression is highly applicable to answering many astrophysical questions," he said. "In a lot of cases in astronomy, people make a linear fit between two parameters and ignore everything else. But nowadays, with these tools, you can go further. Symbolic regression and other artificial intelligence tools can help us go beyond existing two-parameter power laws in a variety of different ways, ranging from investigating small astrophysical systems like exoplanets, to galaxy clusters, the biggest things in the universe."

- AI finds the first stars were not alone

Date: March 23, 2023
Source: Kavli Institute for the Physics and Mathematics of the Universe

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By using machine learning and state-of-the-art supernova nucleosynthesis, a team of researchers have found the majority of observed second-generation stars in the universe were enriched by multiple supernovae, reports a new study in *The Astrophysical Journal*.
Nuclear astrophysics research has shown elements including and heavier than carbon in the universe is produced in stars. But the first stars, stars born soon after the Big Bang, did not contain such heavy elements, which astronomers call 'metals'. The next generation of stars contained only a small number of heavy elements produced by the first stars. To understand the universe in its infancy, it requires researchers to study these metal-poor stars.
Luckily, these second-generation metal-poor stars are observed in our Milky Way Galaxy, and have been studied by a team of Affiliate Members of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) to close in on the physical properties of the first stars in the universe.
The team, led by Kavli IPMU Visiting Associate Scientist and The University of Tokyo Institute for Physics of Intelligence Assistant Professor Tilman Hartwig, including

Visiting Associate Scientist and National Astronomical Observatory of Japan Assistant Professor Miho Ishigaki, Visiting Senior Scientist and University of Hertfordshire Professor Chiaki Kobayashi, Visiting Senior Scientist and National Astronomical Observatory of Japan Professor Nozomu Tominaga, and Visiting Senior Scientist and The University of Tokyo Professor Emeritus Ken'ichi Nomoto, used artificial intelligence to analyse elemental abundances in more than 450 extremely metal-poor stars observed to date. Based on the newly developed supervised machine learning algorithm trained on theoretical supernova nucleosynthesis models, they found that 68 per cent of the observed extremely metal-poor stars have a chemical fingerprint consistent with enrichment by multiple previous supernovae. The team's results give the first quantitative constraint based on observations on the multiplicity of the first stars.

"Multiplicity of the first stars were only predicted from numerical simulations so far, and there was no way to observationally examine the theoretical prediction until now," said lead author Hartwig. "Our result suggests that most first stars formed in small clusters so that multiple of their supernovae can contribute to the metal enrichment of the early interstellar medium," he said.

"Our new algorithm provides an excellent tool to interpret the big data we will have in the next decade from on-going and future astronomical surveys across the world" said Kobayashi, also a Leverhulme Research Fellow.

"At the moment, the available data of old stars are the tip of the iceberg within the solar neighbourhood. The Prime Focus Spectrograph, a cutting-edge multi-object spectrograph on the Subaru Telescope developed by the international collaboration led by Kavli IPMU, is the best instrument to discover ancient stars in the outer regions of the Milky Way far beyond the solar neighbourhood.," said Ishigaki.

The new algorithm invented in this study opens the door to make the most of diverse chemical fingerprints in metal-poor stars discovered by the Prime Focus Spectrograph.

"The theory of the first stars tells us that the first stars should be more massive than the Sun. The natural expectation was that the first star was born in a gas cloud containing the mass million times more than the Sun. However, our new finding strongly suggests that the first stars were not born alone, but instead formed as a part of a star cluster or a binary or multiple star system. This also means that we can expect gravitational waves from the first binary stars soon after the Big Bang, which could be detected future missions in space or on the Moon," said Kobayashi.

- ❖ Surprisingly simple explanation for the alien comet 'Oumuamua's weird orbit

2017 comet's unusual acceleration explained by hydrogen outgassing from ice

Date: March 22, 2023
Source: University of California – Berkeley

An artist's depiction of the interstellar comet 'Oumuamua, as it warmed up in its approach to the sun and outgassed hydrogen (white mist), which slightly altered its orbit. The comet, which is most likely pancake-shaped, is the first known object other than dust grains to visit our solar system from another star. (Image credit: NASA, ESA and Joseph Olmsted and Frank Summers of STScI)

In 2017, a mysterious comet dubbed 'Oumuamua fired the imaginations of scientists and the public alike. It was the first known visitor from outside our solar system, it had no bright coma or dust tail, like most comets, and a peculiar shape -- something between a cigar and a pancake -- and its small size more befitted an asteroid than a comet. But the fact that it was accelerating away from the sun in a way that astronomers could not explain perplexed scientists, leading some to suggest that it was an alien spaceship.

Now, a University of California, Berkeley, Astro chemist and a Cornell University astronomer argue that the comet's mysterious deviations from a hyperbolic path around the sun can be explained by a simple physical mechanism likely common among many icy comets: outgassing of hydrogen as the comet warmed up in the sunlight.

What made 'Oumuamua different from every other well-studied comet in our solar system was its size: It was so small that its gravitational deflection around the sun was

slightly altered by the tiny push created when hydrogen gas spurted out of the ice.
Most comets are essentially dirty snowballs that periodically approach the sun from the outer reaches of our solar system. When warmed by sunlight, a comet ejects water and other molecules, producing a bright halo or coma around it and often tails of gas and dust. The ejected gases act like the thrusters on a spacecraft to give the comet a tiny kick that alters its trajectory slightly from the elliptical orbits typical of other solar system objects, such as asteroids and planets.
When discovered, 'Oumuamua had no coma or tail and was too small and too far from the sun to capture enough energy to eject much water, which led astronomers to speculate wildly about its composition and what was pushing it outward. Was it a hydrogen iceberg outgassing $H_2$? A large, fluffy snowflake pushed by light pressure from the sun? A light sail created by an alien civilization? A spaceship under its own power?
Jennifer Bergner, a UC Berkeley assistant professor of chemistry who studies the chemical reactions that occur on icy rocks in the cold vacuum of space, thought there might be a simpler explanation. She broached the subject with a colleague, Darryl Seligman, now a National Science Foundation postdoctoral fellow at Cornell University, and they decided to work together to test it.
"A comet traveling through the interstellar medium basically is getting cooked by cosmic radiation, forming hydrogen as a result. Our thought was: If this was happening, could you actually trap it in the body, so that when it entered the solar system and it was warmed up, it would outgas that hydrogen?" Bergner said. "Could that quantitatively produce the force that you need to explain the non-gravitational acceleration?"
Surprisingly, she found that experimental research published in the 1970s, '80s and '90s demonstrated that when ice is hit by high-energy particles akin to cosmic rays, molecular hydrogen ($H_2$) is abundantly produced and trapped within the ice. In fact, cosmic rays can penetrate tens of meters into ice, converting a quarter or more of the water to hydrogen gas.
"For a comet several kilometres across, the outgassing would be from a really thin shell relative to the bulk of the object, so both compositionally and in terms of any acceleration, you wouldn't necessarily expect that to be a detectable effect," she said. "But because 'Oumuamua was so small, we think that it actually produced sufficient force to power this acceleration."
The comet, which was slightly reddish, is thought to have been roughly 115 by 111 by 19 meters in size. While the relative dimensions were fairly certain, however, astronomers couldn't be sure of the actual size because it was too small and distant for telescopes to resolve. The size had to be estimated from the comet's brightness and how the brightness changed as the comet tumbled. To date, all the comets observed in our solar system -- the short-period comets originating in the Kuiper belt and the long-period comets from the more distant Oort cloud have ranged from around 1 kilometre to hundreds of kilometres across.
"What's beautiful about Jenny's idea is that it's exactly what should happen to interstellar comets," Seligman said. "We had all these stupid ideas, like hydrogen icebergs and other crazy things, and it's just the most generic explanation."
Bergner and Seligman will publish their conclusions this week in the journal *Nature*. Both were postdoctoral fellows at the University of Chicago when they began collaborating on the paper.

**Messenger from afar**

Comets are icy rocks left over from the formation of the solar system 4.5 billion years ago, so they can tell astronomers about the conditions that existed when our solar system formed. Interstellar comets can also give hints to the conditions around other stars surrounded by planet-forming disks.
"Comets preserve a snapshot of what the solar system looked like when it was in the stage of evolution that protoplanetary disks are now," Bergner said. "Studying them is a way to look back at what our solar system used to look like in the early formation stage."
Faraway planetary systems also seem to have comets, and many are likely to be ejected because of gravitational interactions with other objects in the system, which astronomers know happened over the history of our solar system. Some of these rogue comets should occasionally enter our solar system, providing an opportunity to learn about planet formation in other systems.
"The comets and asteroids in the solar system have arguably taught us more about planet formation than what we've learned from the

actual planets in the solar system," Seligman said. "I think that the interstellar comets could arguably tell us more about extrasolar planets than the extrasolar planets we are trying to get measurements of today."
In the past, astronomers published numerous papers about what we can learn from the failure to observe any interstellar comets in our solar system.
Then, 'Oumuamua came along.
On Oct. 19, 2017, on the island of Maui, astronomers using the Pan-STARRS1 telescope, which is operated by the Institute for Astronomy at the University of Hawaii in Manoa, first noticed what they thought was either a comet or an asteroid. Once they realized that its tilted orbit and high speed -- 87 kilometres per second -- implied that it came from outside our solar system, they gave it the name 1I/'Oumuamua (oh MOO-uh MOO-uh), which is Hawai'ian for "a messenger from afar arriving first." It was the first interstellar object aside from dust grains ever seen in our solar system. A second, 2I/Borisov, was discovered in 2019, though it looked and behaved more like a typical comet.
As more and more telescopes focused on 'Oumuamua, the astronomers were able to chart its orbit and determine that it had already looped around the sun and was headed out of the solar system.
Because 'Oumuamua's brightness changed periodically by a factor of 12 and varied asymmetrically, it was assumed to be highly elongated and tumbling end over end.
Astronomers also noticed a slight acceleration away from the sun larger than seen for asteroids and more characteristic of comets. When comets approach the sun, the water and gases ejected from the surface create a glowing, gaseous coma and release dust in the process. Typically, dust left in the comet's wake becomes visible as one tail, while vapor and dust pushed by light pressure from solar rays produces a second tail pointing away from the sun, plus a little inertial push outward. Other compounds, such as entrapped organic materials and carbon monoxide, also can be released.

**Why was it accelerating?**

But astronomers could detect no coma, outgassed molecules or dust around 'Oumuamua. In addition, calculations showed that the solar energy hitting the comet would be insufficient to sublimate water or organic compounds from its surface to give it the observed non-gravitational kick. Only hyper volatile gases such as $H_2$, $N_2$ or carbon monoxide (CO) could provide enough acceleration to match observations, given the incoming solar energy.
"We had never seen a comet in the solar system that didn't have a dust coma. So, the non-gravitational acceleration really was weird," Seligman said.
This led to much speculation about what volatile molecules could be in the comet to cause the acceleration. Seligman himself published a paper arguing that if the comet was composed of solid hydrogen -- a hydrogen iceberg -- it would outgas enough hydrogen in the heat of the sun to explain the strange acceleration. Under the right conditions, a comet composed of solid nitrogen or solid carbon monoxide would also outgas with enough force to affect the comet's orbit.
But astronomers had to stretch to explain what conditions could lead to the formation of solid bodies of hydrogen or nitrogen, which have never been observed before. And how could a solid $H_2$ body survive for perhaps 100 million years in interstellar space?
Bergner thought that outgassing of hydrogen entrapped in ice might be sufficient to accelerate 'Oumuamua. As both an experimentalist and a theoretician, she studies the interaction of very cold ice -- chilled to 5- or 10-degrees Kelvin, the temperature of the interstellar medium (ISM) -- with the kinds of energetic particles and radiation found in the ISM.
In searching through past publications, she found many experiments demonstrating that high-energy electrons, protons and heavier atoms could convert water ice into molecular hydrogen, and that the fluffy, snowball structure of a comet could entrap the gas in bubbles within the ice. Experiments showed that when warmed, as by the heat of the sun, the ice anneals -- changes from an amorphous to a crystal structure -- and forces the bubbles out, releasing the hydrogen gas. Ice at the surface of a comet, Bergner and Seligman calculated, could emit enough gas, either in a collimated beam or fan-shaped spray, to affect the orbit of a small comet like 'Oumuamua.
"The main takeaway is that 'Oumuamua is consistent with being a standard interstellar comet that just experienced heavy processing," Bergner said. "The models we ran are consistent with what we see in the

solar system from comets and asteroids. So, you could essentially start with something that looks like a comet and have this scenario work."

The idea also explains the lack of a dust coma. "Even if there was dust in the ice matrix, you're not sublimating the ice, you're just rearranging the ice and then letting $H_2$ get released. So, the dust isn't even going to come out," Seligman said.

**'Dark' comets**

Seligman said that their conclusion about the source of 'Oumuamua's acceleration should close the book on the comet. Since 2017, he, Bergner and their colleagues have identified six other small comets with no observable coma, but with small non-gravitational accelerations, suggesting that such "dark" comets are common. While $H_2$ is not likely responsible for the accelerations of dark comets, Bergner noted, together with 'Oumuamua they reveal that there is much to be learned about the nature of small bodies in the solar system.

One of these dark comets, 1998 $KY_{26}$, is the next target for Japan's Hayabusa2 mission, which recently collected samples from the asteroid Ryugu. The 1998 $KY_{26}$ was thought to be an asteroid until it was identified as a dark comet in December.

"Jenny's definitely right about the entrapped hydrogen. Nobody had thought of that before," he said. "Between discovering other dark comets in the solar system and Jenny's awesome idea, I think it's got to be correct. Water is the most abundant component of comets in the solar system and likely in extrasolar systems, as well. And if you put a water rich comet in the Oort cloud or eject it into the interstellar medium, you should get amorphous ice with pockets of $H_2$."

Because $H_2$ should form in any ice-rich body exposed to energetic radiation, the researchers suspect that the same mechanism would be at work in sun-approaching comets from the Oort cloud at the outer reaches of the solar system, where comets are irradiated by cosmic rays, much like an interstellar comet would be. Future observations of hydrogen outgassing from long-period comets could be used to test the scenario of $H_2$ formation and entrapment.

Many more interstellar and dark comets should be discovered by the Rubin Observatory Legacy Survey of Space and Time (LSST), allowing astronomers to determine if hydrogen outgassing is common in comets. Seligman has calculated that the survey, which will be conducted at the Vera C. Rubin Observatory in Chile and is set to become operational in early 2025, should detect between one and three interstellar comets like 'Oumuamua every year, and likely many more that have a tell-tale coma, like Borisov.

Bergner was supported by a NASA Hubble Fellowship grant. Seligman was supported by the National Science Foundation (AST-17152) and NASA (80NSSC19K0444, NNX17AL71A).

- Neutrinos made by a particle collider detected

Discovery promises to help physicists understand nature of universe's most abundant particle

Date: March 22, 2023
Source: University of California – Irvine


The FASER particle detector, located deep underground at CERN's Large Hadron Collider and built-in large part out of spare parts from other experiments'

In a scientific first, a team led by physicists at the University of California, Irvine has detected neutrinos created by a particle collider. The discovery promises to deepen scientists' understanding of the subatomic particles, which were first spotted in 1956 and play a key role in the process that makes stars burn.

The work could also shed light on cosmic neutrinos that travel large distances and collide with the Earth, providing a window on distant parts of the universe.

It's the latest result from the Forward Search Experiment, or FASER, a particle detector designed and built by an international group of physicists and installed at CERN, the European Council for Nuclear Research in Geneva, Switzerland. There, FASER detects particles produced by CERN's Large Hadron Collider.

"We've discovered neutrinos from a brand-new source - particle colliders - where you have two beams of particles smash together at extremely high energy," said UC Irvine particle physicist and FASER Collaboration Co-Spokesman Jonathan Feng, who initiated the project, which involves over 80 researchers at UCI and 21 partner institutions.
Brian Petersen, a particle physicist at CERN, announced the results Sunday on behalf of FASER at the 57th Rencontres de Moriond Electroweak Interactions and Unified Theories conference in Italy.
Neutrinos, which were co-discovered nearly 70 years ago by the late UCI physicist and Nobel laureate Frederick Reines, are the most abundant particle in the cosmos and "were very important for establishing the standard model of particle physics," said Jamie Boyd, a particle physicist at CERN and co-spokesman for FASER. "But no neutrino produced at a collider had ever been detected by an experiment."
Since the ground-breaking work of Reines and others like Hank Sobel, UCI professor of physics & astronomy, the majority of neutrinos studied by physicists have been low-energy neutrinos. But the neutrinos detected by FASER are the highest energy ever produced in a lab and are similar to the neutrinos found when deep-space particles trigger dramatic particle showers in our atmosphere.
"They can tell us about deep space in ways we can't learn otherwise," said Boyd. "These very high-energy neutrinos in the LHC are important for understanding really exciting observations in particle astrophysics."
FASER itself is new and unique among particle-detecting experiments. In contrast to other detectors at CERN, such as ATLAS, which stands several stories tall and weighs thousands of tons, FASER is about one ton and fits neatly inside a small side tunnel at CERN. And it took only a few years to design and construct using spare parts from other experiments.
"Neutrinos are the only known particles that the much larger experiments at the Large Hadron Collider are unable to directly detect, so FASER's successful observation means the collider's full physics potential is finally being exploited," said UCI experimental physicist Dave Casper.
Beyond neutrinos, one of FASER's other chief objectives is to help identify the particles that make up dark matter, which physicists think comprises most of the matter in the universe, but which they've never directly observed.
FASER has yet to find signs of dark matter, but with the LHC set to begin a new round of particle collisions in a few months, the detector stands ready to record any that appear.
"We're hoping to see some exciting signals," said Boyd.

- Searching for life with space dust

A proposed way to search for alien life using tiny rocks ejected from other worlds
Date: March 22, 2023
Source: University of Tokyo

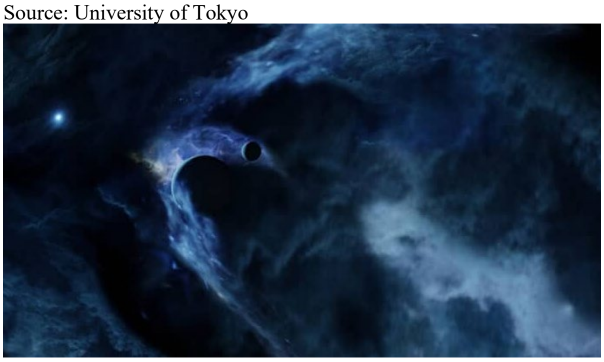


Image: Pixabay

Following enormous collisions, such as asteroid impacts, some amount of material from an impacted world may be ejected into space. This material can travel vast distances and for extremely long periods of time. In theory this material could contain direct or indirect signs of life from the host world, such as fossils of microorganisms. And this material could be detectable by humans in the near future, or even now.
When you hear the words vacuum and dust in a sentence, you may groan at the thought of having to do the housework. But in astronomy, these words have different connotations. Vacuum of course refers to the void of space. Dust, however, means diffuse solid material floating through space. It can be an annoyance to some astronomers as it may hinder their views of some distant object. Or dust could be a useful tool to help other astronomers learn about something distant without having to leave the safety of our own planet. Professor Tomonori Totani from the University of Tokyo's Department of Astronomy has an idea for space dust that might sound like science fiction but actually warrants serious consideration.
"I propose we study well-preserved grains ejected from other worlds for potential signs of life," said Totani. "The search for life outside our solar system typically means a

search for signs of communication, which would indicate intelligent life but precludes any pre-technological life. Or the search is for atmospheric signatures that might hint at life, but without direct confirmation there could always be an explanation that does not require life. However, if there are signs of life in dust grains, not only could we be certain, but we could also find out soon."

The basic idea is that large asteroid strikes can eject ground material into space. There is a chance that recently deceased or even fossilized microorganisms could be contained in some rocky material in this ejecta. This material will vary in size greatly, with different-sized pieces behaving differently once in space. Some larger pieces might fall back down or enter permanent orbits around a local planet or star. And some much smaller pieces might be too small to contain any verifiable signs of life. But grains in the region of 1 micrometre (one-thousandth of a millimetre) could not only host a specimen of a single-celled organism, but they could also potentially escape their host solar system altogether, and under the right circumstances, maybe even venture to ours.

"My paper explores this idea using available data on the different aspects of this scenario," said Totani. "The distances and times involved can be vast, and both reduce the chance any ejecta containing life signs from another world could even reach us. Add to that the number of phenomena in space that can destroy small objects due to heat or radiation, and the chances get even lower. Despite that, I calculate around 100,000 such grains could be landing on Earth every year. Given there are many unknowns involved, this estimate could be too high or too low, but the means to explore it already exist so it seems like a worthwhile pursuit."

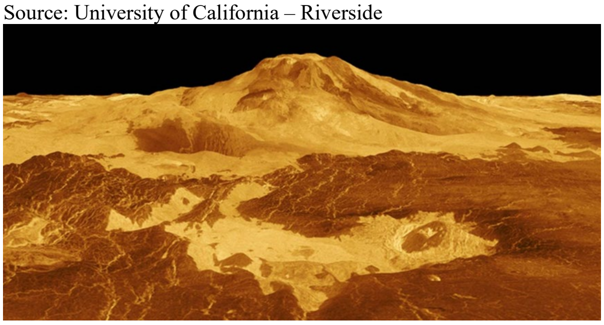
There may be such grains already on Earth, and in plentiful amounts, preserved in places such as the Antarctic ice, or under the seafloor. Space dust in these places could be retrieved relatively easily, but discerning extrasolar material from material originating in our own solar system is still a complex matter. If the search is extended to space itself, however, there are already missions that capture dust in the vacuum using ultralight materials called aerogels.

"I hope that researchers in different fields are interested in this idea and start to examine the feasibility of this new search for extrasolar life in more detail." said Totani.

- Hunting Venus 2.0: Scientists sharpen their sights

Study narrows James Webb Space Telescope targets

Date: March 22, 2023
Source: University of California – Riverside



With the first paper compiling all known information about planets like Venus beyond our solar system, scientists are the closest they've ever been to finding an analogue of Earth's "twin."

If they succeed in locating one, it could reveal valuable insights into Earth's future, and our risk of developing a runaway greenhouse climate as Venus did.

Scientists who wrote the paper began with more than 300 known terrestrial planets orbiting other stars, called exoplanets. They whittled the list down to the five most likely to resemble Venus in terms of their radii, masses, densities, the shapes of their orbits, and perhaps most significantly, distances from their stars.

The paper, published in *The Astronomical Journal*, also ranked the most Venus-like planets in terms of the brightness of the stars they orbit, which increases the likelihood that the James Webb Space Telescope would get more informative signals regarding the composition of their atmospheres.

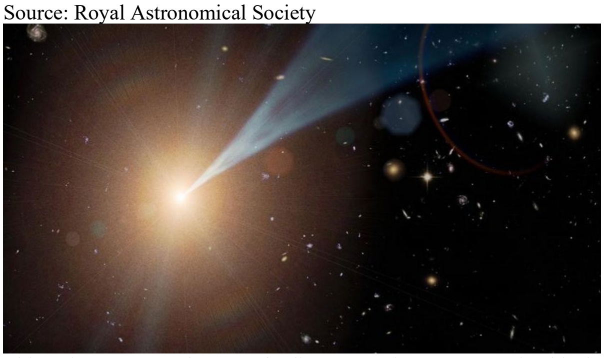
Today's Venus floats in a nest of sulfuric acid clouds, has no water, and features surface temperatures of up to 900 degrees Fahrenheit -- hot enough to melt lead. Using the Webb telescope to observe these possible Venus analogues, or "exoVenuses," scientists hope to learn if things were ever different for our Venus.

"One thing we wonder is if Venus could once have been habitable," said Colby Ostberg, lead study author and UC Riverside Ph.D. student. 'To confirm this, we want to look at the coolest of the planets in the outer edge of the Venus zone, where they get less energy from their stars."

The Venus Zone is a concept proposed by UCR astrophysicist Stephen Kane in 2014. It is similar to the concept of a habitable zone, which is a region around a star where liquid surface water could exist.
"The Venus Zone is where it would be too hot to have water, but not hot enough that the planet's atmosphere gets stripped away," Ostberg explained. "We want to find planets that still have significant atmospheres."
Finding a planet similar to Venus in terms of planet mass is also important because mass affects how long a planet is able to maintain an active interior, with the movement of rocky plates across its outer shell known as plate tectonics.
"Venus has 20% less mass than Earth, and as a result, scientists believe there may not be any tectonic activity there. Therefore, Venus has a hard time taking carbon out of its atmosphere," Ostberg explained. "The planet just can't get rid of it."
Another aspect of an active planet interior is volcanic activity, and evidence uncovered just this month suggests Venus still has active volcanoes. "The large number of Venus analogues identified in our paper will allow us to test if such volcanic activity is the norm amongst similar planets, or not," said Kane, who co-authored the study.
The research team is proposing the planets identified in the paper as targets for the Webb telescope in 2024. Webb is the most expensive and advanced observation tool ever created and will enable scientists not only to see whether the exoVenuses have atmospheres, but also what they're made of. The Webb observations may reveal biosignature gases in the atmosphere of an exoVenus, such as methane, methyl bromide or nitrous oxide, which could signal the presence of life.
"Detecting those molecules on an exoVenus would show that habitable worlds can exist in the Venus Zone and strengthen the possibility of a temperate period in Venus' past," Ostberg said.
These observations will be complemented by NASA's two upcoming missions to Venus, in which Kane will play an active role. The DAVINCI mission will also measure gases in the Venusian atmosphere, while the VERITAS mission will enable 3D reconstructions of the landscape.
All of these observations are leading toward the ultimate question that Kane poses in much of his work, which attempts to understand the Earth-Venus divergence in climate: "Is Earth weird or is Venus the weird one?"
"It could be that one or the other evolved in an unusual way, but it's hard to answer that when we only have two planets to analyse in our solar system, Venus and Earth. The exoplanet explorations will give us the statistical power to explain the differences we see," Kane said.
If the planets on the new list turn out to indeed be much like Venus, that would show the outcome of Venus' evolution is common.
"That would be a warning for us here on Earth because the danger is real. We need to understand what happened there to make sure it doesn't happen here," Kane said.

- Galaxy changes classification as jet changes direction

Date: March 21, 2023
Source: Royal Astronomical Society



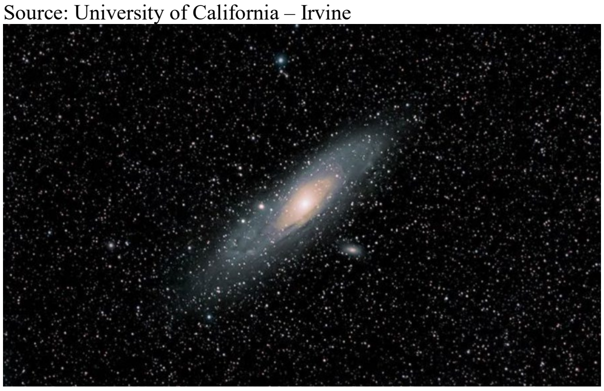
This artist's concept shows a "feeding," or active, supermassive black hole with a jet streaming outward at nearly the speed of light. Not all black holes have jets, but when they do, the jets can be pointed in any direction. If a jet happens to shine at Earth, the object is called a blazar.
Credit
NASA/JPL-Caltech
Licence type


A team of international astronomers have discovered a galaxy that has changed classification due to unique activity within its core. The galaxy, named PBC J2333.9-2343, was previously classified as a radio galaxy, but the new research has revealed otherwise. The work is published in *Monthly Notices of the Royal Astronomical Society*.
PBC J2333.9-2343, located 656 844 372 light years away, has now been classified as a giant radio galaxy that is 4 million light years across and happens to have a blazar in its core; a blazar is an active galactic nucleus (AGN) with a relativistic jet (a jet travelling close to the speed of light) directed towards an observer. Blazars are very high energy objects and are considered to be one of the most powerful phenomena in the Universe. The research has revealed that in PBC J2333.9-2343, the jet changed its direction drastically

by an angle of up to 90 degrees, going from being in the plane of the sky, perpendicular to our line of sight, to pointing directly towards us.
A blazar jet is made of elemental charged particles like electrons or protons that move at velocities close to the speed of light. These move in circles around a strong magnetic field, causing the emission of radiation across the entire electromagnetic spectrum. In PBC J2333.9-2343, the jet is thought to originate from or close to the supermassive black hole in its centre.
With the jet pointing in our direction, the emission is strongly enhanced and can easily exceed that coming from the rest of the galaxy. This in turn drives high-intensity flares stronger than those coming from other radio galaxies, thus changing its categorisation.
The orientation of the jets to us determines how a galaxy is classified. When two jets point towards the plane of the sky, they are classified as a radio galaxy, but if one of the jets points towards us, then the AGN of the galaxy is known as a blazar. With jets in the plane of the sky and one directed at us, PBC J2333.9-2343 has been reclassified as a radio galaxy with a blazar at its centre.
Changes in the direction of jets have been described in the past, for example with X-shaped radio galaxies. This is the first time that such a phenomenon has been observed where it does not suggest the presence of two different phases of jet activity from its morphology observed at radio frequencies -- the direction change appears to have taken place in the same nuclear outburst originating from the AGN.
To find out more about this mysterious galaxy, astronomers had to observe it across a wide range of the electromagnetic spectrum. PBC J2333.9-2343 was observed with radio, optical, infrared, x-ray, ultraviolet and gamma ray telescopes. Data was obtained from the German 100m-Radio Telescope Effelsberg at the Max Planck Institute for Radio Astronomy, the Yale University 1.3m-SMARTS optical telescope, and the Penn State Neil Gehrels Swift Observatory.
The team then compared the properties of PBC J2333.9-2343 with large samples of blazars and non-blazar galaxies provided by the ALeRCE (Automatic Learning for the Rapid Classification of Events) project in Chile with data from the Zwicky Transient Facility (ZTF) and the Asteroid Terrestrial-impact Last Alert System (ATLAS).
Using the observational data, the team concluded that this galaxy has a bright blazar in the centre, with two lobes in the outer areas of the jet. The lobes that are observed are related to the old jets and are no longer being fed by the emission from the nucleus, so these lobes are relics of past radio activity. The AGN no longer drives the lobes as seen in typical radio galaxies.
The team do not yet know what caused the drastic change in direction of the jets. They speculate that it could have been a merging event with another galaxy or any other relatively large object, or a strong burst of activity in the galactic nucleus after a dormant period.
Dr Lorena Hernández-García, lead author of the paper and researcher at the Millennium Institute of Astrophysics, says "We started to study this galaxy as it showed peculiar properties. Our hypothesis was that the relativistic jet of its supermassive black hole had changed its direction, and to confirm that idea we had to carry out a lot of observations."
She adds, "The fact that we see the nucleus is not feeding the lobes anymore means that they are very old. They are the relics of past activity, whereas the structures located closer to the nucleus represent younger and active jets."

- 'Terminator zones' on distant planets could harbour life

These in-between regions could be prime sites for liquid water
Date: March 16, 2023
Source: University of California – Irvine



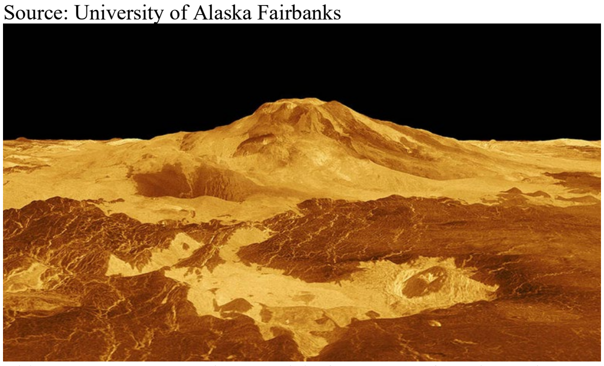
These planets have a permanent day side and a permanent night side and are particularly common as they exist around stars that make up about 70 per cent of the stars seen in the night sky | Photo: Sarath Prabhav

In a new study, University of California, Irvine astronomers describe how extra-terrestrial life has the potential to exist on distant exoplanets inside a special area called

the "terminator zone," which is a ring on planets that have one side that always faces its star and one side that is always dark.
"These planets have a permanent day side and a permanent night side," said Ana Lobo, a postdoctoral researcher in the UCI Department of Physics & Astronomy who led the new work, which just published in *The Astrophysical Journal*. Lobo added that such planets are particularly common because they exist around stars that make up about 70 percent of the stars seen in the night sky -- so-called M-dwarf stars, which are relatively dimmer than our sun.
The terminator is the dividing line between the day and night sides of the planet. Terminator zones could exist in that "just right" temperature zone between too hot and too cold.
"You want a planet that's in the sweet spot of just the right temperature for having liquid water," said Lobo, because liquid water, as far as scientists know, is an essential ingredient for life.
On the dark sides of terminator planets, perpetual night would yield plummeting temperatures that could cause any water to be frozen in ice. The side of the planet always facing its star could be too hot for water to remain in the open for long.
"This is a planet where the dayside can be scorching hot, well beyond habitability, and the night side is going to be freezing, potentially covered in ice. You could have large glaciers on the night side," Lobo said.
Lobo, alongside Aomawa Shields, UCI associate professor of physics & astronomy, modelled the climate of terminator planets using software typically used to model our own planet's climate, but with a few adjustments, including slowing down planetary rotation.
It's believed to be the first-time astronomers have been able to show that such planets can sustain habitable climates confined to this terminator region. Historically, researchers have mostly studied ocean-covered exoplanets in their search for candidates for habitability. But now that Lobo and her team have shown that terminator planets are also viable refuges for life, it increases the options life-hunting astronomers have to choose from.
"We are trying to draw attention to more water-limited planets, which despite not having widespread oceans, could have lakes or other smaller bodies of liquid water, and these climates could actually be very promising," Lobo said.
One key to the finding, Lobo added, was pinpointing exactly what kind of terminator zone planet can retain liquid water. If the planet is mostly covered in water, then the water facing the star, the team found, would likely evaporate and cover the entire planet in a thick layer of vapor.
But if there's land, this effect shouldn't occur. "Ana has shown if there's a lot of land on the planet, the scenario we call 'terminator habitability' can exist a lot more easily," said Shields. "These new and exotic habitability states our team is uncovering are no longer the stuff of science fiction -- Ana has done the work to show that such states can be climatically stable."
Recognizing terminator zones as potential harbours for life also means that astronomers will need to adjust the way they study exoplanet climates for signs of life, because the biosignatures life creates may only be present in specific parts of the planet's atmosphere.
The work will also help inform future efforts by teams using telescopes like the James Webb Space Telescope or the Large Ultraviolet Optical Infrared Surveyor telescope currently in development at NASA as they search for planets that may host extra-terrestrial life.
"By exploring these exotic climate states, we increase our chances of finding and properly identifying a habitable planet in the near future," said Lobo.

- Evidence that Venus is volcanically active

Date: March 15, 2023
Source: University of Alaska Fairbanks



This computer-generated 3D model of Venus' surface shows the summit of Maat Mons, the volcano that is exhibiting signs of activity. A new study found one of Maat Mons' vents became enlarged and changed shape over an eight-month period in 1991, indicating an eruptive event occurred.
Credits: NASA/JPL-Caltech

Venus appears to have volcanic activity, according to a new research paper that offers

strong evidence to answer the lingering question about whether Earth's sister planet currently has eruptions and lava flows.
Venus, although similar to Earth in size and mass, differs markedly in that it does not have plate tectonics. The boundaries of Earth's moving surface plates are the primary locations of volcanic activity.
New research by University of Alaska Fairbanks Geophysical Institute research professor Robert Herrick revealed a nearly 1-square-mile volcanic vent that changed in shape and grew over eight months in 1991. Changes on such a scale on Earth are associated with volcanic activity, whether through an eruption at the vent or movement of magma beneath the vent that causes the vent walls to collapse and the vent to expand.
The research was published today in the journal *Science*.
Herrick studied images taken in the early 1990s during the first two imaging cycles of NASA's Magellan space probe. Until recently, comparing digital images to find new lava flows took too much time, the paper notes. As a result, few scientists have searched Magellan data for feature formation.
"It is really only in the last decade or so that the Magellan data has been available at full resolution, mosaicked and easily manipulable by an investigator with a typical personal workstation," Herrick said.
The new research focused on an area containing two of Venus' largest volcanoes, Ozza and Maat Mons.
"Ozza and Maat Mons are comparable in volume to Earth's largest volcanoes but have lower slopes and thus are more spread out," Herrick said.
Maat Mons contains the expanded vent that indicates volcanic activity.
Herrick compared a Magellan image from mid-February 1991 with a mid-October 1991 image and noticed a change to a vent on the north side of a domed shield volcano that is part of the Maat Mons volcano.
The vent had grown from a circular formation of just under 1 square mile to an irregular shape of about 1.5 square miles.
The later image indicates that the vent's walls became shorter, perhaps only a few hundred feet high, and that the vent was nearly filled to its rim. The researchers speculate that a lava lake formed in the vent during the eight months between the images, though whether the contents were liquid or cooled and solidified isn't known.
The researchers offer one caveat: a nonvolcanic, earthquake-triggered collapse of the vent's walls might have caused the expansion. They note, however, that vent collapses of this scale on Earth's volcanoes have always been accompanied by nearby volcanic eruptions; magma withdraws from beneath the vent because it is going somewhere else.
The surface of Venus is geologically young, especially compared to all the other rocky bodies except Earth and Jupiter's moon Io, Herrick said.
"However, the estimates of how often eruptions might occur on Venus have been speculative, ranging from several large eruptions per year to one such eruption every several or even tens of years," he said.
Herrick contrasts the lack of information about Venusian volcanism with what is known about Jupiter's moon Io and about Mars.
"Io is so active that multiple ongoing eruptions have been imaged every time we've observed it," he said.
On a geological time, scale, relatively young lava flows indicate Mars remains volcanically active, Herrick said.
"However, nothing has occurred in the 45 years that we have been observing Mars, and most scientists would say that you'd probably need to watch the surface for a few million years to have a reasonable chance of seeing a new lava flow," he said.
Herrick's research adds Venus to the small pool of volcanically active bodies in our solar system.
"We can now say that Venus is presently volcanically active in the sense that there are at least a few eruptions per year," he said.
"We can expect that the upcoming Venus missions will observe new volcanic flows that have occurred since the Magellan mission ended three decades ago, and we should see some activity occurring while the two upcoming orbital missions are collecting images."
Co-author Scott Hensley of NASA's Jet Propulsion Laboratory performed the modelling for the research.