South Downs Mercury

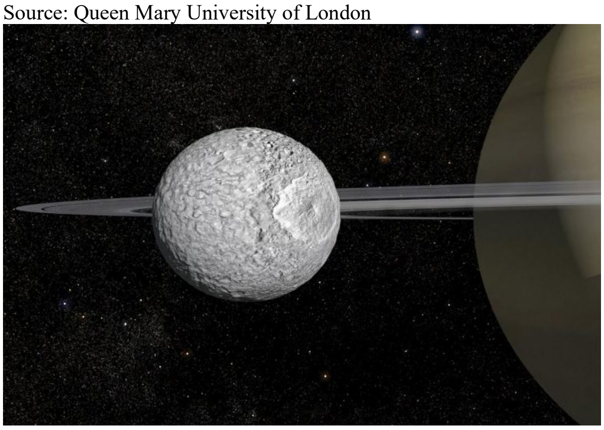
The monthly circular of South Downs Astronomical Society
Issue: 584 – March 1st 2024 Editor: Roger Burgess

Main Talk " Einstein's Theory of General Relativity was published in 1915". In over a century it has not failed a single time despite hundreds of tests and experiments. One of the most extreme environments in which to benchmark Relativity and possible alternative theories of gravity is around pulsars (after black holes, the densest objects in the Universe). In this talk, I will discuss the formidable achievements of the last 50 years in using pulsars to test Einstein's theory and describe some of the strange behaviours of space and time when submitted to extreme gravity. I will also highlight future prospects of detecting gravitational waves with pulsars.

Please support a raffle we are organizing this month.

- Mimas' surprise: Tiny moon of Saturn holds young ocean beneath icy shell

Date: February 7, 2024
Source: Queen Mary University of London



Mimas is the smallest and innermost of Saturn's major moons. Its newly discovered young ocean opens new avenues for exploring life's potential beyond Earth. Credit: Frédéric Durillon, Animea Studio | Observatoire de Paris – PSL, IMCCE

Hidden beneath the heavily cratered surface of Mimas, one of Saturn's smallest moons, lies a secret: a global ocean of liquid water. This astonishing discovery, led by Dr. Valéry Lainey of the Observatoire de Paris-PSL and published in the journal *Nature*, reveals a "young" ocean formed just 5 to 15 million years ago, making Mimas a prime target for studying the origins of life in our Solar System.
"Mimas is a small moon, only about 400 kilometres in diameter, and its heavily cratered surface gave no hint of the hidden ocean beneath," says Dr Nick Cooper, a co-author of the study and Honorary Research Fellow in the Astronomy Unit of the School of Physical and Chemical Sciences at Queen Mary University of London. "This discovery adds Mimas to an exclusive club of moons with internal oceans, including Enceladus and Europa, but with a unique difference: its ocean is remarkably young, estimated to be only 5 to 15 million years old."
This young age, determined through detailed analysis of Mimas's tidal interactions with Saturn, suggests the ocean formed recently, based on the discovery of an unexpected irregularity in its orbit. As a result, Mimas provides a unique window into the early stages of ocean formation and the potential for life to emerge.
"The existence of a recently formed liquid water ocean makes Mimas a prime candidate for study, for researchers investigating the origin of life," explains Dr Cooper. The discovery was made possible by analysing data from NASA's Cassini spacecraft, which meticulously studied Saturn and its moons for over a decade. By closely examining the subtle changes in Mimas's orbit, the researchers were able to infer the presence of a hidden ocean and estimate its size and depth.
Dr Cooper continues: "This has been a great team effort, with colleagues from five different institutions and three different countries coming together under the leadership of Dr Valéry Lainey to unlock another fascinating and unexpected feature of the Saturn system, using data from the Cassini mission."
The discovery of Mimas's young ocean has significant implications for our understanding of the potential for life beyond Earth. It

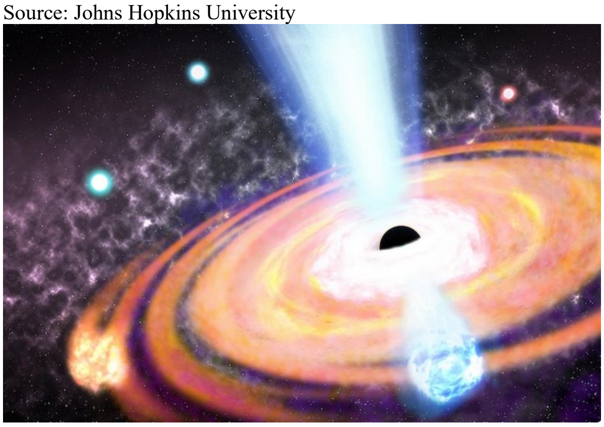
suggests that even small, seemingly inactive moons can harbour hidden oceans capable of supporting life-essential conditions. This opens up exciting new avenues for future exploration, potentially leading us closer to answering the age-old question: are we alone in the universe?

- Which came first: Black holes or galaxies?

Findings 'completely shake up' what we know about galaxy formation

Date: February 6, 2024

Source: Johns Hopkins University



Artist's concept of a magnetic field generated by a supermassive black hole in the early universe. The image shows the turbulent plasma outflows that – according to a recent study – turn gas clouds into stars. So … did black holes come before galaxies and stars? Or did galaxies and stars come first? Image via Roberto Molar Candanosa/ JHU.

Black holes not only existed at the dawn of time, they birthed new stars and supercharged galaxy formation, a new analysis of James Webb Space Telescope data suggests.

The insights upend theories of how black holes shape the cosmos, challenging classical understanding that they formed after the first stars and galaxies emerged. Instead, black holes might have dramatically accelerated the birth of new stars during the first 50 million years of the universe, a fleeting period within its 13.8 billion -- year history.

"We know these monster black holes exist at the centre of galaxies near our Milky Way, but the big surprise now is that they were present at the beginning of the universe as well and were almost like building blocks or seeds for early galaxies," said lead author Joseph Silk, a professor of physics and astronomy at Johns Hopkins University and at Institut of Astrophysics, Paris, Sorbonne University. "They really boosted everything, like gigantic amplifiers of star formation, which is a whole turnaround of what we thought possible before -- so much so that this could completely shake up our understanding of how galaxies form."

The work is newly published in the *Astrophysical Journal Letters.*

Distant galaxies from the very early universe, observed through the Webb telescope, appear much brighter than scientists predicted and reveal unusually high numbers of young stars and supermassive black holes, Silk said.

Conventional wisdom holds that black holes formed after the collapse of supermassive stars and that galaxies formed after the first stars lit up the dark early universe. But the analysis by Silk's team suggests that black holes and galaxies coexisted and influenced each other's fate during the first 100 million years. If the entire history of the universe were a 12-month calendar, those years would be like the first days of January, Silk said.

"We're arguing that black hole outflows crushed gas clouds, turning them into stars and greatly accelerating the rate of star formation," Silk said. "Otherwise, it's very hard to understand where these bright galaxies came from because they're typically smaller in the early universe. Why on earth should they be making stars so rapidly?"

Black holes are regions in space where gravity is so strong that nothing can escape their pull, not even light. Because of this force, they generate powerful magnetic fields that make violent storms, ejecting turbulent plasma and ultimately acting like enormous particle accelerators, Silk said. This process, he said, is likely why Webb's detectors have spotted more of these black holes and bright galaxies than scientists anticipated.

"We can't quite see these violent winds or jets far, far away, but we know they must be present because we see many black holes early on in the universe," Silk explained. "These enormous winds coming from the black holes crush nearby gas clouds and turn them into stars. That's the missing link that explains why these first galaxies are so much brighter than we expected."

Silk's team predicts the young universe had two phases. During the first phase, high-speed outflows from black holes accelerated star formation, and then, in a second phase, the outflows slowed down. A few hundred million years after the big bang, gas clouds collapsed because of supermassive black hole magnetic storms, and new stars were born at a rate far exceeding that observed billions of years later in normal galaxies, Silk said. The creation of stars slowed down because these powerful outflows transitioned into a state of

energy conservation, he said, reducing the gas available to form stars in galaxies.
"We thought that in the beginning, galaxies formed when a giant gas cloud collapsed," Silk explained. "The big surprise is that there was a seed in the middle of that cloud -- a big black hole -- and that helped rapidly turn the inner part of that cloud into stars at a rate much greater than we ever expected. And so, the first galaxies are incredibly bright."
The team expects future Webb telescope observations, with more precise counts of stars and supermassive black holes in the early universe, will help confirm their calculations. Silk expects these observations will also help scientists piece together more clues about the evolution of the universe.
"The big question is, what were our beginnings? The sun is one star in 100 billion in the Milky Way galaxy, and there's a massive black hole sitting in the middle, too. What's the connection between the two?" he said. "Within a year we'll have so much better data, and a lot of our questions will begin to get answers."
Authors include Colin Norman and Rosemary F. G. Wyse of Johns Hopkins; Mitchell C. Begelman of University of Colorado and National Institute of Standards and Technology; and Adi Nusser of the Israel Institute of Technology.
The team is supported by the Israel Science Foundation and the Asher Space Research Institute, as well as Eric and Wendy Schmidt by recommendation of the Schmidt Futures program.

- 'Old smokers' and 'squalling newborns' among hidden stars spotted for first time. 'Hidden' stars including a new type of elderly giant nicknamed an 'old smoker' have been spotted for the first time by astronomers

Date: January 26, 2024
Source: Royal Astronomical Society


Astronomers have spotted ‘old smokers’ and ‘squalling newborns’ among hidden stars (Owen Humphreys/PA)

'Hidden' stars including a new type of elderly giant nicknamed an 'old smoker' have been spotted for the first time by astronomers.
The mystery objects exist at the heart of our Milky Way galaxy and can sit quietly for decades -- fading almost to invisibility -- before suddenly puffing out clouds of smoke, according to a new study published today in the *Monthly Notices of the Royal Astronomical Society.*
An international team of scientists led by Professor Philip Lucas, of the University of Hertfordshire, made their ground-breaking discovery after monitoring almost a billion stars in infrared light during a 10-year survey of the night sky.
They also detected dozens of rarely-seen newborn stars, known as protostars, which undergo extreme outbursts over a period of months, years or decades, as part of the formation of a new solar system.
Most of these newly-spotted stars are hidden from view in visible light by large amounts of dust and gas in the Milky Way -- but infrared light can get through, allowing scientists to see them for the first time.
Astronomers from the UK, Chile, South Korea, Brazil, Germany and Italy carried out their research with the help of the Visible and Infrared Survey Telescope (VISTA) -- a British-built telescope high in the Chilean Andes at Cerro Paranal Observatory, which is part of the European Southern Observatory (ESO).
The team kept a watchful eye on hundreds of millions of stars and analysed 222 that showed the largest changes in brightness.
Professor Lucas said: "About two-thirds of the stars were easy to classify as well-understood events of various types.
"The rest were a bit more difficult so we used ESO's Very Large Telescope to get spectra of many of them individually. A spectrum shows us how much light we can see at a spread of different wavelengths, giving a much clearer idea of what we are looking at."
The work was carried out as part of a long-term survey called 'VISTA Variables in the Via Lactea', or VVV.
Dr Zhen Guo, formerly of the University of Hertfordshire and now based at the University of Valparaiso in Chile, led the work on the spectra.
He said: "Our main aim was to find rarely-seen newborn stars, also called protostars, while they are undergoing a great outburst

that can last for months, years, or even decades.

"These outbursts happen in the slowly spinning disc of matter that is forming a new solar system. They help the newborn star in the middle to grow, but make it harder for planets to form.

"We don't yet understand why the discs become unstable like this."

The team discovered 32 erupting protostars that increased in brightness at least 40-fold, and in some cases over 300-fold.

Most of the eruptions are still ongoing, allowing astronomers for the first time to analyse a large batch of these mysterious events throughout their evolution -- from the initial quiescent state, through the peak of brightness, and into the declining stage.

However, the study also threw up something completely unexpected.

There were 21 red stars near the centre of the Milky Way that showed ambiguous changes in brightness during the 10-year survey.

Professor Lucas explained: "We weren't sure if these stars were protostars starting an eruption, or recovering from a dip in brightness caused by a disc or shell of dust in front of the star -- or if they were older giant stars throwing off matter in the late stages of their life."

Analysis of the spectra for seven of these stars, compared with data from earlier surveys, concluded that they were in fact a new type of red giant star.

Professor Dante Minniti at Andrés Bello University, Chile, founder of the VVV survey, said: "These elderly stars sit quietly for years or decades and then puff out clouds of smoke in a totally unexpected way.

"They look very dim and red for several years, to the point that sometimes we can't see them at all."

A further clue about this new discovery lies in the location of these dwindling giant stars. They are heavily concentrated in the innermost part of the Milky Way, known as the Nuclear Disc, a region where stars tend to be richer in heavy elements than anywhere else.

This should make it easier for dust particles to condense out of gas in the relatively cool outer layers of red giant stars. However, how this leads to the ejection of puffs of dense smoke that the team observed remains a mystery.

The researchers said their discoveries could change what we know about the way that elements are distributed across space, as Professor Lucas explains.

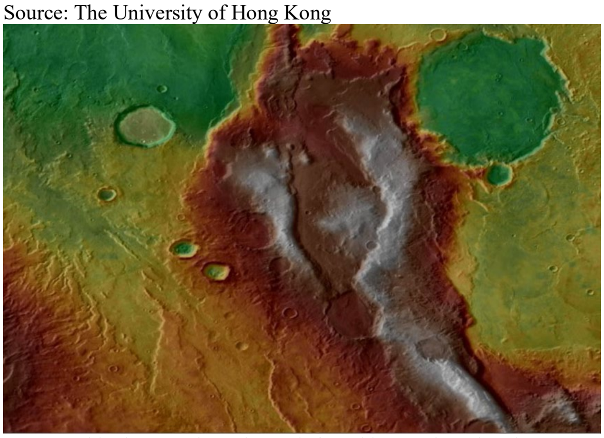
"Matter ejected from old stars plays a key role in the life cycle of the elements, helping to form the next generation of stars and planets," he said.

"This was thought to occur mainly in a well-studied type of star called a Mira variable.

"However, the discovery of a new type of star that throws off matter could have wider significance for the spread of heavy elements in the Nuclear Disc and metal-rich regions of other galaxies."

- ❖ Diverse ancient volcanoes on Mars discovered by planetary scientist may hold clues to pre-plate tectonic activity on Earth

Date: February 15, 2024
Source: The University of Hong Kong



Topographic data are draped over infrared image data showing complex tectonic structures and volcanic deposits in the Eridania region of Mars. Warm colours are higher elevation.
Image Credit: NASA/Mars Odyssey/HRSC

Volcanoes are a common feature on the surfaces of solid planets within the solar system, resulting from magmatic activity occurring within the planetary crust. On Earth, volcanism is driven primarily by heat and crustal recycling associated with plate tectonics, but Mars lacks plate tectonics and the driver of volcanism is not well understood.

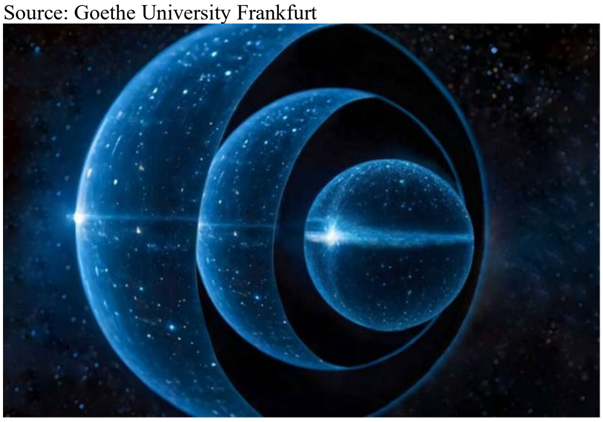
Recent research by Professor Joseph MICHALSKI, a geologist in the Department of Earth Sciences at The University of Hong Kong (HKU), has revealed intriguing insights into the volcanic activity on Mars. He proposes that Mars has significantly more diverse volcanism than previously realised, driven by an early form of crust recycling called vertical tectonics. The findings, recently published in *Nature Astronomy,* shed light on the ancient crust of Mars and its

potential implications for understanding early crustal recycling on both Mars and Earth.
Traditionally, Mars has been known to have large shield volcanoes similar to those in Hawaii. However, it was not known that Mars also possessed the diverse, explosive volcanoes that form on Earth due to crustal recycling.
The recent research conducted by Professor Michalski and his international team discover a vast number of diverse volcanoes in the ancient crust of Mars. 'We have known for decades that Mars has volcanoes, but most of the recognised volcanoes correspond to large basaltic shield volcanoes similar to the ones that make up Hawaii,' he explains. 'In this work, we show that the ancient crust has many other types of volcanoes such as lava domes, stratovolcanoes, calderas and large shields of ash, not lava. Further, most scientists see Mars as a planet composed of basalt, which has low silica content and represents little crustal evolution, but these volcanoes have high silica content which means they formed from a complex process of magma evolution not known before.'
The paper suggests that intense volcanism occurred on ancient Mars, causing the crust to collapse into the mantle, where the rocks re-melted, resulting in magmas that have high silica. This tectonic process, called vertical tectonics, is hypothesised to have occurred on the ancient Earth, but rocks on Earth from that period (the Archean, more than 3 billion years ago) are highly modified by later geological activity, so we cannot see evidence for this process clearly on this planet. Therefore, exploring other planets like Mars, which has volcanism but no plate tectonics, can help reveal the mysteries of early crustal recycling on both the Red Planet, and by analogy, on early Earth.
Professor Michalski concluded, 'Mars contains critical geological puzzle pieces that help us understand not only that planet, but the Earth as well. Martian volcanism is much more complex and diverse than has been previously thought.'
'This is a significant discovery because it has revealed that crustal recycling can occur not only in plate tectonic regimes dominated by horizontal movements, but can also occur in pre-plate tectonic regimes dominated by vertical movements. This finding can help earth scientists revolve the long-term controversial issues of how and when felsic continents formed in our planet (Earth)', said Professor Guochun ZHAO, the Chair Professor of HKU Earth Sciences.

- A star like a Matryoshka doll: New theory for gravastars

Physicists find new solution to Einstein's general theory of relativity

Date: February 15, 2024
Source: Goethe University Frankfurt



According to findings by physicists at Goethe University Frankfurt, a gravastar could look like a matryoshka doll. Credit: Daniel Jampolski and Luciano Rezzolla

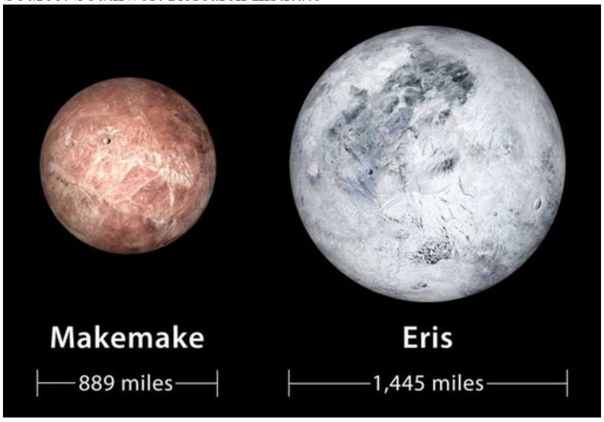
If gravitational condensate stars (or gravastars) actually existed, they would look similar to black holes to a distant observer. Two theoretical physicists at Goethe University Frankfurt have now found a new solution to Albert Einstein's theory of general relativity, according to which gravitational stars could be structured like a Russian matryoshka doll, with one gravastar located inside another.
The interior of black holes remains a conundrum for science. In 1916, German physicist Karl Schwarzschild outlined a solution to Albert Einstein's equations of general relativity, according to which the centre of a black hole consists of a so-called singularity, a point at which space and time no longer exist. Here, the theory goes, all physical laws, including Einstein's general theory of relativity, no longer apply; the principle of causality is suspended. This constitutes a great nuisance for science: after all, it means that no information can escape from a black hole beyond the so-called event horizon.
This could be a reason why Schwarzschild's solution did not attract much attention outside the theoretical realm for a long time -- that is, until the first candidate for a black hole was discovered in 1971, followed by the discovery of the black hole in the centre of our Milky Way in the 2000s, and finally the first image of a black hole, captured by the Event Horizon Telescope Collaboration in 2019.

In 2001, Pawel Mazur and Emil Mottola proposed a different solution to Einstein's field equations that led to objects which they called gravitational condensate stars, or gravastars. Contrary to black holes, gravastars have several advantages from a theoretical astrophysics' perspective. On the one hand, they are almost as compact as black holes and also exhibit a gravity at their surface that is essentially as strong as that of a black hole, hence resembling a black hole for all practical purposes. On the other hand, gravastars do not have an event horizon, that is, a boundary from within which no information can be sent out, and their core does not contain a singularity. Instead, the centre of gravastars is made up of an exotic -- dark -- energy that exerts a negative pressure to the enormous gravitational force compressing the star. The surface of gravastars is represented by a wafer-thin skin of ordinary matter, the thickness of which approaches zero.
Theoretical physicists Daniel Jampolski and Prof. Luciano Rezzolla of Goethe University Frankfurt have now presented a solution to the field equations of general relativity that describes the existence of a gravastar inside another gravastar. They have given this hypothetical celestial object the name "nestar" (from the English "nested").
Daniel Jampolski, who discovered the solution as part of his Bachelor's thesis supervised by Luciano Rezzolla, says: "The nestar is like a matryoshka doll," adding that, "our solution to the field equations allows for a whole series of nested gravastars." Whereas Mazur and Mottola posit that the gravastar has a near infinite thin skin consisting of normal matter, the nestar's matter-composed shell is somewhat thicker: "It's a little easier to imagine that something like this could exist."
Luciano Rezzolla, Professor of Theoretical Astrophysics at Goethe University, explains: "It's great that even 100 years after Schwarzschild presented his first solution to Einstein's field equations from the general theory of relativity, it's still possible to find new solutions. It's a bit like finding a gold coin along a path that has been explored by many others before. Unfortunately, we still have no idea how such a gravastar could be created. But even if nestars don't exist, exploring the mathematical properties of these solutions ultimately helps us to better understand black holes."

- ❖ Evidence of geothermal activity within icy dwarf planets

Webb telescope observes potentially young methane deposits on surfaces of Eris, Makemake

Date: February 15, 2024
Source: Southwest Research Institute



A team co-led by Southwest Research Institute found evidence for hydrothermal or metamorphic activity within the icy dwarf planets Eris and Makemake, located in the Kuiper Belt. Methane detected on their surfaces has the tell-tale signs of warm or even hot geochemistry in their rocky cores, which is markedly different than the signature of methane from a comet.
"We see some interesting signs of hot times in cool places," said SwRI's Dr. Christopher Glein, an expert in planetary geochemistry and lead author of a paper about this discovery. "I came into this project thinking that large Kuiper Belt objects (KBOs) should have ancient surfaces populated by materials inherited from the primordial solar nebula, as their cold surfaces can preserve volatiles like methane. Instead, the James Webb Space Telescope (JWST) gave us a surprise! We found evidence pointing to thermal processes producing methane from within Eris and Makemake.
The Kuiper Belt is a vast donut-shaped region of icy bodies beyond the orbit of Neptune at the edge of the solar system. Eris and Makemake are comparable in size to Pluto and its moon Charon. These bodies likely formed early in the history of our solar system, about 4.5 billion years ago. Far from the heat of our Sun, KBOs were believed to be cold, dead objects. Newly published work from JWST studies made the first observations of isotopic molecules on the surfaces of Eris and Makemake. These so-called isotopologues are molecules that contain atoms having a different number of

neutrons. They provide data that are useful in understanding planetary evolution.
The JWST team measured the composition of the dwarf planets' surfaces, particularly the deuterium (heavy hydrogen, D) to hydrogen (H) ratio in methane. Deuterium is believed to have formed in the Big Bang, and hydrogen is the most abundant nucleus in the universe. The D/H ratio on a planetary body yields information about the origin, geologic history and formation pathways of compounds containing hydrogen.
"The moderate D/H ratio we observed with JWST belies the presence of primordial methane on an ancient surface. Primordial methane would have a much higher D/H ratio," Glein said. "Instead, the D/H ratio points to geochemical origins for methane produced in the deep interior. The D/H ratio is like a window. We can use it in a sense to peer into the subsurface. Our data suggest elevated temperatures in the rocky cores of these worlds so that methane can be cooked up. Molecular nitrogen (N_2) could be produced as well, and we see it on Eris. Hot cores could also point to potential sources of liquid water beneath their icy surfaces."
Over the past two decades, scientists have learned that icy worlds can be much more internally evolved than once believed. Evidence for subsurface oceans has been found at several icy moons such as Saturn's moon Enceladus and Jupiter's moon Europa. Liquid water is one of the key ingredients in determining potential planetary habitability. The possibility of water oceans inside Eris and Makemake is something that scientists are going to study in the years ahead. If either of them is habitable, then it would become the most distant world in the solar system that could possibly support life. Finding chemical indicators of internally driven processes takes them a step in this direction.
"If Eris and Makemake hosted, or perhaps could still host warm, or even hot, geochemistry in their rocky cores, cryovolcanic processes could then deliver methane to the surfaces of these planets, perhaps in geologically recent times," said Dr. Will Grundy, an astronomer at Lowell Observatory, one of Glein's co-authors and lead author of a companion paper. "We found a carbon isotope ratio ($^{13}C/^{12}C$) that suggests relatively recent resurfacing."
This work is part of a paradigm shift in planetary science. It is increasingly being recognized that cold, icy worlds may be warm at heart. Models developed for this study additionally point to the formation of geothermal gases on Saturn's moon Titan, which also has abundant methane.
Furthermore, the inference of unexpected activity on Eris and Makemake underscores the importance of internal processes in shaping what we see on large KBOs and is consistent with findings at Pluto.
"After the New Horizons flyby of the Pluto system, and with this discovery, the Kuiper Belt is turning out to be much more alive in terms of hosting dynamic worlds than we would have imagined," said Glein. "It's not too early to start thinking about sending a spacecraft to fly by another one of these bodies to place the JWST data into a geologic context. I believe that we will be stunned by the wonders that await!"

- ❖ Newly discovered carbon monoxide-runaway gap can help identify habitable exoplanets

Date: February 6, 2024
Source: Tokyo Institute of Technology

Scientists at Tokyo Tech have identified a carbon monoxide (CO)-runaway gap in the atmospheres of Earth-like planets. Their discovery could expand the search for habitable planets.

A carbon monoxide (CO)-runaway gap identified in the atmospheres of Earth-like planets by researchers at Tokyo Tech can help expand the search for habitable planets. This gap, identified through atmospheric modelling, is an indicator of a CO-rich atmosphere on Earth-like planets orbiting Sun-like stars. CO is an important compound for the formation of prebiotic organic compounds, which are building blocks for more complex molecules for the formation of life.
The search for habitable exoplanets involves looking for planets with similar conditions to the Earth, such as liquid water, a suitable temperature range and atmospheric conditions. One crucial factor is the planet's position in the habitable zone, the region

around a star where liquid water could potentially exist on the planet's surface. NASA's Kepler telescope, launched in 2009, revealed that 20-50% of visible stars may host such habitable Earth-sized rocky planets. However, the presence of liquid water alone does not guarantee a planet's habitability. On Earth, carbon compounds such as carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) played a crucial role in shaping the climate and biogeochemistry and could have contributed to the emergence of life.

Taking this into consideration, a recent study by Associate Professor Kazumi Ozaki from Tokyo Institute of Technology, along with Associate Researcher Yasuto Watanabe from The University of Tokyo, aims to expand the search for habitable planets. Published in the *Astrophysical Journal* on 10 January 2024, the researchers used atmospheric modelling to identify conditions that could result in a CO-rich atmosphere on Earth-like planets that orbit sun-like (F-, G-, and K-type) stars. This phenomenon, known as CO runaway, is suggested by atmospheric models to have possibly occurred in early planetary atmospheres, potentially favouring the emergence of life.

"The possibility of CO runaway is critical in resolving the fundamental problem regarding the origin of life on Earth because various organic compounds suitable for the prebiotic chemistry are more likely to form in a CO-rich atmosphere than in a CO_2-rich atmosphere," explains Dr. Ozaki.

The researchers modelled the CO cycle between the atmosphere and the oceans, considering the various sources of CO production, its transport mechanisms and the processes involved in its removal. The photolysis of CO_2, in which CO_2 breaks down into CO when exposed to light, was considered the primary source of CO. Additional sources included photochemical reactions in the atmosphere, emissions from volcanic gases, and the hydrothermal decomposition of formaldehyde (H_2CO) in the ocean. The removal of CO from the atmosphere primarily occurred through its reaction with hydroxyl (OH) radicals formed due to the photolysis of water vapor, and to a lesser extent, by deposition to the planet's surface.

The researchers found that a CO runaway occurs when the CO production surpasses the removal by OH radicals. This can occur due to higher CO_2 levels or the presence of reducing gases from volcanoes which compete for the OH radicals. At a temperature of 277 K, conditions for CO runaway are met when the partial pressure of CO_2 exceeds 0.2 bar. However, at higher temperatures (300 K), a CO runaway needs even higher CO_2 and volcanic gas levels due to increased water vapor in the atmosphere, which is a major source of OH radicals. Once initiated, the CO levels in the atmosphere are limited only by surface deposition, where CO is deposited onto the planet's surface.

Notably, the changes in the CO, CO_2 and CH_4 levels before and after the runaway effect led to a gap reflected in the phase space defined by the ratios of their partial pressures (pCO/pCO_2 and pCH_4/pCO_2). "Our results suggest that this CO-runaway gap is a general feature of Earth-like lifeless planets orbiting Sun-like stars, providing insights into the characteristics and potential habitability of exoplanets," says Dr. Ozaki.

Although the exact conditions that lead to the emergence of life remain uncertain, discoveries like the CO-runaway gap provide valuable clues in our quest to find habitable planets that could facilitate the origin of life among nearly 40 billion Earth-size planets orbiting Sun-like stars in the Milky Way galaxy.

- ❖ Mysterious gap in size distribution of super-earths explained

Date: February 9, 2024
Source: Max Planck Institute for Astronomy

Artistic representation of an exoplanet showing water ice on the surface increasingly vaporizing and forming an atmosphere.

Astronomers from Germany and Switzerland have uncovered evidence of how the enigmatic gap in the size distribution of exoplanets at around two Earth radii emerges. Their computer simulations demonstrate that the migration of icy, so-called sub-Neptunes into the inner regions of their planetary systems could account for this phenomenon. As they draw closer to the central star,

evaporating water ice forms an atmosphere that makes the planets appear larger than in their frozen state. Simultaneously, smaller rocky planets gradually lose a portion of their original gaseous envelope, causing their measured radius to shrink over time.
Ordinarily, planets in evolved planetary systems, such as the Solar System, follow stable orbits around their central star. However, many indications suggest that some planets might depart from their birthplaces during their early evolution by migrating inward or outward. This planetary migration might also explain an observation that has puzzled researchers for several years: the relatively low number of exoplanets with sizes about twice as large as Earth, known as the radius valley or gap. Conversely, there are many exoplanets smaller and larger than this size.
"Six years ago, a reanalysis of data from the Kepler space telescope revealed a shortage of exoplanets with sizes around two Earth radii," Remo Burn explains, an exoplanet researcher at the Max Planck Institute for Astronomy (MPIA) in Heidelberg. He is the lead author of the article reporting the findings outlined in this article, now published in *Nature Astronomy.*

Where does the radius valley come from?

"In fact, we -- like other research groups -- predicted based on our calculations, even before this observation, that such a gap must exist," explains co-author Christoph Mordasini, a member of the National Centre of Competence in Research (NCCR) PlanetS. He heads the Division of Space Research and Planetary Sciences at the University of Bern. This prediction originated during his tenure as a scientist at MPIA, which has been jointly researching this field with the University of Bern for many years.
The most commonly suggested mechanism to explain the emergence of such a radius valley is that planets might lose a part of their original atmosphere due to the irradiation from the central star -- especially volatile gases like hydrogen and helium. "However, this explanation neglects the influence of planetary migration," Burn clarifies. It has been established for about 40 years that under certain conditions, planets can move inward and outward through planetary systems over time. How effective this migration is and to what extent it influences the development of planetary systems impacts its contribution to forming the radius valley.

Enigmatic sub-Neptunes

Two different types of exoplanets inhabit the size range surrounding the gap. On one hand, there are rocky planets, which can be more massive than Earth and are hence called super-Earths. On the other hand, astronomers are increasingly discovering so-called sub-Neptunes (also mini-Neptunes) in distant planetary systems, which are, on average, slightly larger than the super-Earths.
"However, we do not have this class of exoplanets in the Solar System," Burn points out. "That's why, even today, we're not exactly sure about their structure and composition."
Still, astronomers broadly agree that these planets possess significantly more extended atmospheres than rocky planets. Consequently, understanding how these sub-Neptunes' characteristics contribute to the radius gap has been uncertain. Could the gap even suggest that these two types of worlds form differently?

Wandering ice planets

"Based on simulations we already published in 2020, the latest results indicate and confirm that instead, the evolution of sub-Neptunes after their birth significantly contributes to the observed radius valley," concludes Julia Venturini from Geneva University. She is a member of the PlanetS collaboration mentioned above and led the 2020 study.
In the icy regions of their birthplaces, where planets receive little warming radiation from the star, the sub-Neptunes should indeed have sizes missing from the observed distribution. As these presumably icy planets migrate closer to the star, the ice thaws, eventually forming a thick water vapour atmosphere. This process results in a shift in planet radii to larger values. After all, the observations employed to measure planetary radii cannot differentiate whether the determined size is due to the solid part of the planet alone or an additional dense atmosphere.
At the same time, as already suggested in the previous picture, rocky planets 'shrink' by losing their atmosphere. Overall, both mechanisms produce a lack of planets with sizes around two Earth radii.

Physical computer models simulating planetary systems

"The theoretical research of the Bern-Heidelberg group has already significantly

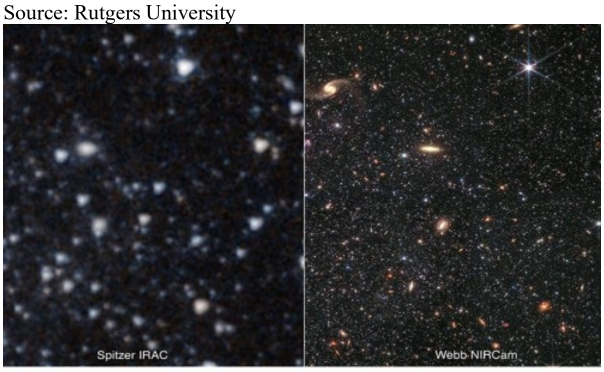
advanced our understanding of the formation and composition of planetary systems in the past," explains MPIA Director Thomas Henning. "The current study is, therefore, the result of many years of joint preparatory work and constant improvements to the physical models."
The latest results stem from calculations of physical models that trace planet formation and subsequent evolution. They encompass processes in the gas and dust disks surrounding young stars that give rise to new planets. These models include the emergence of atmospheres, the mixing of different gases, and radial migration.
"Central to this study were the properties of water at pressures and temperatures occurring inside planets and their atmospheres," explains Burn. Understanding how water behaves over a wide range of pressures and temperatures is crucial for simulations. This knowledge has been of sufficient quality only in recent years. It is this component which permits realistic calculation of the sub-Neptunes' behaviour, hence explaining the manifestation of extensive atmospheres in warmer regions.
"It's remarkable how, as in this case, physical properties on molecular levels influence large-scale astronomical processes such as the formation of planetary atmospheres," Henning adds.
"If we were to expand our results to cooler regions, where water is liquid, this might suggest the existence of water worlds with deep oceans," Mordasini says. "Such planets could potentially host life and would be relatively straightforward targets for searching for biomarkers thanks to their size."

Further work ahead

However, the current work is just an important milestone. Although the simulated size distribution closely matches the observed one, and the radius gap is in the right place, the details still have some inconsistencies. For instance, too many ice planets end up too close to the central star in the calculations. Nonetheless, researchers do not perceive this circumstance as a disadvantage but hope to learn more about planetary migration in this way.
Observations with telescopes like the James Webb Space Telescope (JWST) or the under-construction Extremely Large Telescope (ELT) could also assist. They would be capable of determining the composition of planets depending on their size, thus providing a test for the simulations described here.

- ❖ A long, long time ago in a galaxy not so far away

Astronomer searching for clues about the early universe
Date: February 6, 2024
Source: Rutgers University



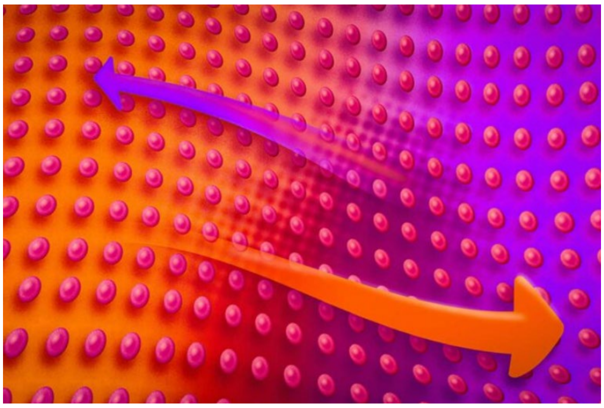
Two views of a portion of the WLM galaxy, one taken by NASA's Hubble Space Telescope (left), the second by its James Webb Space Telescope.

Employing massive data sets collected through NASA's James Webb Space Telescope, a research team led by a Rutgers University-New Brunswick astronomer is unearthing clues to conditions existing in the early universe.
The team has catalogued the ages of stars in the Wolf-Lundmark-Melotte (WLM) galaxy, constructing the most detailed picture of it yet, according to the researchers. WLM, a neighbour of the Milky Way, is an active centre of star formation that includes ancient stars formed 13 billion years ago.
"In looking so deeply and seeing so clearly, we've been able to, effectively, go back in time," said Kristen McQuinn, an assistant professor in the Department of Physics and Astronomy in the School of Arts and Sciences, who led the research, described in the *Astrophysical Journal*. "You're basically going on a kind of archaeological dig, to find the very low mass stars that were formed early in the history of the universe."
McQuinn credited the Amarel high performance computing cluster managed by the Rutgers Office of Advanced Research Computing for enabling the team to calculate the galaxy's history of stellar development.
One aspect of the research involved taking one massive calculation and repeating it 600 times, McQuinn said.
The major computation effort also helped confirm telescope calibrations and data processing procedures that will benefit the wider scientific community, she added.

So-called "low mass" galaxies are of special interest to McQuinn. Because they are believed to have dominated the early universe, they allow researchers to study the formation of stars, the evolution of chemical elements and the impact of star formation on the gas and structure of a galaxy. Faint and spread across the sky, they constitute the majority of galaxies in the local universe. Advanced telescopes such as the Webb are allowing scientists a closer look.
WLM -- an "irregular" galaxy, meaning it doesn't possess a distinct shape, such as a spiral or ellipse -- was discovered by the German astronomer Max Wolf in 1909 and characterized in greater detail in 1926 by Swedish astronomer Knut Lundmark and British astronomer Philibert Jacques Melotte. It is positioned at the outskirts of the Local Group, a dumbbell-shaped group of galaxies that includes the Milky Way.
Being at the edge of the Local Group has protected WLM from the ravages of intermingling with other galaxies, leaving its star population in a pristine state and useful for study, McQuinn noted. WLM also is interesting to astronomers because it is a dynamic, complex system with lots of gas, enabling it to actively form stars.
To formulate the galaxy's star formation history -- the rate at which stars have been born across different epochs of time in the universe -- McQuinn and her team employed the telescope to painstakingly zero in on swaths of sky containing hundreds of thousands of individual stars. To determine the age of a star, they measured its colour -- a proxy for temperature -- and its brightness.
"We can use what we know about stellar evolution and what these colours and brightnesses indicate to basically age the galaxy's stars," said McQuinn, adding the researchers then counted the stars of different ages and mapped out the birth rate of stars over the history of the universe. "What you end up with is a sense of how old this structure is that you're looking at."
Cataloguing the stars in this way showed the researchers that WLM's star producing abilities ebbed and flowed over time. The team's observations, which confirm earlier assessments by scientists using the Hubble Space Telescope, show that the galaxy produced stars early in the history of the universe over a period of 3 billion years. It paused for a while, then re-ignited.
McQuinn said she believes that the pause was caused by conditions specific to the early universe.
"The universe back then was really hot," she said. "We think the temperature of the universe ended up heating the gas in this galaxy, and kind of turned off star formation for a while. The cool down period lasted a few billion years and then star formation proceeded again."
The research is part of NASA's Early Release Program, where designated scientists work with the Space Telescope Science Institute and conduct research designed to highlight Webb's capabilities and help astronomers prepare for future observations.
NASA launched the Webb telescope in December 2021. The large-mirrored instrument orbits the sun a million miles away from Earth. Scientists compete for time on the telescope to study a host of topics including the conditions of the early universe, the history of the solar system, and the search for exoplanets.
"There's a lot of science that's going to come out of this program that hasn't been done yet," McQuinn said.
Other Rutgers researchers on the study included Max Newman, a doctoral student, and Roger Cohen, a postdoctoral associate, both in the Department of Physics and Astronomy, Rutgers School of Arts and Sciences.
Other scientists involved with the study are from institutions including: the University of California-Berkeley; Raytheon Technologies; the University of Arizona; the University of Washington; the Space Telescope Science Institute in Baltimore, Md.; Instituto Nazionale di Astrofisica Osservatorio Astronomico in Rome, Italy; the Space Science Data Centre, Rome, Italy; University of Tasmania, Australia; Yale University; Johns Hopkins University; the University of Virginia; the University of California-San Diego; the University of Minnesota; the University of Maryland; the University of Texas-Austin; and the Padova Astronomical Observatory, Padova, Italy.

- Physicists capture the first sounds of heat 'sloshing' in a superfluid

Date: February 8, 2024
Source: Massachusetts Institute of Technology



For the first time, MIT physicists have captured direct images of "second sound," the movement of heat sloshing back and forth within a superfluid. The results will expand scientists' understanding of heat flow in superconductors and neutron stars. Credits: Jose-Luis Olivares, MIT

In most materials, heat prefers to scatter. If left alone, a hotspot will gradually fade as it warms its surroundings. But in rare states of matter, heat can behave as a wave, moving back and forth somewhat like a sound wave that bounces from one end of a room to the other. In fact, this wave-like heat is what physicists call "second sound."

Signs of second sound have been observed in only a handful of materials. Now MIT physicists have captured direct images of second sound for the first time.

The new images reveal how heat can move like a wave, and "slosh" back and forth, even as a material's physical matter may move in an entirely different way. The images capture the pure movement of heat, independent of a material's particles.

"It's as if you had a tank of water and made one half nearly boiling," Assistant Professor Richard Fletcher offers as analogy. "If you then watched, the water itself might look totally calm, but suddenly the other side is hot, and then the other side is hot, and the heat goes back and forth, while the water looks totally still."

Led by Martin Zwierlein, the Thomas A Frank Professor of Physics, the team visualized second sound in a superfluid -- a special state of matter that is created when a cloud of atoms is cooled to extremely low temperatures, at which point the atoms begin to flow like a completely friction-free fluid. In this superfluid state, theorists have predicted that heat should also flow like a wave, though scientists had not been able to directly observe the phenomenon until now.

The new results, reported in the journal *Science*, will help physicists get a more complete picture of how heat moves through superfluids and other related materials, including superconductors and neutron stars.

"There are strong connections between our puff of gas, which is a million times thinner than air, and the behaviour of electrons in high-temperature superconductors, and even neutrons in ultra dense neutron stars," Zwierlein says. "Now we can probe pristinely the temperature response of our system, which teaches us about things that are very difficult to understand or even reach."

Zwierlein and Fletcher's co-authors on the study are first author and former physics graduate student Zhenjie Yan and former physics graduate students Parth Patel and Biswaroop Mikherjee, along with Chris Vale at Swinburne University of Technology in Melbourne, Australia. The MIT researchers are part of the MIT-Harvard Centre for Ultracold Atoms (CUA).

Super sound

When clouds of atoms are brought down to temperatures close to absolute zero, they can transition into rare states of matter. Zwierlein's group at MIT is exploring the exotic phenomena that emerge among ultracold atoms, and specifically fermions -- particles, such as electrons, that normally avoid each other.

Under certain conditions, however, fermions can be made to strongly interact and pair up. In this coupled state, fermions can flow in unconventional ways. For their latest experiments, the team employs fermionic lithium-6 atoms, which are trapped and cooled to nanokelvin temperatures.

In 1938, the physicist László Tisza proposed a two-fluid model for superfluidity -- that a superfluid is actually a mixture of some normal, viscous fluid and a friction-free superfluid. This mixture of two fluids should allow for two types of sound, ordinary density waves and peculiar temperature waves, which physicist Lev Landau later named "second sound."

Since a fluid transition into a superfluid at a certain critical, ultracold temperature, the MIT team reasoned that the two types of fluid should also transport heat differently: In normal fluids, heat should dissipate as usual, whereas in a superfluid, it could move as a wave, similarly to sound.

"Second sound is the hallmark of superfluidity, but in ultracold gases so far you could only see it in this faint reflection of the density ripples that go along with it," Zwierlein says. "The character of the heat wave could not be proven before."

Tuning in
Zwierlein and his team sought to isolate and observe second sound, the wave-like movement of heat, independent of the physical motion of fermions in their superfluid. They did so by developing a new method of thermography -- a heat-mapping technique. In conventional materials one would use infrared sensors to image heat sources.
But at ultracold temperatures, gases do not give off infrared radiation. Instead, the team developed a method to use radio frequency to "see" how heat moves through the superfluid. They found that the lithium-6 fermions resonate at different radio frequencies depending on their temperature: When the cloud is at warmer temperatures, and carries more normal liquid, it resonates at a higher frequency. Regions in the cloud that are colder resonate at a lower frequency.
The researchers applied the higher resonant radio frequency, which prompted any normal, "hot" fermions in the liquid to ring in response. The researchers then were able to zero in on the resonating fermions and track them over time to create "movies" that revealed heat's pure motion -- a sloshing back and forth, similar to waves of sound.
"For the first time, we can take pictures of this substance as we cool it through the critical temperature of superfluidity, and directly see how it transitions from being a normal fluid, where heat equilibrates boringly, to a superfluid where heat sloshes back and forth," Zwierlein says.
The experiments mark the first time that scientists have been able to directly image second sound, and the pure motion of heat in a superfluid quantum gas. The researchers plan to extend their work to more precisely map heat's behaviour in other ultracold gases. Then, they say their findings can be scaled up to predict how heat flows in other strongly interacting materials, such as in high-temperature superconductors, and in neutron stars.
"Now we will be able to measure precisely the thermal conductivity in these systems, and hope to understand and design better systems," Zwierlein concludes.
This work was supported by the National Science Foundation (NSF), the Air Force Office of Scientific Research, and the Vannevar Bush Faculty Fellowship. The MIT team is part of the MIT-Harvard Centre for Ultracold Atoms (an NSF Physics Frontier Centre) and affiliated with the MIT Department of Physics and the Research Laboratory of Electronics (RLE).

- Astrophysicists crack the case of 'disappearing' Sulphur in planetary nebulae

Date: February 7, 2024
Source: The University of Hong Kong

The press release "HKU Astrophysicists Crack the Case of the "Disappearing" Sulphur in Planetary Nebulae" was posted on HKU FoS website on 7 February 2024.

Two astrophysicists from the Laboratory for Space Research (LSR) at The University of Hong Kong (HKU) have finally solved a 20-year-old astrophysical puzzle concerning the lower-than-expected amounts of the element Sulphur found in Planetary Nebulae (PNe) in comparison to expectations and measurements of other elements and other types of astrophysical objects.
The expected levels of Sulphur have long appeared to be "missing in action." However, they have now finally reported for duty after hiding in plain sight, as a result of leveraging highly accurate and reliable data. The team has recently reported their findings in *Astrophysical Journal Letters*.
Background
PNe are the short-lived glowing, ejected, gaseous shrouds of dying stars that have long fascinated and enthused professional and amateur astronomers alike with their colourful and varied shapes. PNe live for only a few tens of thousands of years compared to their host stars, which can take billions of years before they pass through the PN phase on the way to becoming "white dwarfs." Consequently, PNe provide an almost

instantaneous snapshot of stellar death throes. They are a vital, scientific window into late-stage stellar evolution as their rich emission line spectra enable detailed studies of their chemical compositions.

The Enigmatic Sulphur Anomaly

Past studies showed that PNe optical spectra appeared to have a varying deficit of the element Sulphur. This deficit was difficult to explain because Sulphur, known as an "α element," should be produced in lockstep with other elements like oxygen, neon, argon and chlorine in more massive stars. As a result, its cosmic abundance should also be directly proportional.

Surprisingly, while strong correlations between Sulphur and Oxygen abundances have been observed in H II regions (Hydrogen ionised region) and blue compact galaxies, PNe originating from low- to intermediate-mass stars consistently exhibit lower Sulphur levels, giving rise to the so-called mysterious "sulphur anomaly" that has perplexed and annoyed astronomers for decades.

Our Work Solving the Mystery

Ms Shuyu TAN, a graduate of HKU MPhil in Physics and Research Assistant at HKU LSR, along with her supervisor Professor Quentin PARKER, the Director of LSR, utilised an unprecedented sample of exceptional high signal to noise (S/N) optical spectra for approximately 130 PNe located in the centre of our Galaxy. This exceptional dataset had minimal background noise, allowing for a clear and detailed examination of the spectral features, helping the team effectively tackle and solve the mystery.

These PNe were observed using the world-leading European Southern Observatory (ESO) 8m Very Large Telescope in Chile. It turns out the anomaly was essentially a result of poor data quality for Sulphur emission lines in PNe spectra. It was found that using Oxygen as the base metallicity comparator to other elements was not accurate, and instead, Argon demonstrated a stronger correlation with Oxygen for Sulphur and has been suggested as a more reliable indicator of metallicity and a suitable comparison element. So, when a large, carefully selected sample of PNe are spectroscopically observed at high S/N on a large telescope, not only did the data reveal a strong "lock-step" behaviour or Sulphur in PNe for the first time, as seen and expected for other types of astrophysical objects, but the anomaly itself effectively went away.

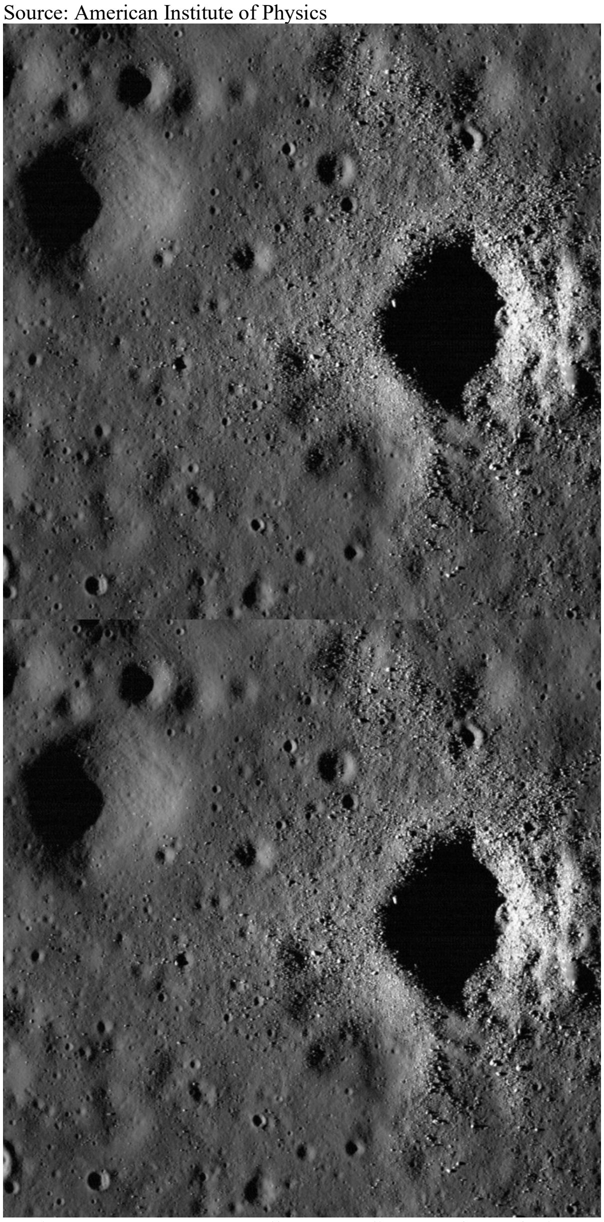
The authors have effectively disproven previous claims suggesting that the sulphur anomaly in Planetary Nebulae was a result of underestimated higher sulphur ionization stages or weak sulphur line fluxes. This finding underscores the critical importance of high-quality data in unravelling scientific mysteries.

- Understanding the moon's history with Chang'e-5 sample

The lunar sample returned by China's 2020 lunar mission contained minerals that provide clues to their origin

Date: February 6, 2024

Source: American Institute of Physics



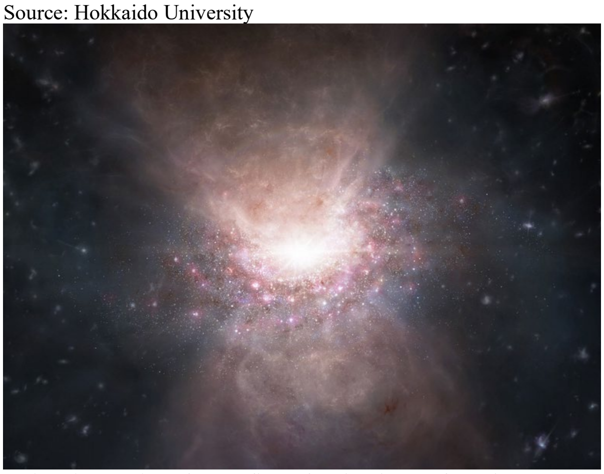
Fresh Crater on Oceanus Procellarum. Credit: NASA/GSFC/Arizona State University

Earth's moon achieved its Swiss cheese appearance from celestial objects crashing into its surface, forming impact craters. But craters weren't all that was left behind; the intense pressure and temperature of such a

collision also impacts the rocks and dust covering the lunar surface, known as regolith, altering its mineral composition and structure. Analysing the resulting minerals provides modern researchers clues to the moon's past.
China's Chang'e-5, the first lunar sample return mission since the Soviet Union's Luna 24 in 1976, delivered 1.73 kilograms of regolith from the Oceanus Procellarum, a plane named for its vast size. The sample landed with Chang'e-5 (CE-5) in late 2020 and included a new mineral, Changesite-(Y), as well as a perplexing combination of silica minerals.
In *Matter and Radiation at Extremes,* an AIP Publishing journal, researchers from the Chinese Academy of Sciences compared CE-5's material composition to other lunar and Martian regolith samples. They examined potential causes and origins for the lunar sample's unique makeup.
Asteroids and comets collide with the moon at extreme velocities, causing impact (shock) metamorphism in the lunar rocks. This temperature and pressure change occurs rapidly and has distinctive features, including the formation of silica polymorphs like stishovite and seifertite, which are chemically identical to quartz but have different crystalline structures.
"Although the lunar surface is covered by tens of thousands of impact craters, high-pressure minerals are uncommon in lunar samples," said author Wei Du. "One of the possible explanations for this is that most high-pressure minerals are unstable at high temperatures. Therefore, those formed during impact could have experienced a retrograde process."
However, a silica fragment in the CE-5 sample contains both stishovite and seifertite, minerals that theoretically only coexist at much higher pressures than the sample seemingly experienced.
The authors determined that seifertite exists as the phase between stishovite and a third silica polymorph, α-cristobalite, also present in the sample.
"In other words, seifertite could form from α-cristobalite during the compressing process, and some of the sample transformed to stishovite during the subsequent temperature-increasing process," said Du.
This mission also returned a new lunar mineral, Changesite-(Y), a phosphate mineral characterized by colourless, transparent columnar crystals.
The researchers estimated the peak pressure (11-40 GPa) and impact duration (0.1-1.0 second) of the collision that shaped the sample. Combining that information with shock wave models, they estimated the resulting crater to be anywhere from 3 to 32 kilometres wide, depending on the impact angle.
Remote observations show that distant ejecta in CE-5 regolith mainly come from four impact craters, and the Aristarchus crater is the youngest among the four distant craters. Because seifertite and stishovite are easily disturbed by thermal metamorphism, they inferred the silica fragment likely originated from the collision that formed the Aristarchus crater.
This sample return mission demonstrated the power of modern analysis and how it can help uncover the history of celestial bodies.

- Gas on the run -- ALMA spots the shadow of a molecular outflow from a quasar when the Universe was less than one billion years old

Date: February 1, 2024
Source: Hokkaido University



Artist's impression of an outflow of molecular gas from the quasar J2054-0005 (Credit: ALMA (ESO/NAOJ/NRAO))

Theoretical predictions have been confirmed with the discovery of an outflow of molecular gas from a quasar when the Universe was less than a billion years old.
A quasar is a compact region powered by a supermassive black hole located in the centre of a massive galaxy. They are extremely luminous, with a point-like appearance similar to stars, and are extremely distant from Earth. Owing to their distance and brightness, they provide a peek into conditions of the early Universe, when it was less than 1 billion years old.

A team of researchers led by Assistant Professor Dragan Salak at Hokkaido University, Assistant Professor Takuya Hashimoto at the University of Tsukuba, and Professor Akio Inoue at Waseda University, has discovered the first evidence of suppression of star formation driven by an outflow of molecular gas in a quasar-host galaxy in the early Universe. Their findings, based on observations they made using the Atacama Large Millimetre/submillimetre Array (ALMA), in Chile, were published in *The Astrophysical Journal*.

Molecular gas is vital to the formation of stars. As the primary fuel of star formation, the ubiquity and high concentrations of molecular gas within a galaxy would lead to a vast number of stars being formed. By ejecting this gas into intergalactic space faster than it could be consumed by star formation, molecular outflows effectively suppress the formation of stars in galaxies that host quasars.

"Theoretical work suggests that molecular gas outflows play an important role in the formation and evolution of galaxies from an early age, because they can regulate star formation," Salak explains. "Quasars are especially energetic sources, so we expected that they may be able to generate powerful outflows."

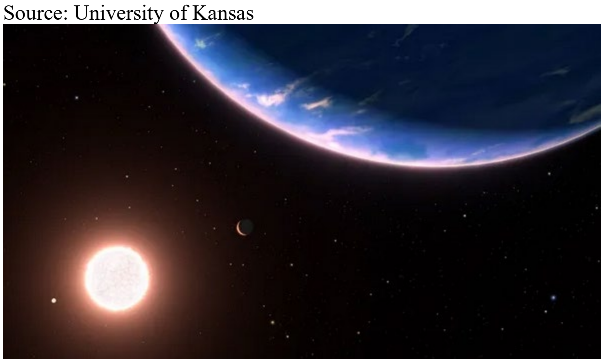
The quasar the researchers observed, J2054-0005, has a very high redshift -- it and the Earth are apparently moving away from each other very fast. "J2054-0005 is one of the brightest quasars in the distant Universe, so we decided to target this object as an excellent candidate to study powerful outflows," Hashimoto says. The researchers used ALMA to observe the outflow of molecular gas from the quasar. As the only telescope in the world that has the sensitivity and frequency coverage to detect molecular gas outflows in the early Universe, ALMA was key to this study.

Speaking about the method used in the study, Salak comments: "The outflowing molecular (OH) gas was discovered in absorption. This means we did not observe microwave radiation coming directly from the OH molecules; instead, we observed the radiation coming from the bright quasar -- and absorption means that OH molecules happened to absorb a part of the radiation from the quasar. So, it was like revealing the presence of a gas by seeing the 'shadow' it cast in front of the light source."

The findings from this study are the first strong evidence that powerful molecular gas outflows from quasar-host galaxies exist and impact galaxy evolution at the early cosmic age. "Molecular gas is a very important constituent of galaxies because it is the fuel for star formation," Salak concludes. "Our findings show that quasars are capable of suppressing star formation in their host galaxies by ejecting molecular gas into intergalactic space."

- ❖ Neptune-like exoplanets can be cloudy or clear

Date: February 2, 2024
Source: University of Kansas



An Illustration shows an Neptune-like exoplanet around its star (Image credit: NASA/ESA/Leah Hustak, Ralf Crawford, Space Telescope Science Institute)

The study of "exoplanets," the sci-fi-sounding name for all planets in the cosmos beyond our own solar system, is a pretty new field. Mainly, exoplanet researchers like those in the ExoLab at the University of Kansas use data from space-borne telescopes such as the Hubble Space Telescope and Webb Space Telescope. Whenever news headlines offer findings of "Earth-like" planets or planets with the potential to support humanity, they're talking about exoplanets within our own Milky Way.

Jonathan Brande, a doctoral candidate in the ExoLab at the University of Kansas, has just published findings in the open-access scientific journal *The Astrophysical Journal Letters* showing new atmospheric detail in a set of 15 exoplanets similar to Neptune. While none could support humanity, a better understanding of their behaviour might help us to understand why we don't have a small Neptune, while most solar systems seem to feature a planet of this class.

"Over the past several years at KU, my focus has been studying the atmospheres of exoplanets through a technique known as transmission spectroscopy," Brande said. "When a planet transits, meaning it moves between our line of sight and the star it orbits, light from the star passes through the planet's atmosphere, getting absorbed by the various gases present. By capturing a spectrum of the star -- passing the light through an instrument called a spectrograph, akin to passing it through a prism -- we observe a rainbow, measuring the brightness of different constituent colours. Varied areas of brightness or dimness in the spectrum reveal the gases absorbing light in the planet's atmosphere."

With this methodology, several years ago Brande published a paper concerning the "warm Neptune" exoplanet TOI-674 b, where he presented observations indicating the presence of water vapor in its atmosphere. These observations were part of a broader program led by Brande's adviser, Ian Crossfield, associate professor of physics & astronomy at KU, to observe atmospheres of Neptune-sized exoplanets.

"We want to comprehend the behaviours of these planets, given that those slightly larger than Earth and smaller than Neptune are the most common in the galaxy," Brande said.

This recent ApJL paper summarizes observations from that program, incorporating data from additional observations to address why some planets appear cloudy while others are clear.

"The goal is to explore the physical explanations behind the distinct appearances of these planets," Brande said.

Brande and his co-authors took special note of regions where exoplanets tend to form clouds or hazes high up in their atmosphere. When such atmospheric aerosols are present, the KU researcher said hazes can block the light filtering through the atmosphere.

"If a planet has a cloud right above the surface with hundreds of kilometres of clear air above it, starlight can easily pass through the clear air and be absorbed only by the specific gases in that part of the atmosphere," Brande said. "However, if the cloud is positioned very high, clouds are generally opaque across the electromagnetic spectrum. While hazes have spectral features, for our work, where we focus on a relatively narrow range with Hubble, they also produce mostly flat spectra."

According to Brande, when these aerosols are present high in the atmosphere, there's no clear path for light to filter through.

"With Hubble, the single gas we're most sensitive to is water vapor," he said. "If we observe water vapor in a planet's atmosphere, that's a good indication that there are no clouds high enough to block its absorption. Conversely, if water vapor is not observed and only a flat spectrum is seen, despite knowing that the planet should have an extended atmosphere, it suggests the likely presence of clouds or hazes at higher altitudes."

Brande led the work of an international team of astronomers on the paper, including Crossfield at KU and collaborators from the Max Planck Institute in Heidelberg, Germany, a cohort led by Laura Kreidberg, and investigators at the University of Texas, Austin, led by Caroline Morley.

Brande and his co-authors approached their analysis differently than previous efforts by focusing on determining the physical parameters of the small-Neptune atmospheres. In contrast, previous analyses often involved fitting a single model spectrum to observations.

"Typically, researchers would take an atmospheric model with pre-computed water content, scale and shift it to match observed planets in their sample," Brande said. "This approach indicates whether the spectrum is clear or cloudy but provides no information about the amount of water vapor or the location of clouds in the atmosphere."

Instead, Brande employed a technique known as "atmospheric retrieval."

"This involved modelling the atmosphere across various planet parameters such as water vapor quantity and cloud location, iterating through hundreds and thousands of simulations to find the best fit configuration," he said. "Our retrievals gave us a best-fit model spectrum for each planet, from which we calculated how cloudy or clear the planet appeared to be. Then, we compared those measured clarities to a separate suite of models by Caroline Morley, which let us see that our results are in line with expectations for similar planets. In examining cloud and haze behaviour, our models indicated that clouds were a better fit than hazes. The sedimentation efficiency parameter, reflecting cloud compactness, suggested observed planets had relatively low sedimentation efficiencies, resulting in fluffy clouds. These clouds, made up of particles like water droplets, remained lofted in the atmosphere due to their low settling tendency."

Brande's findings provide insights into the behaviour of these planetary atmospheres and caused "substantial interest" when he presented them at a recent meeting of the American Astronomical Society.

Other findings

Moreover, Brande is part of an international observation program, led by Crossfield, that just announced findings of water vapor on GJ 9827d -- a planet as hot as Venus 97 light-years from Earth in the constellation Pisces. The observations, made with the Hubble Space Telescope, show the planet may be just one example of water-rich planets in the Milky Way. They were announced by a team led by Pierre-Alexis Roy of the Trottier Institute for Research on Exoplanets at Université de Montréal.

"We were searching for water vapor on the atmospheres of sub-Neptune-type planets," Brande said. "Pierre-Alexis' paper is the latest from that main effort because it took approximately 10 or 11 orbits or transits of the planet to make the water-vapor detection. Pierre-Alexis' spectrum made it into our paper as one of our trend-data points, and we included all the planets from their proposal and others studied in the literature, making our results stronger. We were in close communication with them during the process of both papers to ensure we were using the proper updated results and accurately reflecting their findings."

- Bright galaxies put dark matter to the test

If cold dark matter theories are correct, Webb Space Telescope should find tiny, bright galaxies of early universe

Date: January 31, 2024
Source: University of California - Los Angeles

An image of Stephan's Quintet taken by the James Webb Space Telescope. (Image credit: NASA, ESA, CSA, STScI)

For the past year and a half, the James Webb Space Telescope has delivered astonishing images of distant galaxies formed not long after the Big Bang, giving scientists their first glimpses of the infant universe. Now, a group of astrophysicists has upped the ante: Find the tiniest, brightest galaxies near the beginning of time itself, or scientists will have to totally rethink their theories about dark matter.

The team, led by UCLA astrophysicists, ran simulations that track the formation of small galaxies after the Big Bang and included, for the first time, previously neglected interactions between gas and dark matter. They found that the galaxies created are very tiny, much brighter, and form more quickly than they do in typical simulations that don’t take these interactions into account, instead revealing much fainter galaxies.

Small galaxies, also called dwarf galaxies, are present throughout the universe, and are often thought to represent the earliest type of galaxy. Small galaxies are thus especially interesting to scientists studying the origins of the universe. But the small galaxies they find don't always match what they think they should find. Those closest to the Milky Way spin quicker or are not as dense as in simulations, indicating that the models might have omitted something, such as these gas-dark matter interactions.

The new research, published in *The Astrophysical Journal Letters,* improves the simulations by adding dark matter interactions with gas and finds that these faint galaxies may have been much brighter than expected early in the universe's history, when they were just beginning to form. The authors suggest scientists should try to find small galaxies that are much brighter than expected using telescopes like the Webb telescope. If they only find faint ones, then some of their ideas about dark matter might be wrong.

Dark matter is a type of hypothetical matter that does not interact with electromagnetism or light. Thus, it is impossible to observe using optics, electricity or magnetism. But dark matter does interact with gravity, and its presence has been inferred from the gravitational effects it has on ordinary matter -- the stuff that makes up all the observable universe. Even though 84% of the matter in the universe is thought to be made of dark matter, it has never been detected directly.

All galaxies are surrounded by a vast halo of dark matter, and scientists think that dark matter was essential to their formation. The "standard cosmological model" astrophysicists use to understand galaxy formation describes how clumps of dark matter in the very early universe drew in ordinary matter through gravity, causing the formation of stars and creating the galaxies we see today. Because most dark matter particles -- called cold dark matter -- are thought to move much slower than the speed of light, this process of accumulation would have occurred gradually.

But over 13 billion years ago, prior to the formation of the first galaxies, ordinary matter, consisting of hydrogen and helium gas from the Big Bang, and dark matter were moving relative to one another. The gas streamed at supersonic velocities past dense thickets of more slowly moving dark matter that should have pulled it in to form galaxies.

"Indeed, in models that do not take streaming into account, this is exactly what happens," said Claire Williams, a UCLA doctoral student and the paper's first author. "Gas is attracted to the gravitational pull of dark matter, forms clumps and knots so dense that hydrogen fusion can occur, and thus forms stars like our sun."

But Williams and co-authors on the Supersonic Project team, a group of astrophysicists from the United States, Italy and Japan led by UCLA physics and astronomy professor Smadar Naoz, found if they added the streaming effect of different velocities between dark and ordinary matter to the simulations, the gas landed far away from the dark matter and was prevented from forming stars right away. When the accumulated gas fell back into the galaxy millions of years later, a massive burst of star formation occurred all at once. Because these galaxies had many more young, hot, luminous stars than ordinary small galaxies for a time, they shone much brighter.

"While the streaming suppressed star formation in the smallest galaxies, it also boosted star formation in dwarf galaxies, causing them to outshine the non-streaming patches of the universe," Williams said. "We predict that the Webb telescope will be able to find regions of the universe where galaxies will be brighter, heightened by this velocity. The fact that they should be so bright might make it easier for the telescope to discover these small galaxies, which are typically extremely hard to detect only 375 million years after the Big Bang."

Because dark matter is impossible to study directly, searching for bright patches of galaxies in the early universe could offer an effective test for theories about dark matter, which has been fruitless so far.

"The discovery of patches of small, bright galaxies in the early universe would confirm that we are on the right track with the cold dark matter model because only the velocity between two kinds of matter can produce the type of galaxy we're looking for," said Naoz, the Howard and Astrid Preston Professor of Astrophysics. "If dark matter does not behave like standard cold dark matter and the streaming effect isn't present, then these bright dwarf galaxies won't be found and we need to go back to the drawing board."

The research was supported by the National Science Foundation and NASA.