South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 592 – December 6th 2024 Editor: Roger Burgess

Main Talk Michael **Foulkes "Transit Phenomena"**

This talk discusses the most famous of transit events, I.e. transits of Mercury and Venus. It looks at the history of Venus transits and the attempts to use these events to measure the distance between the Earth to the Sun. It also discusses other types of transit phenomena including how transits have been used to find exo planets.

Michael is the Director of the BAA Saturn, Uranus and Neptune Section.

Please support a raffle we are organizing this month.

- Ancient hot water on Mars points to habitable past

Date: November 22, 2024
Source: Curtin University

New Curtin University-led research has uncovered what may be the oldest direct evidence of ancient hot water activity on Mars, revealing the planet may have been habitable at some point in its past.

The study analysed a 4.45-billion-year-old zircon grain from the famous Martian meteorite NWA7034, also known as Black Beauty, and found geochemical 'fingerprints' of water-rich fluids.

Study co-author Dr Aaron Cavosie from Curtin's School of Earth and Planetary Sciences said the discovery opened up new avenues for understanding ancient Martian hydrothermal systems associated with magmatism, as well as the planet's past habitability.

"We used nano-scale geochemistry to detect elemental evidence of hot water on Mars 4.45 billion years ago," Dr Cavosie said.

"Hydrothermal systems were essential for the development of life on Earth and our findings suggest Mars also had water, a key ingredient for habitable environments, during the earliest history of crust formation."

"Through nano-scale imaging and spectroscopy, the team identified element patterns in this unique zircon, including iron, aluminium, yttrium and sodium. These elements were added as the zircon formed 4.45 billion years ago, suggesting water was present during early Martian magmatic activity."

Dr Cavosie said the research showed that even though Mars' crust endured massive meteorite impacts that caused major surface upheaval, water was present during the early Pre-Noachian period, prior to about 4.1 billion years ago.

"A 2022 Curtin study of the same zircon grain found it had been 'shocked' by a meteorite impact, marking it as the first and only known shocked zircon from Mars," Dr Cavosie said.

"This new study takes us a step further in understanding early Mars, by way of identifying tell-tale signs of water-rich fluids from when the grain formed, providing geochemical markers of water in the oldest known Martian crust."

Lead author Dr Jack Gillespie from the University of Lausanne was a Postdoctoral Research Associate at Curtin's School of Earth and Planetary Sciences at the time of the study, which was co-authored by researchers from Curtin's Space Science and Technology Centre, the John de Laeter Centre and the University of Adelaide, with funding from the Australian Research Council, Curtin University, University of Adelaide and the Swiss National Science Foundation.

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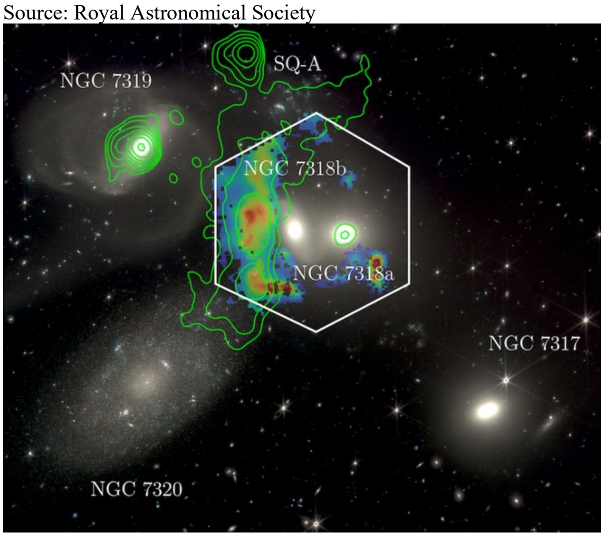
❖ 3.2 million km/h galaxy smash-up

Date: November 22, 2024
Source: Royal Astronomical Society



WEAVE data overlaid on a James Webb Space Telescope image of Stephan's Quintet, with green contours showing radio data from the Low Frequency Array (LOFAR) radio telescope. The orange and blue colours follow the brightness of Hydrogen-alpha obtained with the WEAVE LIFU, which trace where the intergalactic gas is ionised. The hexagon denotes the approximate coverage of the new WEAVE observations of the system, which is 36 kpc wide (similar in size to our own galaxy, the Milky Way).
Credit
University of Hertfordshire
Licence type

A massive collision of galaxies sparked by one travelling at a scarcely-believable 2 million mph (3.2 million km/h) has been seen in unprecedented detail by one of Earth's most powerful telescopes.
The dramatic impact was observed in Stephan's Quintet, a nearby galaxy group made up of five galaxies first sighted almost 150 years ago.
It sparked an immensely powerful shock akin to a "sonic boom from a jet fighter" -- the likes of which are among the most striking phenomena in the Universe.
Stephan's Quintet represents "a galactic crossroad where past collisions between galaxies have left behind a complex field of debris," which has now been reawakened by the passage of the galaxy, NGC 7318b.
The collision was spotted by a team of scientists using the first observations from the new 20-million Euro (£16.7million) William Herschel Telescope Enhanced Area Velocity Explorer (WEAVE) wide-field spectrograph in La Palma, Spain.
This cutting-edge, next generation science facility will not only reveal how our Milky Way galaxy was built up over billions of years, but also offer new insights into millions of other galaxies across the Universe.
The discovery of NGC 7318b smashing through Stephan's Quintet was observed by a team of more than 60 astronomers and has been published today in *Monthly Notices of the Royal Astronomical Society*.
The system is an ideal laboratory to understand the chaotic and often violent relationship between galaxies, which is why it was the focus of the first-light observation by the WEAVE Large Integral Field Unit (LIFU).
Lead researcher Dr Marina Arnaudova, of the University of Hertfordshire, said: "Since its discovery in 1877, Stephan's Quintet has captivated astronomers, because it represents a galactic crossroad where past collisions between galaxies have left behind a complex field of debris.
"Dynamical activity in this galaxy group has now been reawakened by a galaxy smashing through it at an incredible speed of over 2 million mph (3.2 million km/h), leading to an immensely powerful shock, much like a sonic boom from a jet fighter."
The international team has uncovered a dual nature behind the shock front, previously unknown to astronomers.
"As the shock moves through pockets of cold gas, it travels at hypersonic speeds -- several times the speed of sound in the intergalactic medium of Stephan's Quintet* -- powerful enough to rip apart electrons from atoms, leaving behind a glowing trail of charged gas, as seen with WEAVE," Dr Arnaudova said.
However, when the shock passes through the surrounding hot gas, it becomes much weaker, according to PhD student Soumyadeep Das, of the University of Hertfordshire.
He added: "Instead of causing significant disruption, the weak shock compresses the hot gas, resulting in radio waves that are picked up by radio telescopes like the Low Frequency Array (LOFAR)."
The new insight and unprecedented detail came from WEAVE's LIFU, combining data with other cutting-edge instruments such as the LOFAR, the Very Large Array (VLA), and the James Webb Space Telescope (JWST).
WEAVE is a state-of-the-art super-fast mapping device that has been connected to the William Herschel Telescope to analyse the composition of stars and gas both in the Milky Way and in distant galaxies.
This is done with the help of a spectroscope, which reveals the elements that stars are made of by generating a bar code-style pattern

within a prism of colours that make up a source of light.

It was designed and built following a multi-lateral agreement by France, Italy and the countries of the Isaac Newton Group of Telescopes partnership (the UK, Spain and the Netherlands).

Astronomers hope that WEAVE will help reveal how our galaxy formed in unprecedented detail and revolutionise our understanding of the Universe.

Dr Daniel Smith, of the University of Hertfordshire, said: "It's really neat work that Marina has put together with this large team, but this first WEAVE science paper also represents just a taste of what is to come over the next five years now that WEAVE is becoming fully operational."

Professor Gavin Dalton, WEAVE principal investigator at RAL Space and the University of Oxford, said: "It's fantastic to see the level of detail uncovered here by WEAVE.

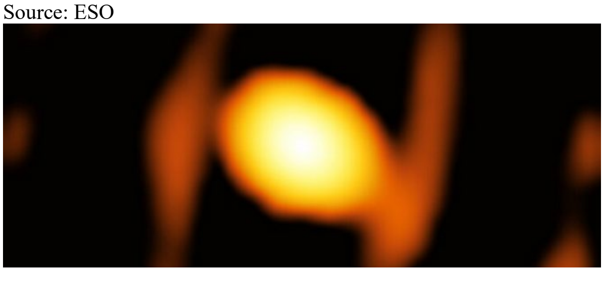
"As well as the details of the shock and the unfolding collision that we see in Stephan's Quintet, these observations provide a remarkable perspective on what may be happening in the formation and evolution of the barely resolved faint galaxies that we see at the limits of our current capabilities."

Dr Marc Balcells, director of the Isaac Newton Group of Telescopes, said: "I'm excited to see that the data gathered at the WEAVE first light already provide a high-impact result, and I'm sure this is just an early example of the types of discoveries that will be made possible with WEAVE on the William Herschel Telescope in the coming years."

C-UKRI) of the United Kingdom, the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO) of the Netherlands, and the IAC in Spain. IAC's contribution to the ING is funded by the Spanish Ministry of Science, Innovation and Universities.

- ❖ Astronomers take the first close-up picture of a star outside our galaxy

Date: November 21, 2024
Source: ESO



"For the first time, we have succeeded in taking a zoomed-in image of a dying star in a galaxy outside our own Milky Way," says Keiichi Ohnaka, an astrophysicist from Universidad Andrés Bello in Chile. Located a staggering 160 000 light-years from us, the star WOH G64 was imaged thanks to the impressive sharpness offered by the European Southern Observatory's Very Large Telescope Interferometer (ESO's VLTI). The new observations reveal a star puffing out gas and dust, in the last stages before it becomes a supernova.

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"We discovered an egg-shaped cocoon closely surrounding the star," says Ohnaka, the lead author of a study reporting the observations published today in *Astronomy & Astrophysics*. "We are excited because this may be related to the drastic ejection of material from the dying star before a supernova explosion."

While astronomers have taken about two dozen zoomed-in images of stars in our galaxy, unveiling their properties, countless other stars dwell within other galaxies, so far away that observing even one of them in detail has been extremely challenging. Up until now.

The newly imaged star, WOH G64, lies within the Large Magellanic Cloud, one of the small galaxies that orbits the Milky Way. Astronomers have known about this star for decades and have appropriately dubbed it the 'behemoth star'. With a size roughly 2000 times that of our Sun, WOH G64 is classified as a red supergiant.

Ohnaka's team had long been interested in this behemoth star. Back in 2005 and 2007, they used ESO's VLTI in Chile's Atacama Desert to learn more about the star's features, and carried on studying it in the years since. But an actual image of the star had remained elusive.

For the desired picture, the team had to wait for the development of one of the VLTI's second-generation instruments, GRAVITY. After comparing their new results with other previous observations of WOH G64, they were surprised to find that the star had become dimmer over the past decade.

"We have found that the star has been experiencing a significant change in the last 10 years, providing us with a rare opportunity to witness a star's life in real time," says Gerd Weigelt, an astronomy professor at the Max Planck Institute for Radio Astronomy in Bonn, Germany and a co-author of the study.
In their final life stages, red super giants like WOH G64 shed their outer layers of gas and dust in a process that can last thousands of years. "This star is one of the most extreme of its kind, and any drastic change may bring it closer to an explosive end," adds co-author Jacco van Loon, Keele Observatory Director at Keele University, UK, who has been observing WOH G64 since the 1990s.
The team thinks that these shed materials may also be responsible for the dimming and for the unexpected shape of the dust cocoon around the star. The new image shows that the cocoon is stretched-out, which surprised scientists, who expected a different shape based on previous observations and computer models. The team believes that the cocoon's egg-like shape could be explained by either the star's shedding or by the influence of a yet-undiscovered companion star.
As the star becomes fainter, taking other close-up pictures of it is becoming increasingly difficult, even for the VLTI. Nonetheless, planned updates to the telescope's instrumentation, such as the future GRAVITY+, promise to change this soon. "Similar follow-up observations with ESO instruments will be important for understanding what is going on in the star," concludes Ohnaka.

- Meteorite contains evidence of liquid water on Mars 742 million years ago

Researchers show the Lafayette Meteorite was exposed to liquid water while located on Mars

Date: November 13, 2024
Source: Purdue University

Most of the Lafayette meteorite is kept at the Smithsonian National Museum of Natural History. (NMNH)

An asteroid struck Mars 11 million years ago and sent pieces of the red planet hurtling through space. One of these chunks of Mars eventually crashed into the Earth somewhere near Purdue and is one of the few meteorites that can be traced directly to Mars. This meteorite was rediscovered in a drawer at Purdue University in 1931 and therefore named the Lafayette Meteorite.
During early investigations of the Lafayette Meteorite, scientists discovered that it had interacted with liquid water while on Mars. Scientists have long wondered when that interaction with liquid water took place. An international collaboration of scientists including two from Purdue University's College of Science have recently determined the age of the minerals in the Lafayette Meteorite that formed when there was liquid water. The team has published its findings in *Geochemical Perspective Letters.*
Marissa Tremblay, assistant professor with the Department of Earth, Atmospheric, and Planetary Sciences (EAPS) at Purdue University, is the lead author of this publication. She uses noble gases like helium, neon and argon, to study the physical and chemical processes shaping the surfaces of Earth and other planets. She explains that some meteorites from Mars contain minerals that formed through interaction with liquid water while still on Mars.
"Dating these minerals can therefore tell us when there was liquid water at or near the surface of Mars in the planet's geologic past," she says. "We dated these minerals in the Martian meteorite Lafayette and found that they formed 742 million years ago. We do not think there was abundant liquid water on the surface of Mars at this time. Instead, we think the water came from the melting of nearby subsurface ice called permafrost, and that the permafrost melting was caused by magmatic activity that still occurs periodically on Mars to the present day."
In this publication, her team demonstrated that the age obtained for the timing of water-rock interaction on Mars was robust and that the chronometer used was not affected by things that happened to Lafayette after it was altered in the presence of water.
"The age could have been affected by the impact that ejected the Lafayette Meteorite from Mars, the heating Lafayette experienced during the 11 million years it was floating out in space, or the heating Lafayette experienced when it fell to Earth and burned up a little bit in Earth's atmosphere," she says. "But we were able to demonstrate that none of these

things affected the age of aqueous alteration in Lafayette."

Ryan Ickert, senior research scientist with Purdue EAPS, is a co-author of the paper. He uses heavy radioactive and stable isotopes to study the timescales of geological processes. He demonstrated that other isotope data (previously used to estimate the timing of water-rock interaction on Mars) were problematic and had likely been affected by other processes.

"This meteorite uniquely has evidence that it has reacted with water. The exact date of this was controversial, and our publication dates when water was present," he says.

Found in a drawer

Thanks to research, quite a bit is known about the Lafayette Meteorite's origin story. It was ejected from the surface of Mars about 11 million years ago by an impact event.

"We know this because once it was ejected from Mars, the meteorite experienced bombardment by cosmic ray particles in outer space, that caused certain isotopes to be produced in Lafayette," Tremblay says. "Many meteoroids are produced by impacts on Mars and other planetary bodies, but only a handful will eventually fall to Earth."

But once Lafayette hit Earth, the story gets a little muddy. It is known for certain that the meteorite was found in a drawer at Purdue University in 1931. But how it got there is still a mystery. Tremblay and others made strides in explaining the history of the post-Earth timeline in a recent publication.

"We used organic contaminants from Earth found on Lafayette (specifically, crop diseases) that were particularly prevalent in certain years to narrow down when it might have fallen, and whether the meteorite fall may have been witnessed by someone," Tremblay says.

Meteorites: time capsules of the universe

Meteorites are solid time capsules from planets and celestial bodies from our universe. They carry with them bits of data that can be unlocked by geochronologists. They set themselves apart from rocks that may be found on Earth by a crust that forms from its descent through our atmosphere and often form a fiery entrance visible in the night's sky.

"We can identify meteorites by studying what minerals are present in them and the relationships between these minerals inside the meteorite," says Tremblay. "Meteorites are often denser than Earth rocks, contain metal, and are magnetic. We can also look for things like a fusion crust that forms during entry into Earth's atmosphere. Finally, we can use the chemistry of meteorites (specifically their oxygen isotope composition) to fingerprint which planetary body they came from or which type of meteorite it belongs to."

An international collab

The team involved with this publication included an international collaboration of scientists. The team also includes Darren F. Mark, Dan N. Barfod, Benjamin E. Cohen, Martin R. Lee, Tim Tomkinson and Caroline L. Smith representing the Scottish Universities Environmental Research Centre (SUERC), the Department of Earth and Environmental Science at the University of St Andrews, the School of Geographical and Earth Sciences at the University of Glasgow, the School of Earth Sciences at the University of Bristol, and the Science Group at The Natural History Museum in London.

"Before moving to Purdue, Ryan and I were both based at the Scottish Universities Environmental Research Centre, where the argon-argon isotopic analyses of the alteration minerals in Lafayette took place" Tremblay says. "Our collaborators at SUERC, the University of Glasgow, and the Natural History Museum have previously done a lot of work studying the history of Lafayette."

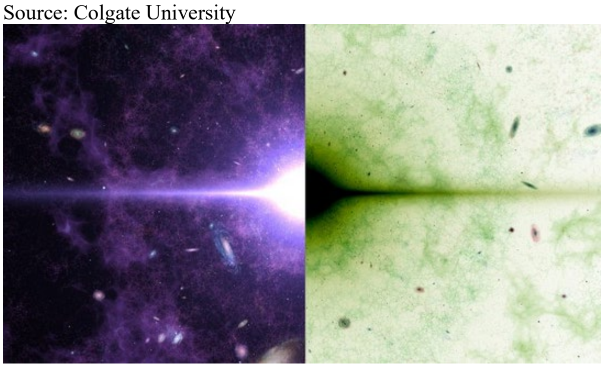
Dating the alteration minerals in Lafayette and, more generally, in this class of meteorites from Mars called nakhlites, has been a long-term objective in planetary science because scientists know that the alteration happened in the presence of liquid water on Mars. However, these materials are especially difficult to date, and previous attempts at dating them had either been very uncertain and/or likely affected by processes other than aqueous alteration.

"We have demonstrated a robust way to date alteration minerals in meteorites that can be applied to other meteorites and planetary bodies to understand when liquid water might have been present," Tremblay says.

Because of the Stahura Undergraduate Meteorite Fund, Tremblay and Ickert will be able to continue studying the geochemistry and histories of meteorites and undergraduates at Purdue EAPS will be able to assist in this research.

❖ Possible origins of dark matter in 'Dark Big Bang' scenario

Date: November 18, 2024
Source: Colgate University



Dark matter may have sprung from its own "Dark Big Bang," separate from the traditional Big Bang, with potential proof coming from future experiments detecting gravitational waves. Credit: NASA's Goddard Space Flight Centre/CI Lab, edited

Recent research by a student-faculty team at Colgate University unlocks new clues that could radically change the world's understanding of the origin of dark matter. Assistant Professor of Physics and Astronomy Cosmin Ilie and Richard Casey '24 have explored an idea put forth by two scientists at the University of Texas at Austin, Katherine Freese and Martin Winkler, suggesting that dark matter may have originated from a separate "Dark Big Bang," occurring shortly after the birth of the universe.

It is widely accepted that all the matter filling our universe (including dark matter) originated from one major event -- the Big Bang. This corresponds to the end of the cosmic inflation period, when the vacuum energy that drove the very brief extreme expansion initial phase of our universe was converted into a hot plasma of radiation and particles.

One of the most pressing mysteries is the origin and the nature of dark matter, which accounts for about 25% of the energy budget of the Universe today. While not yet directly detected in underground experiments, or observed in accelerators, the gravitational effects of dark matter have been firmly established on galactic and extragalactic scales. Moreover, dark matter leaves observable imprints on the electromagnetic afterglow of the Big Bang, the so-called cosmic microwave background radiation.

In 2023, Freese and Winkler proposed that dark matter, unlike ordinary matter, may have arisen from a distinct Big Bang event, which could have taken place months after the conventional Big Bang. In this model, dark matter particles are produced via the decay of a quantum field that only couples to the Dark Sector and is initially trapped in a false metastable vacuum state.

In their recent study, Ilie and Casey explore and refine this Dark Big Bang model by determining all the possible scenarios for its realization that remain consistent with current experimental data. Most notably, their work uncovers a previously unexplored range of possible parameters that could explain dark matter's origin. The study also determines the potential observable consequences of these new scenarios, particularly the generation of gravitational waves that could be detectable by future experiments.

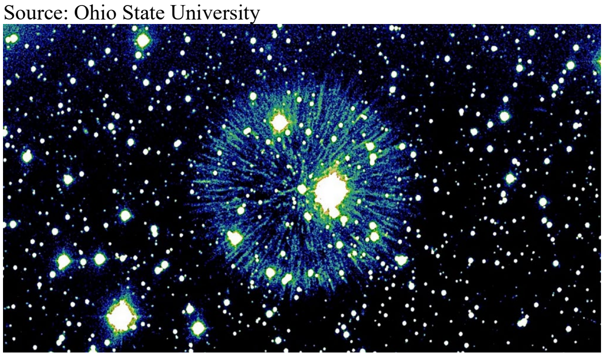
"Detecting gravitational waves generated by the Dark Big Bang could provide crucial evidence for this new theory of dark matter," said Ilie "With current experiments like the International Pulsar Timing Array (IPTA) and the Square Kilometre Array (SKA) on the horizon, we may soon have the tools to test this model in unprecedented ways."

The 2023 detection of background gravitational waves by the NANOGrav collaboration, part of IPTA, could be linked to a realization of the Dark Big Bang. As future experiments provide more precise measurements, the study's findings could help refine our understanding of the parameters governing the Dark Big Bang and potentially confirm it as the true origin of dark matter.

The implications of these discoveries could extend beyond dark matter, as they offer a new perspective on the early history of the universe and the forces that shaped its evolution. The search for answers to the mysteries of dark matter and its origins continues to drive research at the forefront of modern cosmology.

❖ Novel supernova observations grant astronomers a peek into the cosmic past

Date: November 25, 2024
Source: Ohio State University



Researchers imaged Pa 30's fireworks display using an optical filter that is sensitive to sulphur. Credit: Robert Fesen (Dartmouth College)

An international team of researchers has made new observations of an unusual supernova, finding the most metal-poor stellar explosion ever observed.
This rare supernova, called 2023ufx, originated from the core collapse of a red supergiant star, exploded on the outskirts of a nearby dwarf galaxy. Results of the study showed that observations of both this supernova and the galaxy it was discovered in are of low metallicity, meaning they lack an abundance of elements heavier than hydrogen or helium.
Since the metals produced within supernovae inform their properties, including how stars evolve and die, learning more about their formation can tell astronomers much about the state of the universe when it began, especially since there were essentially no metals around during the time of its birth, said Michael Tucker, lead author of the study and a fellow at the Centre for Cosmology and AstroParticle Physics at The Ohio State University.
"If you're someone who wants to predict how the Milky Way came to be, you want to have a good idea of how the first exploding stars seeded the next generation," said Tucker. "Understanding that gives scientists a great example of how those first objects affected their surroundings."
Dwarf galaxies in particular are useful local analogues to conditions scientists might expect to see in the early universe. Because of them, astronomers know that while the first galaxies were metal-poor, all the big, bright galaxies near the Milky Way had plenty of time for stars to explode and increase the amount of metal content, said Tucker.
The number of metals a supernova has also influences aspects like the number of nuclear reactions it may have or how long its explosion remains bright. It's also one of the reasons that many low-mass stars also occasionally run the risk of collapsing into black holes.
The study was published recently in *The Astrophysical Journal*.
While the event observed by Tucker's team is only the second supernova to be found with low metallicity, what's most unusual about it is its location relative to the Milky Way, said Tucker.
Typically, any metal-poor supernova that astronomers would expect to find would likely be too faint to see from our galaxy because of how far away they are. Now, due to the advent of more powerful instruments like NASA's James Webb Space Telescope, detecting distant metal-poor galaxies has been made exponentially easier.
"There are not that many metal-poor locations in the nearby universe and before JWST, it was difficult to find them," said Tucker.
But the sighting of 2023ufx turned out to be a happy accident for researchers. New-found observations of this particular supernova revealed that many of its properties and behaviours are distinctly different from other supernovae in nearby galaxies.
For example, this supernova had a period of brightness that stayed steady for about 20 days before declining, whereas the brightness of its metal-rich counterparts usually lasted for about 100 days. The study also showed that a large amount of fast-moving material was ejected during the explosion, suggesting that it must have been spinning very quickly when it exploded.
This result implies that rapidly spinning metal-poor stars must have been relatively common during the early days of the universe, said Tucker. His team's theory is that the supernova likely had weak stellar winds -- streams of particles emitted from the atmosphere of the star -- which led it to cultivate and release so much energy.
Overall, their observations lay the groundwork for astronomers to better investigate how metal-poor stars survive in different cosmic environments, and may even help some theorists more accurately model how supernovae behaved in the early universe.
"If you're someone who wants to predict how galaxies form and evolve, the first thing you want is a good idea of how the first exploding stars influenced their local area," said Tucker.
Future research may aim to determine if the supernova was larger at one point, whether just by being a super-massive star or if its materials were stripped away by a still undiscovered binary companion.
Until then, researchers will have to wait for more data to become available.
"We're so early in the JWST era that we're still finding so many things we don't understand about galaxies," said Tucker. "The long-term hope is that this study acts as a benchmark for similar discoveries."
This work was supported by the National Science Foundation, the European Research Council (ERC), the Australian Research

Council Discovery Early Career Researcher Award (DECRA), and NASA. Christopher S. Kochanek from Ohio State was also a co-author.

- Uranus's swaying moons will help spacecraft seek out hidden oceans

Date: November 25, 2024
Source: University of Texas at Austin

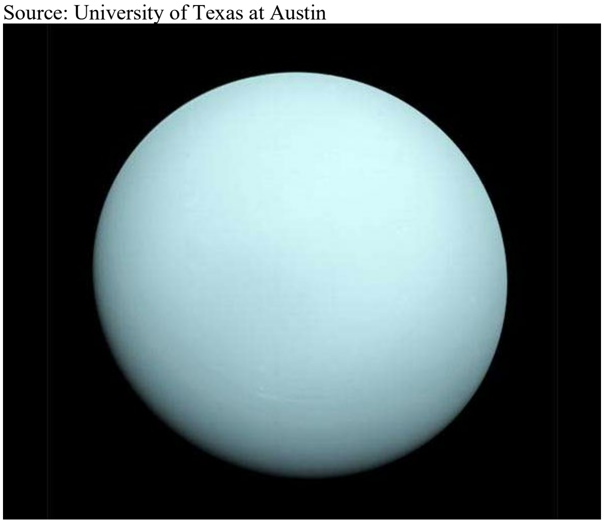


illustration only

When NASA's Voyager 2 flew by Uranus in 1986, it captured grainy photographs of large ice-covered moons. Now nearly 40 years later, NASA plans to send another spacecraft to Uranus, this time equipped to see if those icy moons are hiding liquid water oceans.
The mission is still in an early planning stage. But researchers at the University of Texas Institute for Geophysics (UTIG) are preparing for it by building a new computer model that could be used to detect oceans beneath the ice using just the spacecraft's cameras.
The research is important because scientists don't know which ocean detection method will work best at Uranus. Scientists want to know if there's liquid water there because it's a key ingredient for life.
The new computer model works by analysing small oscillations -- or wobbles -- in the way a moon spins as it orbits its parent planet. From there it can calculate how much water, ice and rock there is inside. Less wobble means a moon is mostly solid, while a large wobble means the icy surface is floating on a liquid water ocean. When combined with gravity data, the model computes the ocean's depth as well as the thickness of the overlying ice.
Uranus, along with Neptune, is in a class of planets called ice giants. Astronomers have detected more ice giant-sized bodies outside of our solar system than any other kind of exoplanet. If Uranus's moons are found to have interior oceans, that could mean there are vast numbers of potentially life-harbouring worlds throughout the galaxy, said UTIG planetary scientist Doug Hemingway, who developed the model.
"Discovering liquid water oceans inside the moons of Uranus would transform our thinking about the range of possibilities for where life could exist," he said.
The UTIG research, which was published in the journal *Geophysical Research Letters*, will help mission scientists and engineers improve their chances of detecting oceans. UTIG is a research unit of the Jackson School of Geosciences at The University of Texas at Austin.
All large moons in the solar system, including Uranus's, are tidally locked. This means that gravity has matched their spin so that the same side always faces their parent planet while they orbit. This doesn't mean their spin is completely fixed, however, and all tidally locked moons oscillate back and forth as they orbit. Determining the extent of the wobbles will be key to knowing if Uranus's moons contain oceans, and if so, how large they might be.
Moons with a liquid water ocean sloshing about on the inside will wobble more than those that are solid all the way through. However, even the largest oceans will generate only a slight wobble: A moon's rotation might deviate only a few hundred feet as it travels through its orbit.
That's still enough for passing spacecraft to detect. In fact, the technique was previously used to confirm that Saturn's moon Enceladus has an interior global ocean.
To find out if the same technique would work at Uranus, Hemingway made theoretical calculations for five of its moons and came up with a range of plausible scenarios. For example, if Uranus's moon Ariel wobbles 300 feet, then it's likely to have an ocean 100 miles deep surrounded by a 20-mile-thick ice shell.
Detecting smaller oceans will mean a spacecraft will have to get closer or pack extra powerful cameras. But the model gives mission designers a slide rule to know what will work, said UTIG Research Associate Professor Krista Soderlund.
"It could be the difference between discovering an ocean or finding we don't have that capability when we arrive," said Soderlund, who was not involved in the current research.

Soderlund has worked with NASA on Uranus mission concepts. She is also part of the science team for NASA's Europa Clipper mission, which recently launched and carries an ice penetrating radar imager developed by UTIG.

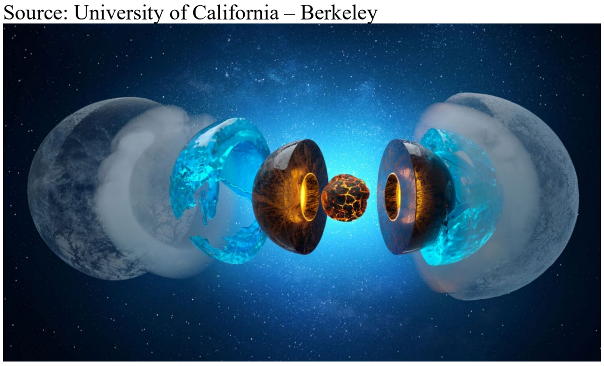
The next step, Hemingway said, is to extend the model to include measurements by other instruments to see how they improve the picture of the moons' interiors.

The journal article was coauthored by Francis Nimmo at the University of California, Santa Cruz. The research was funded by UTIG.

- A clue to what lies beneath the bland surfaces of Uranus and Neptune

Layers of material that, like oil and water, don't mix can explain planets' unusual magnetic fields

Date: November 25, 2024
Source: University of California – Berkeley



An exploded view of an ice giant planet such as Uranus or Neptune. A new theory proposes that below the dense atmosphere lies a water-rich layer (blue) that has separated from a deeper layer of hot, high-pressure carbon, nitrogen and hydrogen (amber). The pressure squeezes hydrogen out of methane and ammonia molecules, creating stratified hydrocarbon layers that cannot mix with the water layer, which prevents the convection that creates a dipolar magnetic field.

Courtesy of Quanta magazine

Diamond rain? Super-ionic water?

These are just two proposals that planetary scientists have come up with for what lies beneath the thick, bluish, hydrogen-and-helium atmospheres of Uranus and Neptune, our solar system's unique, but superficially bland, ice giants.

A planetary scientist at the University of California, Berkeley, now proposes an alternative theory -- that the interiors of both these planets are layered, and that the two layers, like oil and water, don't mix. That configuration neatly explains the planets' unusual magnetic fields and implies that earlier theories of the interiors are unlikely to be true.

In a paper appearing this week in the journal *Proceedings of the National Academy of Sciences*, Burkhard Militzer argues that a deep ocean of water lies just below the cloud layers and, below that, a highly compressed fluid of carbon, nitrogen and hydrogen. Computer simulations show that under the temperatures and pressures of the planets' interiors, a combination of water (H_2O), methane (CH_3) and ammonia (NH_3) would naturally separate into two layers, primarily because hydrogen would be squeezed out of the methane and ammonia that comprise much of the deep interior.

These immiscible layers would explain why neither Uranus nor Neptune has a magnetic field like Earth's. That was one of the surprising discoveries about our solar system's ice giants made by the Voyager 2 mission in the late 1980s.

"We now have, I would say, a good theory why Uranus and Neptune have really different fields, and it's very different from Earth, Jupiter and Saturn," said Militzer, a UC Berkeley professor of earth and planetary science. "We didn't know this before. It's like oil and water, except the oil goes below because hydrogen is lost."

If other star systems have similar compositions to ours, Militzer said, ice giants around those stars could well have similar internal structures. Planets about the size of Uranus and Neptune -- so-called sub-Neptune planets -- are among the most common exoplanets discovered to date.

Convection leads to magnetic fields

As a planet cools from its surface downward, cold and denser material sinks, while blobs of hotter fluid rise like boiling water -- a process called convection. If the interior is electrically conducting, a thick layer of convecting material will generate a dipole magnetic field similar to that of a bar magnet. Earth's dipole field, created by its liquid outer iron core, produces a magnetic field that loops from the North Pole to the South Pole and is the reason compasses point toward the poles.

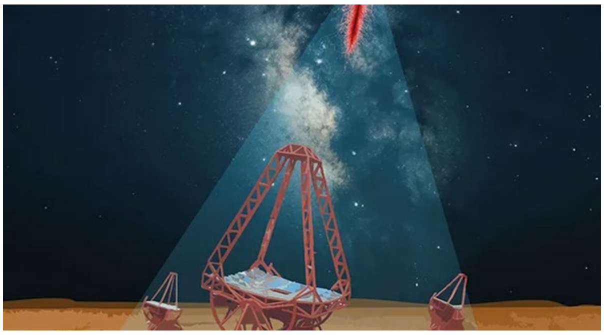
But Voyager 2 discovered that neither of the two ice giants has such a dipole field, only disorganized magnetic fields. This implies that there's no convective movement of material in a thick layer in the planets' deep interiors.

To explain these observations, two separate research groups proposed more than 20 years ago that the planets must have layers that can't mix, thus preventing large-scale convection and a global dipolar magnetic field.

Convection in one of the layers could produce a disorganized magnetic field, however. But neither group could explain what these non-mixing layers were made of.
Ten years ago, Militzer tried repeatedly to solve the problem, using computer simulations of about 100 atoms with the proportions of carbon, oxygen, nitrogen and hydrogen reflecting the known composition of elements in the early solar system. At the pressures and temperatures predicted for the planets' interiors -- 3.4 million times Earth's atmospheric pressure and 4,750 Kelvin (8,000°F), respectively -- he could not find a way for layers to form.
Last year, however, with the help of machine learning, he was able to run a computer model simulating the behaviour of 540 atoms and, to his surprise, found that layers naturally form as the atoms are heated and compressed.
"One day, I looked at the model, and the water had separated from the carbon and nitrogen. What I couldn't do 10 years ago was now happening," he said. "I thought, 'Wow! Now I know why the layers form: One is water-rich and the other is carbon-rich, and in Uranus and Neptune, it's the carbon-rich system that is below. The heavy part stays in the bottom, and the lighter part stays on top and it cannot do any convecting.'"
"I couldn't discover this without having a large system of atoms, and the large system I couldn't simulate 10 years ago," he added.
The amount of hydrogen squeezed out increases with pressure and depth, forming a stably stratified carbon-nitrogen-hydrogen layer, almost like a plastic polymer, he said. While the upper, water-rich layer likely convects to produce the observed disorganized magnetic field, the deeper, stratified hydrocarbon-rich layer cannot.
When he modelled the gravity produced by a layered Uranus and Neptune, the gravity fields matched those measured by Voyager 2 nearly 40 years ago.
"If you ask my colleagues, 'What do you think explains the fields of Uranus and Neptune?' they may say, 'Well, maybe it's this diamond rain, but maybe it's this water property which we call superionic,'" he said. "From my perspective, this is not plausible. But if we have this separation into two separate layers, that should explain it."
Militzer predicts that below Uranus' 3,000-mile-thick atmosphere lies a water-rich layer about 5,000 miles thick and below that a hydrocarbon-rich layer also about 5,000 miles thick. Its rocky core is about the size of the planet Mercury. Though Neptune is more massive than Uranus, it is smaller in diameter, with a thinner atmosphere, but similarly thick water-rich and hydrocarbon rich layers. Its rocky core is slightly larger than that of Uranus, approximately the size of Mars.
He hopes to work with colleagues who can test with laboratory experiments under extremely high temperatures and pressures whether layers form in fluids with the proportions of elements found in the protosolar system. A proposed NASA mission to Uranus could also provide confirmation, if the spacecraft has on board a Doppler imager to measure the planet's vibrations. A layered planet would vibrate at different frequencies than a convecting planet, Militzere said. His next project is to use his computational model to calculate how the planetary vibrations would differ.
The research was supported by the National Science Foundation (PHY-2020249) as part of the Centre for Matter at Atomic Pressures.

- Most energetic cosmic-ray electrons and positrons ever observed

Date: November 25, 2024
Source: CNRS


Visualization of the H.E.S.S. telescope array capturing the showers of particles produced by high-energy cosmic electrons and positrons, as well as gamma rays. (Image credit: Collaboration MPIK/H.E.S.S.)

The Universe teems with extreme environments, ranging from the very coldest temperatures to the highest energy sources possible. As a consequence, extreme objects such as supernova remnants, pulsars and active galactic nuclei are capable of emitting charged particles and gamma rays with incredibly high energies, so high that they exceed the energy produced by the nuclear fusion in stars by several orders of magnitude. The gamma rays detected on Earth tell us a great deal about these sources, since they travel through space undisturbed. However, in the case of charged particles, also known as cosmic rays, things are more complicated because they are constantly buffeted by the

magnetic fields present everywhere in the Universe, and impact the Earth isotopically, in other words from all directions. What's more, these charged particles lose some of their energy along the way, when they interact with light and magnetic fields. These energy losses are especially significant for the most energetic electrons and positrons, known as cosmic-ray electrons (CRe), whose energy exceeds one teraelectronvolt (TeV) (i.e. 1000 billion times greater than that of visible light)[1]. It is therefore impossible to determine the point of origin of such charged particles in space, although their detection on Earth is a clear indicator that there are powerful cosmic-ray particle accelerators in its vicinity.
However, detecting electrons and positrons with energies of several teraelectronvolts is particularly challenging. Space-based instruments, with detection areas of around one square metre, are unable to capture sufficient numbers of such particles, which become increasingly rare the higher their energy. Ground-based instruments on the other hand, which indirectly detect the arrival of cosmic rays via the showers of particles they produce in the Earth's atmosphere, are faced with the challenge of differentiating the showers triggered by cosmic-ray electrons (or positrons) from the much more frequent showers produced by the impact of the heavier cosmic-ray protons and nuclei. The H.E.S.S. Observatory[2] located in Namibia uses five large telescopes to capture and record the faint Cherenkov radiation produced by the heavily charged particles and photons that enter the Earth's atmosphere, producing a shower of particles in their wake. Although the Observatory's main purpose is to detect and select gamma rays in order to investigate their sources, the data can also be used to search for cosmic-ray electrons.
In the most extensive analysis ever carried out, H.E.S.S. collaboration scientists have now obtained new information about the origin of these particles. The astrophysicists did this by combing through the huge data set collected over the course of a decade by the four 12-metre telescopes, applying new, more powerful selection algorithms capable of extracting the CRe from the background noise with unprecedented efficiency. This resulted in an unrivalled set of statistical data for the analysis of cosmic-ray electrons. More specifically, the H.E.S.S. researchers were able to obtain for the first time data about CRe in the highest energy ranges, all the way up to 40 TeV. This enabled them to identify a surprisingly sharp break in the energy distribution of the cosmic-ray electrons.
"This is an important result, as we can conclude that the measured CRe most likely originate from very few sources in the vicinity of our own solar system, up to a maximum of a few 1000 light years away, a very small distance compared to the size of our Galaxy," explains Kathrin Egberts, from the University of Potsdam, one of the corresponding authors of the study.
"We were able to put severe constrains on the origin of these cosmic electrons with our detailed analysis for the first time," adds Prof. Hofmann from the Max-Planck-Institut für Kernphysik, co-author of the study. "The very low fluxes at larger TeV limit the possibilities of space-based missions to compete with this measurement. Thereby, our measurement does not only provide data in a crucial and previously unexplored energy range, impacting our understanding of the local neighbourhood, but it is also likely to remain a benchmark for the coming years," Mathieu de Naurois, CNRS Researcher from the Laboratoire Leprince-Ringuet, adds.

Footnotes :

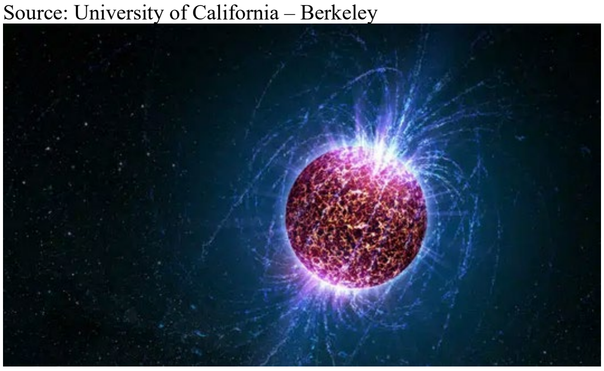
1. 1 TeV = 10^{12} electronvolts.
2. High-energy gamma rays can be observed from the ground only because of a very specific phenomenon. When a gamma ray enters the atmosphere, it collides with its atoms and molecules, producing new particles that sweep towards the ground rather like an avalanche. The particles emit flashes lasting mere billionths of a second (Cherenkov radiation), which can be observed using large, specially equipped ground-based telescopes. The H.E.S.S. Observatory, located in the Khomas Highlands of Namibia at an altitude of 1835 m, officially began operation in 2002. It comprises an array of five telescopes. Four telescopes with mirrors 12 m in diameter are located at the corners of a square, with another 28 m telescope at the centre. This makes it possible to detect cosmic gamma rays ranging from a few tens of gigaelectron volts (GeV, 10^9 electronvolts) to a few tens of teraelectronvolts (TeV, 10^{12}

electronvolts). By comparison, photons of visible light have an energy of two to three electronvolts. H.E.S.S. is currently the only instrument observing the southern sky in high-energy gamma-ray light. It is also the largest and most sensitive telescope system of its kind.

- ❖ A nearby supernova could end the search for dark matter

Axion dark matter should be produced and converted to gamma rays during a supernova. Will we be lucky enough to see them?

Date: November 21, 2024
Source: University of California – Berkeley



An artist's concept of a highly magnetized neutron star. According to current theory, axions would be created in the hot interior of the neutron star. UC Berkeley astrophysicists say that the strong magnetic field of the star will transform these axions into gamma rays that can be detected from Earth, pinpointing the mass of the axion. Casey Reed, courtesy of Penn State;

The search for the universe's dark matter could end tomorrow -- given a nearby supernova and a little luck.
The nature of dark matter has eluded astronomers for 90 years, since the realization that 85% of the matter in the universe is not visible through our telescopes. The most likely dark matter candidate today is the axion, a lightweight particle that researchers around the world are desperately trying to find.
Astrophysicists at the University of California, Berkeley, now argue that the axion could be discovered within seconds of the detection of gamma rays from a nearby supernova explosion. Axions, if they exist, would be produced in copious quantities during the first 10 seconds after the core collapse of a massive star into a neutron star, and those axions would escape and be transformed into high-energy gamma rays in the star's intense magnetic field.
Such a detection is possible today only if the lone gamma-ray telescope in orbit, the Fermi Gamma-ray Space Telescope, is pointing in the direction of the supernova at the time it explodes. Given the telescope's field of view, that is about one chance in 10.
Yet, a single detection of gamma rays would pinpoint the mass of the axion, in particular the so-called QCD axion, over a huge range of theoretical masses, including mass ranges now being scoured in experiments on Earth. The lack of a detection, however, would eliminate a large range of potential masses for the axion, and make most current dark matter searches irrelevant.
The problem is that, for the gamma rays to be bright enough to detect, the supernova has to be nearby -- within our Milky Way galaxy or one of its satellite galaxies -- and nearby stars explode only on average every few decades. The last nearby supernova was in 1987 in the Large Magellanic Cloud, one of the Milky Way's satellites. At the time, a now defunct gamma-ray telescope, the Solar Maximum Mission, was pointing in the supernova's direction, but it wasn't sensitive enough to be able to detect the predicted intensity of gamma rays, according to the UC Berkeley team's analysis.
"If we were to see a supernova, like supernova 1987A, with a modern gamma-ray telescope, we would be able to detect or rule out this QCD axion, this most interesting axion, across much of its parameter space -- essentially the entire parameter space that cannot be probed in the laboratory, and much of the parameter space that can be probed in the laboratory, too," said Benjamin Safdi, a UC Berkeley associate professor of physics and senior author of a paper that was published online Nov. 19 in the journal *Physical Review Letters*. "And it would all happen within 10 seconds."
The researchers are anxious, however, that when the long-overdue supernova pops off in the nearby universe, we won't be ready to see the gamma rays produced by axions. The scientists are now talking with colleagues who build gamma-ray telescopes to judge the feasibility of launching one or a fleet of such telescopes to cover 100% of the sky 24/7 and be assured of catching any gamma-ray burst. They have even proposed a name for their full-sky gamma-ray satellite constellation -- the GALactic AXion Instrument for Supernova, or GALAXIS.
"I think all of us on this paper are stressed about there being a next supernova before we have the right instrumentation," Safdi said. "It would be a real shame if a supernova went off

tomorrow and we missed an opportunity to detect the axion -- it might not come back for another 50 years."

Safdi's co-authors are graduate student Yujin Park and postdoctoral fellows Claudio Andrea Manzari and Inbar Savoray. All four are members of UC Berkeley's physics department and the Theoretical Physics Group at Lawrence Berkeley National Laboratory.

QCD axions

Searches for dark matter originally focused on faint, massive compact halo objects (MACHOs) theoretically sprinkled throughout our galaxy and the cosmos, but when those didn't materialize, physicists began to look for elementary particles that theoretically are all around us and should be detectable in Earth-bound labs. These weakly interacting massive particles (WIMPs) also failed to show up. The current best candidate for dark matter is the axion, a particle that fits nicely within the standard model of physics and solves several other outstanding puzzles in particle physics. Axions also fall neatly out of string theory, a hypothesis about the underlying geometry of the universe, and might be able to unify gravity, which explains interactions on cosmic scales, with the theory of quantum mechanics, which describes the infinitesimal.

"It seems almost impossible to have a consistent theory of gravity combined with quantum mechanics that does not have particles like the axion," Safdi said.

The strongest candidate for an axion, called a QCD axion -- named after the reigning theory of the strong force, quantum chromodynamics -- theoretically interacts with all matter, though weakly, through the four forces of nature: gravity, electromagnetism, the strong force, which holds atoms together, and the weak force, which explains the breakup of atoms. One consequence is that, in a strong magnetic field, an axion should occasionally turn into an electromagnetic wave, or photon.

The axion is distinctly different from another lightweight, weakly-interacting particle, the neutrino, which only interacts through gravity and the weak force and totally ignores the electromagnetic force.

Lab bench experiments -- such as the ALPHA Consortium (Axion Longitudinal Plasma HAloscope), DMradio and ABRACADABRA, all of which involve UC Berkeley researchers -- employ compact cavities that, like a tuning fork, resonate with and amplify the faint electromagnetic field or photon produced when a low-mass axion transforms in the presence of a strong magnetic field.

Alternatively, astrophysicists have proposed looking for axions produced inside neutron stars immediately after a core-collapse supernova, like 1987A. Until now, however, they've focused primarily on detecting gamma rays from these axions' slow transformation into photons in the magnetic fields of galaxies. Safdi and his colleagues realized that that process is not very efficient at producing gamma rays, or at least not enough to detect from Earth.

Instead, they explored the production of gamma rays by axions in the strong magnetic fields around the very star that generated the axions. That process, supercomputer simulations showed, very efficiently creates a burst of gamma rays that is dependent on the mass of the axion, and the burst should occur simultaneously with a burst of neutrinos from inside the hot neutron star. That burst of axions, however, lasts a mere 10 seconds after the neutron star forms -- after that, the production rate drops dramatically -- though hours before the outer layers of the star explode.

"This has really led us to thinking about neutron stars as optimal targets for searching for axions as axion laboratories," Safdi said. "Neutron stars have a lot of things going for them. They are extremely hot objects. They also host very strong magnetic fields. The strongest magnetic fields in our universe are found around neutron stars, such as magnetars, which have magnetic fields tens of billions of times stronger than anything we can build in the laboratory. That helps convert these axions into observable signals."

Two years ago, Safdi and his colleagues put the best upper limit on the mass of the QCD axion at about 16 million electron volts, or about 32 times less than the mass of the electron. This was based on the cooling rate of neutron stars, which would cool faster if axions were produced along with neutrinos inside these hot, compact bodies.

In the current paper, the UC Berkeley team not only describes the production of gamma rays following core collapse to a neutron star, but also uses the non-detection of gamma rays from the 1987A supernova to put the best constraints yet on the mass of axion-like particles, which differ from QCD axions in that they do not interact via the strong force.

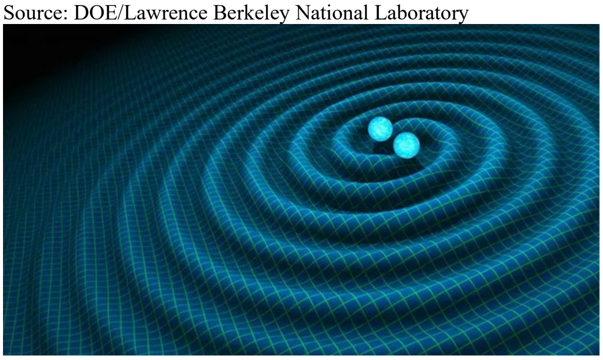
They predict that a gamma ray detection would allow them to identify the QCD axion mass if it is above 50 microelectron volts (micro-eV, or μeV), or about one 10-billionth the mass of the electron. A single detection could refocus existing experiments to confirm the mass of the axion, Safdi said. While a fleet of dedicated gamma-ray telescopes is the best option for detecting gamma rays from a nearby supernova, a lucky break with Fermi would be even better.

"The best-case scenario for axions is Fermi catches a supernova. It's just that the chance of that is small," Safdi said. "But if Fermi saw it, we'd be able to measure its mass. We'd be able to measure its interaction strength. We'd be able to determine everything we need to know about the axion, and we'd be incredibly confident in the signal because there's no ordinary matter which could create such an event."

The research was supported by funds from the U.S. Department of Energy.

- Research on gravity in line with Einstein's theory of general relativity

Date: November 20, 2024
Source: DOE/Lawrence Berkeley National Laboratory



One manifestation of general relativity is gravitational waves, depicted here as created by two colliding black holes. (Image credit: R. Hurt/Caltech-JPL)

Gravity has shaped our cosmos. Its attractive influence turned tiny differences in the amount of matter present in the early universe into the sprawling strands of galaxies we see today. A new study using data from the Dark Energy Spectroscopic Instrument (DESI) has traced how this cosmic structure grew over the past 11 billion years, providing the most precise test to date of gravity at very large scales.

DESI is an international collaboration of more than 900 researchers from over 70 institutions around the world and is managed by the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab). In their new study, DESI researchers found that gravity behaves as predicted by Einstein's theory of general relativity. The result validates our leading model of the universe and limits possible theories of modified gravity, which have been proposed as alternative ways to explain unexpected observations -- including the accelerating expansion of our universe that is typically attributed to dark energy.

"General relativity has been very well tested at the scale of solar systems, but we also needed to test that our assumption works at much larger scales," said Pauline Zarrouk, a cosmologist at the French National Centre for Scientific Research (CNRS) working at the Laboratory of Nuclear and High-Energy Physics (LPNHE), who co-led the new analysis. "Studying the rate at which galaxies formed lets us directly test our theories and, so far, we're lining up with what general relativity predicts at cosmological scales."

The study also provided new upper limits on the mass of neutrinos, the only fundamental particles whose masses have not yet been precisely measured. Previous neutrino experiments found that the sum of the masses of the three types of neutrinos should be at least 0.059 eV/c^2. (For comparison, an electron has a mass of about 511,000 eV/c^2.) DESI's results indicate that the sum should be less than 0.071 eV/c^2, leaving a narrow window for neutrino masses.

The DESI collaboration shared their results in several papers posted to the online repository arXiv today. The complex analysis used nearly 6 million galaxies and quasars and lets researchers see up to 11 billion years into the past. With just one year of data, DESI has made the most precise overall measurement of the growth of structure, surpassing previous efforts that took decades to make.

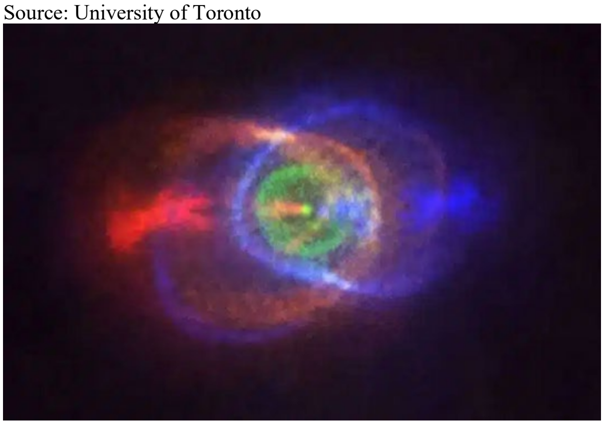
Today's results provide an extended analysis of DESI's first year of data, which in April made the largest 3D map of our universe to date and revealed hints that dark energy might be evolving over time. The April results looked at a particular feature of how galaxies cluster known as baryon acoustic oscillations (BAO). The new analysis, called a "full-shape analysis," broadens the scope to extract more information from the data, measuring how galaxies and matter are distributed on different scales throughout space. The study required months of additional work and cross-checks. Like the previous study, it used a technique to hide the result from the scientists until the end, mitigating any unconscious bias.

"Both our BAO results and the full-shape analysis are spectacular," said Dragan Huterer, professor at the University of Michigan and co-lead of DESI's group interpreting the cosmological data. "This is the first time that DESI has looked at the growth of cosmic structure. We're showing a tremendous new ability to probe modified gravity and improve constraints on models of dark energy. And it's only the tip of the iceberg."
DESI is a state-of-the-art instrument that can capture light from 5,000 galaxies simultaneously. It was constructed and is operated with funding from the DOE Office of Science. DESI is mounted on the U.S. National Science Foundation's Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory (a program of NSF NOIRLab). The experiment is now in its fourth of five years surveying the sky and plans to collect roughly 40 million galaxies and quasars by the time the project ends.
The collaboration is currently analysing the first three years of collected data and expects to present updated measurements of dark energy and the expansion history of our universe in spring 2025. DESI's expanded results released today are consistent with the experiment's earlier preference for an evolving dark energy, adding to the anticipation of the upcoming analysis.
"Dark matter makes up about a quarter of the universe, and dark energy makes up another 70 percent, and we don't really know what either one is," said Mark Maus, a PhD student at Berkeley Lab and UC Berkeley who worked on theory and validation modelling pipelines for the new analysis. "The idea that we can take pictures of the universe and tackle these big, fundamental questions is mind-blowing."
DESI is supported by the DOE Office of Science and by the National Energy Research Scientific Computing Centre, a DOE Office of Science user facility. Additional support for DESI is provided by the U.S. National Science Foundation; the Science and Technology Facilities Council of the United Kingdom; the Gordon and Betty Moore Foundation; the Heising-Simons Foundation; the French Alternative Energies and Atomic Energy Commission (CEA); the National Council of Humanities, Sciences, and Technologies of Mexico; the Ministry of Science and Innovation of Spain; and by the DESI member institutions.
The DESI collaboration is honoured to be permitted to conduct scientific research on I'oligam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation.

Several related papers:
https://data.desi.lbl.gov/doc/papers/

- Astronomers discover first pairs of white dwarf and main sequence stars in clusters, shining new light on stellar evolution

Date: November 19, 2024
Source: University of Toronto



This image from the ALMA telescope shows star system HD101584 and the complex gas clouds surrounding the binary. It is the result of a pair of stars sharing a common outer layer during their last moments. Credit: ALMA (ESO/NAOJ/NRAO), Olofsson et al / Robert Cumming

Astronomers at the University of Toronto (U of T) have discovered the first pairs of white dwarf and main sequence stars -- "dead" remnants and "living" stars -- in young star clusters. Described in a new study published in *The Astrophysical Journal*, this breakthrough offers new insights on an extreme phase of stellar evolution, and one of the biggest mysteries in astrophysics. Scientists can now begin to bridge the gap between the earliest and final stages of binary star systems -- two stars that orbit a shared centre of gravity -- to further our understanding of how stars form, how galaxies evolve, and how most elements on the periodic table were created. This discovery could also help explain cosmic events like supernova explosions and gravitational waves, since binaries containing one or more of these compact dead stars are thought to be the origin of such phenomena.
Most stars exist in binary systems. In fact, nearly half of all stars similar to our sun have at least one companion star. These paired stars usually differ in size, with one star often being

more massive than the other. Though one might be tempted to assume that these stars evolve at the same rate, more massive stars tend to live shorter lives and go through the stages of stellar evolution much faster than their lower mass companions.

In the stage where a star approaches the end of its life, it will expand to hundreds or thousands of times its original size during what we call the red giant or asymptotic giant branch phases. In close binary systems, this expansion is so dramatic that the dying star's outer layers can sometimes completely engulf its companion. Astronomers refer to this as the common envelope phase, as both stars become wrapped in the same material.

The common envelope phase remains one of the biggest mysteries in astrophysics. Scientists have struggled to understand how stars spiralling together during this critical period affects the stars' subsequent evolution. This new research may solve this enigma.

Remnants left behind after stars die are compact objects called white dwarfs. Finding these post-common envelope systems that contain both a "dead" stellar remnant and "living" star -- otherwise known as white dwarf-main sequence binaries -- provides a unique way to investigate this extreme phase of stellar evolution.

"Binary stars play a huge role in our universe," says lead author Steffani Grondin, a graduate student in the David A. Dunlap Department for Astronomy & Astrophysics at U of T. "This observational sample marks a key first step in allowing us to trace the full life cycles of binaries and will hopefully allow us to constrain the most mysterious phase of stellar evolution."

The researchers used machine learning to analyse data from three major sources: the European Space Agency's *Gaia* mission -- a space telescope that has studied over a billion stars in our galaxy -- along with observations from the 2MASS and Pan-STARRS1 surveys. This combined data set enabled the team to search for new binaries in clusters with characteristics resembling those of known white dwarf-main sequence pairs.

Even though these types of binary systems should be very common, they have been tricky to find, with only two candidates confirmed within clusters prior to this research. This research has the potential to increase that number to 52 binaries across 38 star clusters. Since the stars in these clusters are thought to have all formed at the same time, finding these binaries in open star clusters allows astronomers to constrain the age of the systems and to trace their full evolution from before the common envelope conditions to the observed binaries in their post-common envelope phase.

"The use of machine learning helped us to identify clear signatures for these unique systems that we weren't able to easily identify with just a few datapoints alone," says co-author Joshua Speagle, a professor in the David A. Dunlap Department for Astronomy & Astrophysics and Department of Statistical Sciences at U of T. "It also allowed us to automate our search across hundreds of clusters, a task that would have been impossible if we were trying to identify these systems manually."

"It really points out how much in our universe is hiding in plain sight -- still waiting to be found," says co-author Maria Drout, also a professor in the David A. Dunlap Department for Astronomy & Astrophysics at U of T. "While there are many examples of this type of binary system, very few have the age constraints necessary to fully map their evolutionary history. While there is plenty of work left to confirm and fully characterize these systems, these results will have implications across multiple areas of astrophysics."

Binaries containing compact objects are also the progenitors for an extreme stellar explosion called a Type Ia supernova and the sort of merger that causes gravitational waves, which are ripples in spacetime that can be detected by instruments such as the Laser Interferometer Gravitational-Wave Observatory (LIGO). As the team uses data from the Gemini, Keck and Magellan Telescopes to confirm and measure the properties of these binaries, this catalogue will ultimately shed light on the many elusive transient phenomena in our universe.

Contributing institutions include the David A. Dunlap Department of Astronomy & Astrophysics, the Dunlap Institute for Astronomy & Astrophysics, the Department for Statistical Sciences, and the Data Sciences Institute at the University of Toronto, as well as the National Technical Institute for the Deaf and Centre for Computational Relativity and Gravitation at the Rochester Institute of Technology, the Department of Astronomy & The Institute for Astrophysical Research at

Boston University, and the Department of Astronomy at the University of California, Berkeley.

- New research explores volcanic caves, advancing the search for life on Mars

Date: November 18, 2024
Source: University of South Florida

A view into the La Corona lava tube system in Lanzarote, Spain, where there is massive accumulations of gypsum and other sulphates.

Through the intricate study of lava tubes -- caves formed following volcanic eruptions when lava cools down -- an international team of researchers has uncovered clues about Earth's ancient environments that could be significant in the search for life on Mars.
Bogdan P. Onac, professor in the USF School of Geosciences, collaborated with researchers from Portugal, Spain and Italy to shed light on how lava tubes may serve as valuable analogues for Martian caves and the search for extraterrestrial life.
On the Spanish island of Lanzarote, just west of North Africa, the team explored six lava tubes to gather mineral deposits. Some of the tubes are so large, they are used to host underground concerts.
"While the lava tubes on Lanzarote were discovered several years ago, we are the first to complete such a detailed study of minerals and microorganisms," Onac said.
In the study, published in *Communications Earth & Environment*, Onac and the team used a range of advanced molecular, isotopic and mineralogical techniques to examine the deposits and create a comprehensive understanding of the minerals they held. They learned the volcanic rock in the lava tubes created a protective environment that helped shield the minerals and organic compounds from weathering, ultimately preserving the minerals as records of past ecosystems.
The team found preserved biosignatures, including calcium and sodium sulphates. This discovery indicates microbial activity and microorganisms, such as bacteria, were once active in the caves.
"This study adds to our understanding of geological and environmental changes on Earth and highlights lava tubes as potential refuges for microbial life, holding significant implications for astrobiology, particularly in identifying biosignatures on Mars and other celestial bodies," Onac said.
Given that Martian lava tubes are similarly shielded and likely contain sulphate-rich minerals, they may also hold signs of past microbial life, giving us clues about potential life beyond Earth. The findings may significantly impact the way scientists approach planetary exploration, particularly for upcoming missions aimed at studying the habitability of Mars.
The team will publish several additional studies on these lava tubes in the coming months and they are also planning to examine newly formed lava tubes in Iceland.