South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk **Neil Phillipson "Hubble - the $6billion telescope" From the original idea, through its development and deployment, and finally skirting disaster to become one of the most productive science platforms ever created - this is the story of the 20th Century's most ambitious astronomy project and the quantum leap in knowledge it has given and continues to give us even now**

Please support a raffle we are organizing this month AGM this the one meeting during the year when the Trustees of the South Downs AS run the first half of the meeting. We have to appoint a new committee; anyone wishing to put their name forward can do so at the beginning of the meeting. If you know someone who might be able to serve on the committee, please ask them before nominating them. Being a committee member does not involve too much time or effort, the main thing is to be willing to take on some quite simple tasks, such as meet and greet at the main meetings, attend around six committee meetings each year.

- Astronomers detect seismic ripples in ancient galactic disk

Date: December 21, 2023
Source: Australian National University

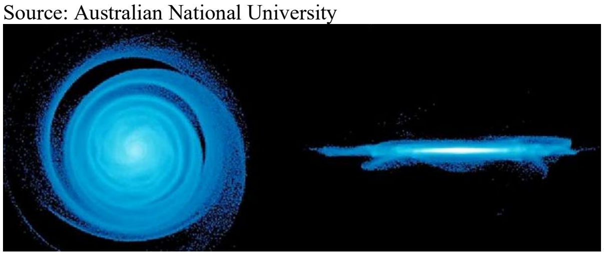


Illustration of a galaxy disk being disturbed. Credit: Jonathan Bland-Hawthorn and Thorsten Tepper-Garcia/University of Sydney.

A new snapshot of an ancient, far-off galaxy could help scientists understand how it formed and the origins of our own Milky Way.

At more than 12 billion years old, BRI 1335-0417 is the oldest and furthest known spiral galaxy in our universe.

Lead author Dr Takafumi Tsukui said a state-of-the-art telescope called ALMA allowed them to look at this ancient galaxy in much greater detail.

"Specifically, we were interested in how gas was moving into and throughout the galaxy," Dr Tsukui said.

"Gas is a key ingredient for forming stars and can give us important clues about how a galaxy is actually fuelling its star formation."

In this case, the researchers were able to not only capture the motion of the gas around BRI 1335-0417, but also reveal a seismic wave forming -- a first in this type of early galaxy.

The galaxy's disk, a flattened mass of rotating stars, gas and dust, moves in a way not dissimilar to ripples spreading on a pond after a stone is thrown in.

"The vertically oscillating motion of the disk is due to an external source, either from new gas streaming into the galaxy or by coming into contact with other smaller galaxies," Dr Tsukui said.

"Both possibilities would bombard the galaxy with new fuel for star formation.

"Additionally, our study revealed a bar-like structure in the disk. Galactic bars can disrupt gas and transport it towards the galaxy's centre. The bar discovered in BRI 1335-0417 is the most distant known structure of this kind.

"Together, these results show the dynamic growth of a young galaxy."

Because BRI 1335-0417 is so far away, its light takes longer to reach Earth.

The images seen through a telescope in the present day are a throwback to the galaxy's early days -- when the Universe was just 10 per cent of its current age.

"Early galaxies have been found to form stars at a much faster rate than modern galaxies. This is true for BRI 1335-0417, which, despite having a similar mass to our Milky Way, forms stars at rate a few hundred times faster," co-author Associate Professor Emily Wisnioski said.

"We wanted to understand how gas is supplied to keep up with this rapid rate of star formation.

"Spiral structures are rare in the early Universe, and exactly how they form also

remains unknown. This study also gives us crucial information on the most likely scenarios.
"While it is impossible to observe the galaxy's evolution directly, as our observations only give us a snapshot, computer simulations can help piece the story together."

- Some icy exoplanets may have habitable oceans and geysers

Date: December 13, 2023
Source: NASA/Goddard Space Flight Centre

NASA's Cassini spacecraft captured this image of Enceladus on Nov. 30, 2010. The shadow of the body of Enceladus on the lower portions of the jets is clearly visible.
NASA/JPL-Caltech/Space Science Institute

A NASA study expands the search for life beyond our solar system by indicating that 17 exoplanets (worlds outside our solar system) could have oceans of liquid water, an essential ingredient for life, beneath icy shells. Water from these oceans could occasionally erupt through the ice crust as geysers. The science team calculated the amount of geyser activity on these exoplanets, the first time these estimates have been made. They identified two exoplanets sufficiently close where signs of these eruptions could be observed with telescopes.
The search for life elsewhere in the Universe typically focuses on exoplanets that are in a star's "habitable zone," a distance where temperatures allow liquid water to persist on their surfaces. However, it's possible for an exoplanet that's too distant and cold to still have an ocean underneath an ice crust if it has enough internal heating. Such is the case in our solar system where Europa, a moon of Jupiter, and Enceladus, a moon of Saturn, have subsurface oceans because they are heated by tides from the gravitational pull of the host planet and neighbouring moons.
These subsurface oceans could harbour life if they have other necessities, such as an energy supply as well as elements and compounds used in biological molecules. On Earth, entire ecosystems thrive in complete darkness at the bottom of oceans near hydrothermal vents, which provide energy and nutrients.
"Our analyses predict that these 17 worlds may have ice-covered surfaces but receive enough internal heating from the decay of radioactive elements and tidal forces from their host stars to maintain internal oceans," said Dr. Lynnae Quick of NASA's Goddard Space Flight Centre in Greenbelt, Maryland. "Thanks to the amount of internal heating they experience, all planets in our study could also exhibit cryovolcanic eruptions in the form of geyser-like plumes." Quick is lead author of a paper on the research published on October 4 in the *Astrophysical Journal.*
The team considered conditions on 17 confirmed exoplanets that are roughly Earth-sized but less dense, suggesting that they could have substantial amounts of ice and water instead of denser rock. Although the planets' exact compositions remain unknown, initial estimates of their surface temperatures from previous studies all indicate that they are much colder than Earth, suggesting that their surfaces could be covered in ice.
The study improved estimates of each exoplanet's surface temperature by recalculating using the known surface brightness and other properties of Europa and Enceladus as models. The team also estimated the total internal heating in these exoplanets by using the shape of each exoplanet's orbit to get the heat generated from tides and adding it to the heat expected from radioactive activity. Surface temperature and total heating estimates gave the ice layer thickness for each exoplanet since the oceans cool and freeze at the surface while being heated from the interior. Finally, they compared these figures to Europa's and used estimated levels of geyser activity on Europa as a conservative baseline to estimate geyser activity on the exoplanets.
They predict that surface temperatures are colder than previous estimates by up to 60 degrees Fahrenheit (16 degrees Celsius). Estimated ice shell thickness ranged from about 190 feet (58 meters) for Proxima Centauri b and one mile (1.6 kilometres) for LHS 1140 b to 24 miles (38.6 kilometres) for MOA 2007 BLG 192Lb, compared to Europa's estimated average of 18 miles (almost 29 kilometres). Estimated geyser activity went from just 17.6 pounds per second (about 8 kilograms/second) for Kepler 441b to 639,640 pounds/second (290,000

kilograms/second) for LHS 1140b and 13.2 million pounds/second (six million kilograms/second) for Proxima Centauri b, compared to Europa at 4,400 pounds/second (2,000 kilograms/second).

"Since our models predict that oceans could be found relatively close to the surfaces of Proxima Centauri b and LHS 1140 b, and their rate of geyser activity could exceed Europa's by hundreds to thousands of times, telescopes are most likely to detect geological activity on these planets," said Quick, who is presenting this research December 12at the American Geophysical Union meeting in San Francisco, California.

This activity could be seen when the exoplanet passes in front of its star. Certain colours of starlight could be dimmed or blocked by water vapor from the geysers.

"Sporadic detections of water vapor in which the amount of water vapor detected varies with time, would suggest the presence of cryovolcanic eruptions," said Quick. The water might contain other elements and compounds that could reveal if it can support life. Since elements and compounds absorb light at specific "signature" colours, analysis of the starlight would let scientists determine the geyser's composition and evaluate the exoplanet's habitability potential.

For planets like Proxima Centauri b that don't cross their stars from our vantage point, geyser activity could be detected by powerful telescopes that are able to measure light that the exoplanet reflects while orbiting its star. Geysers would expel icy particles at the exoplanet's surface which would cause the exoplanet to appear very bright and reflective.

The research was funded by NASA's Habitable Worlds Program, the University of Washington's Astrobiology Program, and the Virtual Planetary Laboratory, a member of the NASA Nexus for Exoplanet System Science coordination group.

- Ancient stars made extraordinarily heavy elements

Date: December 7, 2023
Source: North Carolina State University

Courtesy NASA/JPL-Caltech

How heavy can an element be? An international team of researchers has found that ancient stars were capable of producing elements with atomic masses greater than 260, heavier than any element on the periodic table found naturally on Earth. The finding deepens our understanding of element formation in stars.

We are, literally, made of star stuff. Stars are element factories, where elements constantly fuse or break apart to create other lighter or heavier elements.

When we refer to light or heavy elements, we're talking about their atomic mass. Broadly speaking, atomic mass is based on the number of protons and neutrons in the nucleus of one atom of that element.

The heaviest elements are only known to be created in neutron stars via the rapid neutron capture process, or r-process.

Picture a single atomic nucleus floating in a soup of neutrons.

Suddenly, a bunch of those neutrons get stuck to the nucleus in a very short time period -- usually in less than one second -- then undergo some internal neutron-to-proton changes, and voila!

A heavy element, such as gold, platinum or uranium, forms.

The heaviest elements are unstable or radioactive, meaning they decay over time. One way that they do this is by splitting, a process called fission.

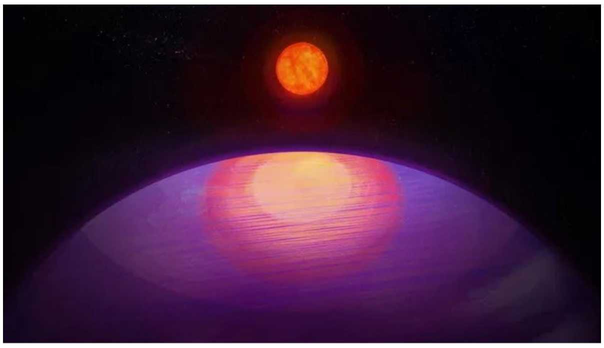
"The r-process is necessary if you want to make elements that are heavier than, say, lead and bismuth," says Ian Roederer, associate professor of physics at North Carolina State University and lead author of the research. Roederer was previously at the University of Michigan.

"You have to add many neutrons very quickly, but the catch is that you need a lot of energy and a lot of neutrons to do so," Roederer says.

"We have a general idea of how the r-process works, but the conditions of the process are quite extreme," Roederer says.
"We don't have a good sense of how many different kinds of sites in the universe can generate the r-process, we don't know how the r-process ends, and we can't answer questions like, how many neutrons can you add? Or, how heavy can an element be? So, we decided to look at elements that could be made by fission in some well-studied old stars to see if we could start to answer some of these questions."
The team took a fresh look at the amounts of heavy elements in 42 well-studied stars in the Milky Way.
The stars were known to have heavy elements formed by the r-process in earlier generations of stars.
By taking a broader view of the amounts of each heavy element found in these stars collectively, rather than individually as is more common, they identified previously unrecognized patterns.
Those patterns signalled that some elements listed near the middle of the periodic table -- such as silver and rhodium -- were likely the remnants of heavy element fission.
The team was able to determine that the r-process can produce atoms with an atomic mass of at least 260 before they fission.
"That 260 is interesting because we haven't previously detected anything that heavy in space or naturally on Earth, even in nuclear weapon tests," Roederer says.
"But seeing them in space gives us guidance for how to think about models and fission -- and could give us insight into how the rich diversity of elements came to be."
The work appears in science and was supported in part by the National Science Foundation and the National Aeronautics and Space Administration.

- ❖ Discovery of planet too big for its sun throws off solar system formation models

Date: November 30, 2023
Source: Penn State



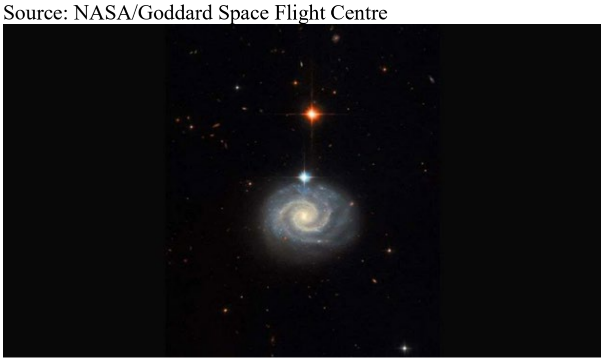
"Astronomers have discovered a massive extrasolar planet, or 'exoplanet,' orbiting an ultracool dwarf star that is way too small to host such a world, challenging scientists' models of how planets and planetary systems are born." —Space.com. Image credit: Penn State

The discovery of a planet that is far too massive for its sun is calling into question what was previously understood about the formation of planets and their solar systems, according to Penn State researchers.
In a paper published online today (Nov. 30) in the journal *Science*, researchers report the discovery of a planet more than 13 times as massive as Earth orbiting the "ultracool" star LHS 3154, which itself is nine times less massive than the sun. The mass ratio of the newly found planet with its host star is more than 100 times higher than that of Earth and the sun.
The finding reveals the most massive known planet in a close orbit around an ultracool dwarf star, the least massive and coldest stars in the universe. The discovery goes against what current theories would predict for planet formation around small stars and marks the first time a planet with such high mass has been spotted orbiting such a low-mass star.
"This discovery really drives home the point of just how little we know about the universe," said Suvrath Mahadevan, the Verne M. Willaman Professor of Astronomy and Astrophysics at Penn State and co-author on the paper. "We wouldn't expect a planet this heavy around such a low-mass star to exist."
He explained that stars are formed from large clouds of gas and dust. After the star is formed, the gas and dust remain as disks of material orbiting the newborn star, which can eventually develop into planets.
"The planet-forming disk around the low-mass star LHS 3154 is not expected to have enough solid mass to make this planet," Mahadevan said. "But it's out there, so now we need to reexamine our understanding of how planets and stars form."
The researchers spotted the oversized planet, named LHS 3154b, using an astronomical spectrograph built at Penn State by a team of scientists led by Mahadevan. The instrument,

called the Habitable Zone Planet Finder or HPF, was designed to detect planets orbiting the coolest stars outside our solar system with the potential for having liquid water -- a key ingredient for life -- on their surfaces.
While such planets are very difficult to detect around stars like our sun, the low temperature of ultracool stars means that planets capable of having liquid water on their surface are much closer to their star relative to Earth and the sun. This shorter distance between these planets and their stars, combined with the low mass of the ultracool stars, results in a detectable signal announcing the presence of the planet, Mahadevan explained.
"Think about it like the star is a campfire. The more the fire cools down, the closer you'll need to get to that fire to stay warm," Mahadevan said. "The same is true for planets. If the star is colder, then a planet will need to be closer to that star if it is going to be warm enough to contain liquid water. If a planet has a close enough orbit to its ultracool star, we can detect it by seeing a very subtle change in the colour of the star's spectra or light as it is tugged on by an orbiting planet."
Located at the Hobby-Eberly Telescope at the McDonald Observatory in Texas, the HPF provides some of the highest precision measurements to date of such infrared signals from nearby stars.
"Making the discovery with HPF was extra special, as it is a new instrument that we designed, developed and built from the ground-up for the purpose of looking at the uncharted planet population around the lowest mass stars," said Guðmundur Stefánsson, NASA Sagan Fellow in Astrophysics at Princeton University and lead author on the paper, who helped develop HPF and worked on the study as a graduate student at Penn State. "Now we are reaping the rewards, learning new and unexpected aspects of this exciting population of planets orbiting some of the most nearby stars."
The instrument has already yielded critical information in the discovery and confirmation of new planets, Stefánsson explained, but the discovery of the planet LHS 3154b exceeded all expectations.
"Based on current survey work with the HPF and other instruments, an object like the one we discovered is likely extremely rare, so detecting it has been really exciting," said Megan Delamer, astronomy graduate student at Penn State and co-author on the paper. "Our current theories of planet formation have trouble accounting for what we're seeing."
In the case of the massive planet discovered orbiting the star LHS 3154, the heavy planetary core inferred by the team's measurements would require a larger amount of solid material in the planet-forming disk than current models would predict, Delamer explained. The finding also raises questions about prior understandings of the formation of stars, as the dust-mass and dust-to-gas ratio of the disk surrounding stars like LHS 3154 -- when they were young and newly formed -- would need to be 10 times higher than what was observed in order to form a planet as massive as the one the team discovered.
"What we have discovered provides an extreme test case for all existing planet formation theories," Mahadevan said. "This is exactly what we built HPF to do, to discover how the most common stars in our galaxy form planets -- and to find those planets."
Other Penn State authors on the paper are Eric Ford, Brianna Zawadzki, Fred Hearty, Andrea Lin, Lawrence Ramsey and Jason Wright.
Other authors on the paper are Joshua Winn of Princeton University, Yamila Miguel of the University of Leiden, Paul Robertson of the University of California, Irvine, and Rae Holcomb of the University of California, Shubham Kanodia of the Carnegie Institution for Science, Caleb Cañas of the NASA Goddard Space Flight Centre, Joe Ninan of India's Tata Institute of Fundamental Research, Ryan Terrien of Carleton College, Brendan Bowler, William Cochran, Michael Endl and Gary Hill of The University of Texas at Austin, Chad Bender of The University of Arizona, Scott Diddams, Connor Fredrick and Andrew Metcalf of the University of Colorado, Samuel Halverson of California Institute of Technology's Jet Propulsion Laboratory, Andrew Monson of the University of Arizona, Arpita Roy of Johns Hopkins University, Christian Schwab of Australia 's Macquarie University, and Gregory Zeimann of the Hobby-Eberly Telescope at UT Austin.
The work was funded by the Centre for Exoplanets and Habitable Worlds at Penn State, the Pennsylvania Space Grant Consortium, the National Aeronautics and Space Administration, the National Science Foundation and the Heising-Simons Foundation.

❖ Hubble sights a galaxy with 'forbidden' light

Date: December 22, 2023
Source: NASA/Goddard Space Flight Centre



Hubble Telescope images galaxy with forbidden light

A whirling image features a bright spiral galaxy known as MCG-01-24-014, which is located about 275 million light-years from Earth. In addition to being a well-defined spiral galaxy, MCG-01-24-014 has an extremely energetic core known as an active galactic nucleus (AGN) and is categorized as a Type-2 Seyfert galaxy. Seyfert galaxies, along with quasars, host one of the most common subclasses of AGN. While the precise categorization of AGNs is nuanced, Seyfert galaxies tend to be relatively nearby and their central AGN does not outshine its host, while quasars are very distant AGNs with incredible luminosities that outshine their host galaxies.

There are further subclasses of both Seyfert galaxies and quasars.

In the case of Seyfert galaxies, the predominant subcategories are Type-1 and Type-2. Astronomers distinguish them by their spectra, the pattern that results when light is split into its constituent wavelengths. The spectral lines that Type-2 Seyfert galaxies emit are associated with specific 'forbidden' emission lines.

To understand why emitted light from a galaxy could be forbidden, it helps to understand why spectra exist in the first place. Spectra look the way they do because certain atoms and molecules absorb and emit light at very specific wavelengths.

The reason for this is quantum physics: electrons (the tiny particles that orbit the nuclei of atoms and molecules) can only exist at very specific energies, and therefore electrons can only lose or gain very specific amounts of energy.

These very specific amounts of energy correspond to the wavelengths of light that are absorbed or emitted.

Forbidden emission lines should not exist according to certain rules of quantum physics. But quantum physics is complex, and some of the rules used to predict it were formulated under laboratory conditions here on Earth. Under those rules, this emission is 'forbidden' -- so improbable that it's disregarded. But in space, in the midst of an incredibly energetic galactic core, those assumptions don't hold anymore, and the 'forbidden' light gets a chance to shine out toward us.

❖ Researchers study a million galaxies to find out how the universe began

Date: December 22, 2023
Source: Kavli Institute for the Physics and Mathematics of the Universe

Galaxies, galaxies everywhere, as far as the Hubble Space Telescope can see. This view of nearly 10,000 galaxies is the deepest visible-light image of the cosmos. Called the Hubble Ultra Deep Field, this galaxy-studded view represents a core sample of the universe that cuts across 13 billion years of cosmic history. Credit: NASA, ESA, S. Beckwith (STScI) and the HUDF Team

A team of researchers has analysed more than one million galaxies to explore the origin of the present-day cosmic structures, reports a recent study published in *Physical Review D* as an Editors' Suggestion.

Until today, precise observations and analyses of the cosmic microwave background (CMB) and large-scale structure (LSS) have led to the establishment of the standard framework of the universe, the so-called ΛCDM model, where cold dark matter (CDM) and dark energy (the cosmological constant, Λ) are significant characteristics.

This model suggests that primordial fluctuations were generated at the beginning of the universe, or in the early universe, which acted as triggers, leading to the creation of all things in the universe including stars, galaxies, galaxy clusters, and their spatial distribution throughout space.

Although they are very small when generated, fluctuations grow with time due to the

gravitational pulling force, eventually forming a dense region of dark matter, or a halo.
Then, different halos repeatedly collided and merged with one another, leading to the formation of celestial objects such as galaxies.
Since the nature of the spatial distribution of galaxies is strongly influenced by the nature of the primordial fluctuations that created them to begin with, statistical analyses of galaxy distributions have been actively conducted to observationally explore the nature of primordial fluctuations.
In addition to this, the spatial pattern of galaxy shapes distributed over a wide area of the universe also reflects the nature of the underlying primordial fluctuations.
However, conventional analysis of large-scale structure has focused only on the spatial distribution of galaxies as points.
More recently, researchers have started studying galaxy shapes, because it not only provides additional information, but it also provides a different perspective into the nature of the primordial fluctuations.
A team of researchers, led by at-the-time Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) graduate student Toshiki Kurita (currently a postdoctoral researcher at the Max Planck Institute for Astrophysics), and Kavli IPMU Professor Masahiro Takada developed a method to measure the power spectrum of galaxy shapes, which extracts key statistical information from galaxy shape patterns by combining the spectroscopic data of spatial distribution of galaxies and imaging data of individual galaxy shapes.
The researchers simultaneously analysed the spatial distribution and shape pattern of approximately one million galaxies from the Sloan Digital Sky Survey (SDSS), the world's largest survey of galaxies today.
As a result, they successfully constrained statistical properties of the primordial fluctuations that seeded the formation of the structure of the entire universe.
They found a statistically significant alignment of the orientations of two galaxies' shapes more than 100 million light years apart.
Their result showed correlations exist between distant galaxies whose formation processes are apparently independent and causally unrelated.
"In this research, we were able to impose constraints on the properties of the primordial fluctuations through statistical analysis of the 'shapes' of numerous galaxies obtained from the large-scale structure data. There are few precedents for research that uses galaxy shapes to explore the physics of the early universe, and the research process, from the construction of the idea and development of analysis methods to the actual data analysis, was a series of trial and error. Because of that, I faced many challenges. But I am glad that I was able to accomplish them during my doctoral program. I believe that this achievement will be the first step to open up a new research field of cosmology using galaxy shapes," said Kurita.
Furthermore, a detailed investigation of these correlations confirmed they are consistent with the correlations predicted by inflation, and do not exhibit a non-Gaussian feature of the primordial fluctuation.
"This research is the result of Toshiki's doctoral dissertation. It's a wonderful research achievement in which we developed a method to validate a cosmological model using galaxy shapes and galaxy distributions, applied it to data, and then tested the physics of inflation. It was a research topic that no one had ever done before, but he did all three steps: theory, measurement, and application. Congratulations! I am very proud of the fact that we were able to do all three steps. Unfortunately, I did not make the great discovery of detecting a new physics of inflation, but we have set a path for future research. We can expect to open up further areas of research using the Subaru Prime Focus Spectrograph," said Takada.
The methods and results of this study will allow researchers in the future to further test inflation theory.
Details of this study were published on October 31 in *Physical Review D* as an Editors' Suggestion.

- Organic compounds in asteroids formed in colder regions of space

Date: December 21, 2023
Source: Curtin University

Analysis of organic compounds -- calledpolycyclic aromatic hydrocarbons (PAHs) -- extracted from the Ryugu asteroid and Murchison meteorite has found that certain PAHs likely formed in the cold areas of space between stars rather than in hot regions near stars as was previously thought. The findings open new possibilities for studying life beyond Earth and the chemistry of objects in space.

The only Australian members of an international research team, scientists from Curtin's WA-Organic and Isotope Geochemistry Centre (WA-OIGC) carried out controlled burnings of plants to produce PAHs.

ARC Laureate Fellow John Curtin Distinguished Professor Kliti Grice, director of WA-OIGC, said PAHs are organic compounds made up of carbon and hydrogen that are common on Earth but are also found in celestial bodies like asteroids and meteorites.

"We performed controlled burn experiments on Australian plants, which were isotopically compared to PAHs from fragments of the Ryugu asteroid that were returned to Earth by a Japanese spacecraft in 2020, and the Murchison meteorite that landed in Australia in 1969. The bonds between light and heavy carbon isotopes in the PAHs were analysed to reveal the temperature at which they were formed," Professor Grice said.

"Select PAHs from Ryugu and Murchison were found to have different characteristics: the smaller ones likely in cold outer space, while bigger ones probably formed in warmer environments, like near a star or inside a celestial body."

Study co-author Dr Alex Holman, also from WA-OIGC, said understanding the isotopic composition of PAHs helps unravel the conditions and environments in which these molecules were created, offering insights into the history and chemistry of celestial bodies like asteroids and meteorites.

"This research gives us valuable insights into how organic compounds form beyond Earth and where they come from in space," Dr Holman said.

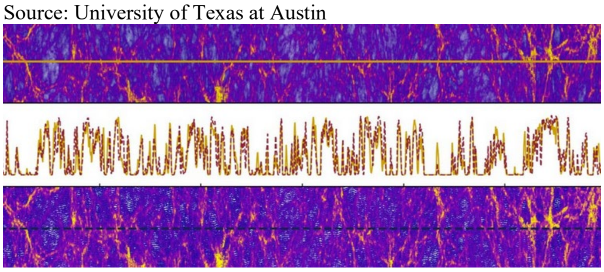
"The use of high-tech methods and creative experiments has shown that select PAHs on asteroids can be formed in cold space."

The full research paper, '*Polycyclic aromatic hydrocarbons in samples of Ryugu formed in the interstellar medium'* will be published in the journal *Science*.

- Cosmic lights in the forest

Date: December 21, 2023

Source: University of Texas at Austin



TACC's Frontera supercomputer helped astronomers develop PRIYA, the largest suite of hydrodynamic simulations yet made of large-scale structure in the universe. Example Lyman-α forest spectra from quasar light and corresponding gas density and temperature from simulations at redshift z = 4. Top panel shows high resolution, bottom panel shows low resolution, middle panel shows the Lyman-α forest spectra. Credit: DOI: 10.48550/arXiv.2309.03943

Like a celestial beacon, distant quasars make the brightest light in the universe. They emit more light than our entire Milky Way galaxy. The light comes from matter ripped apart as it is swallowed by a supermassive black hole. Cosmological parameters are important numerical constraints astronomers use to trace the evolution of the entire universe billions of years after the Big Bang.

Quasar light reveals clues about the large-scale structure of the universe as it shines through enormous clouds of neutral hydrogen gas formed shortly after the Big Bang on the scale of 20 million light years across or more.

Using quasar light data, the National Science Foundation (NSF)-funded Frontera supercomputer at the Texas Advanced Computing Centre (TACC) helped astronomers develop PRIYA, the largest suite of hydrodynamic simulations yet made for simulating large-scale structure in the universe.

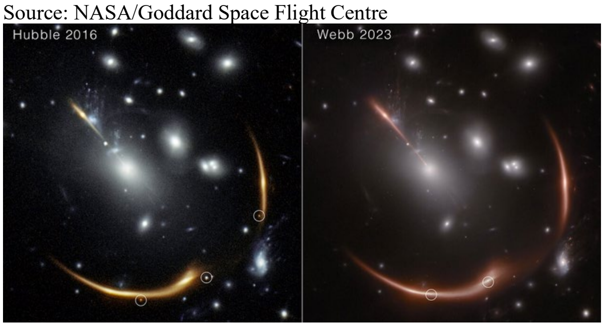
"We've created a new simulation model to compare data that exists at the real universe," said Simeon Bird, an assistant professor in astronomy at the University of California, Riverside.

Bird and colleagues developed PRIYA, which takes optical light data from the Extended Baryon Oscillation Spectroscopic Survey (eBOSS) of the Sloan Digital Sky Survey (SDSS). He and colleagues published their work announcing PRIYA October 2023 in the *Journal of Cosmology and Astroparticle Physics (JCAP).*
"We compare eBOSS data to a variety of simulation models with different cosmological parameters and different initial conditions to the universe, such as different matter densities," Bird explained. "You find the one that works best and how far away from that one you can go without breaking the reasonable agreement between the data and simulations. This knowledge tells us how much matter there is in the universe, or how much structure there is in the universe."
The PRIYA simulation suite is connected to large-scale cosmological simulations also co-developed by Bird, called ASTRID, which is used to study galaxy formation, the coalescence of supermassive black holes, and the re-ionization period early in the history of the universe. PRIYA goes a step further. It takes the galaxy information and the black hole formation rules found in ASTRID and changes the initial conditions.
"With these rules, we can we take the model that we developed that matches galaxies and black holes, and then we change the initial conditions and compare it to the Lyman-𝛼 forest data from eBOSS of the neutral hydrogen gas," Bird said.
The 'Lyman-𝛼 forest' gets its name from the 'forest' of closely packed absorption lines on a graph of the quasar spectrum resulting from electron transitions between energy levels in atoms of neutral hydrogen. The 'forest' indicates the distribution, density, and temperature of enormous intergalactic neutral hydrogen clouds. What's more, the lumpiness of the gas indicates the presence of dark matter, a hypothetical substance that cannot be seen yet is evident by its observed tug on galaxies.
PRIYA simulations have been used to refine cosmological parameters in work submitted to JCAP September 2023 and authored by Simeon Bird and his UC Riverside colleagues, M.A. Fernandez and Ming-Feng Ho.
Previous analysis of the neutrino mass parameters did not agree with data from the Cosmic Microwave Background radiation (CMB), described as the afterglow of the Big Bang. Astronomers use CMB data from the Plank space observatory to place tight constraints on the mass of neutrinos. Neutrinos are the most abundant particle in the universe, so pinpointing their mass value is important for cosmological models of large-scale structure in the universe.
"We made a new analysis with simulations that were a lot larger and better designed than anything before. The earlier discrepancies with the Planck CMB data disappeared, and were replaced with another tension, similar to what is seen in other low redshift large-scale structure measurements," Bird said. "The main result of the study is to confirm the σ8 tension between CMB measurements and weak lensing exists out to redshift 2, ten billion years ago."
One well-constrained parameter from the PRIYA study is on σ8, which is the amount of neutral hydrogen gas structures on a scale of 8 megaparsecs, or 2.6 million light years. This indicates the number of clumps of dark matter that are floating around there," Bird said.
Another parameter constrained was ns, the scalar spectral index. It is connected to how the clumsiness of dark matter varies with the size of the region analysed. It indicates how fast the universe was expanding just moments after the Big Bang.
"The scalar spectral index sets up how the universe behaves right at the beginning. The whole idea of PRIYA is to work out the initial conditions of the universe, and how the high energy physics of the universe behaves," Bird said.
Supercomputers were needed for the PRIYA simulations, Bird explained, simply because they were so big.
"The memory requirements for PRIYA simulations are so big you cannot put them on anything other than a supercomputer," Bird said.
TACC awarded Bird a Leadership Resource Allocation on the Frontera supercomputer. Additionally, analysis computations were performed using the resources of the UC Riverside High Performance Computer Cluster.
The PRIYA simulations on Frontera are some of the largest cosmological simulations yet made, needing over 100,000 core-hours to simulate a system of 3072^3 (about 29 billion) particles in a 'box' 120 megaparsecs on edge, or about 3.91 million light years across.

PRIYA simulations consumed over 600,000 node hours on Frontera.
"Frontera was very important to the research because the supercomputer needed to be big enough that we could run one of these simulations fairly easily, and we needed to run a lot of them. Without something like Frontera, we wouldn't be able to solve them. It's not that it would take a long time -- they just they wouldn't be able to run at all," Bird said.
In addition, TACC's Ranch system provided long-term storage for PRIYA simulation data.
"Ranch is important, because now we can reuse PRIYA for other projects. This could double or triple our science impact," Bird said. "
"Our appetite for more compute power is insatiable," Bird concluded. "It's crazy that we're sitting here on this little planet observing most of the universe."

- Supernova encore: Second lensed supernova in a distant galaxy

Date: December 21, 2023
Source: NASA/Goddard Space Flight Centre



Left: In 2016 the NASA/ESA Hubble Space Telescope spotted a multiply imaged supernova, nicknamed Supernova Requiem, in a distant galaxy lensed by the intervening galaxy cluster MACS J0138. Three images of the supernova are visible, and a fourth image is expected to arrive in 2035. In this near-infrared image, light at 1.05 microns is represented in blue and 1.60 microns is orange.

Right: In November 2023 the NASA/ESA/CSA James Webb Space Telescope identified a second multiply imaged supernova in the same galaxy using its NIRCam (Near-Infrared Camera) instrument. This is the first known system to produce more than one multiply-imaged supernova.

In November 2023, NASA's James Webb Space Telescope observed a massive cluster of galaxies named MACS J0138.0-2155. Through an effect called gravitational lensing, first predicted by Albert Einstein, a distant galaxy named MRG-M0138 appears warped by the powerful gravity of the intervening galaxy cluster. In addition to warping and magnifying the distant galaxy, the gravitational lensing effect caused by MACS J0138 produces five different images of MRG-M0138.
In 2019, astronomers announced the surprising find that a stellar explosion, or supernova, had occurred within MRG-M0138, as seen in images from NASA's Hubble Space Telescope taken in 2016.
When another group of astronomers examined the 2023 Webb images, they were astonished to find that seven years later, the same galaxy is home to a second supernova.
Justin Pierel (NASA Einstein Fellow at the Space Telescope Science Institute) and Andrew Newman (staff astronomer at the Observatories of the Carnegie Institution for Science) tell us more about this first time that two gravitationally lensed supernovae were found in the same galaxy.
"When a supernova explodes behind a gravitational lens, its light reaches Earth by several different paths. We can compare these paths to several trains that leave a station at the same time, all traveling at the same speed and bound for the same location. Each train takes a different route, and because of the differences in trip length and terrain, the trains do not arrive at their destination at the same time. Similarly, gravitationally lensed supernova images appear to astronomers over days, weeks, or even years. By measuring differences in the times that the supernova images appear, we can measure the history of the expansion rate of the universe, known as the Hubble constant, which is a major challenge in cosmology today. The catch is that these multiply-imaged supernovae are extremely rare: fewer than a dozen have been detected until now.
"Within this small club, the 2016 supernova in MRG-M0138, named Requiem, stood out for several reasons. First, it was 10 billion light-years distant. Second, the supernova was likely the same type (Ia) that is used as a 'standard candle' to measure cosmic distances. Third, models predicted that one of the supernova images is so delayed by its path through the extreme gravity of the cluster that it will not appear to us until the mid-2030s. Unfortunately, since Requiem was not discovered until 2019, long after it had faded from view, it was not possible to gather sufficient data to measure the Hubble constant then.
"Now we have found a second gravitationally lensed supernova within the same galaxy as Requiem, which we call Supernova Encore. Encore was discovered serendipitously, and we are now actively following the ongoing

supernova with a time-critical director's discretionary program. Using these Webb images, we will measure and confirm the Hubble constant based on this multiply imaged supernova. Encore is confirmed to be a standard candle or type Ia supernova, making Encore and Requiem by far the most distant pair of standard-candle supernova 'siblings' ever discovered.

"Supernovae are normally unpredictable, but in this case, we know when and where to look to see the final appearances of Requiem and Encore. Infrared observations around 2035 will catch their last hurrah and deliver a new and precise measurement of the Hubble constant."

- New 1.5-billion-pixel image shows Running Chicken Nebula in unprecedented detail

Date: December 21, 2023
Source: ESO

While many holiday, traditions involve feasts of turkey, soba noodles, latkes or Pan de Pascua, this year, the European Southern Observatory (ESO) is bringing you a holiday chicken. The so-called Running Chicken Nebula, home to young stars in the making, is revealed in spectacular detail in this 1.5-billion-pixel image captured by the VLT Survey Telescope (VST), hosted at ESO's Paranal site in Chile

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This vast stellar nursery is located in the constellation Centaurus (the Centaur), at about 6500 light-years from Earth.

Young stars within this nebula emit intense radiation that makes the surrounding hydrogen gas glow in shades of pink.

The Running Chicken Nebula actually comprises several regions, all of which we can see in this vast image that spans an area in the sky of about 25 full Moons [1]. The brightest region within the nebula is called IC 2948, where some people see the chicken's head and others its rear end.

The wispy pastel contours are ethereal plumes of gas and dust.

Towards the centre of the image, marked by the bright, vertical, almost pillar-like, structure, is IC 2944.

The brightest twinkle in this particular region is Lambda Centauri, a star visible to the naked eye that is much closer to us than the nebula itself.

There are, however, many young stars within IC 2948 and IC 2944 themselves -- and while they might be bright, they're most certainly not merry.

As they spit out vast amounts of radiation, they carve up their environment much like, well, a chicken.

Some regions of the nebula, known as Bok globules, can withstand the fierce bombardment from the ultraviolet radiation pervading this region.

If you zoom in to the image, you might see them: small, dark, and dense pockets of dust and gas dotted across the nebula.

Other regions pictured here include, to the upper right, Gum 39 and 40, and to the lower right, Gum 41. Aside from nebulae, there are countless orange, white and blue stars, like fireworks in the sky.

Overall, in this image, there are more wonders than can be described -- zoom in and pan across, and you'll have a feast for the eyes.

This image is a large mosaic comprising hundreds of separate frames carefully stitched together.

The individual images were taken through filters that let through light of different colours, which were then combined into the final result presented here.

The observations were conducted with the wide-field camera OmegaCAM on the VST, a telescope owned by the National Institute for Astrophysics in Italy (INAF) and hosted by ESO at its Paranal site in Chile's Atacama Desert that is ideally suited for mapping the southern sky in visible light.

The data that went into making this mosaic were taken as part of the VST Photometric Hα Survey of the Southern Galactic Plane and Bulge (VPHAS+), a project aimed at better understanding the life cycle of stars.

Notes

[1] This image, edge to edge, is 270 light-years wide. It would take an average chicken almost 21 billion years to run across it. That's much longer than our Universe has been around for.

❖ NASA's Hubble watches 'spoke season' on Saturn

Date: December 21, 2023
Source: NASA/Goddard Space Flight Centre

This photo of Saturn was taken by NASA's Hubble Space Telescope on October 22, 2023, when the ringed planet was approximately 850 million miles from Earth. Hubble's ultra-sharp vision reveals a phenomenon called ring spokes.
Saturn's spokes are transient features that rotate along with the rings.
Their ghostly appearance only persists for two or three rotations around Saturn.
During active periods, freshly-formed spokes continuously add to the pattern.
In 1981, NASA's Voyager 2 first photographed the ring spokes.
NASA's Cassini orbiter also saw the spokes during its 13-year-long mission that ended in 2017.
Hubble continues observing Saturn annually as the spokes come and go. This cycle has been captured by Hubble's Outer Planets Atmospheres Legacy (OPAL) program that began nearly a decade ago to annually monitor weather changes on all four gas-giant outer planets.
Hubble's crisp images show that the frequency of spoke apparitions is seasonally driven, first appearing in OPAL data in 2021 but only on the morning (left) side of the rings.
Long-term monitoring show that both the number and contrast of the spokes vary with Saturn's seasons.
Saturn is tilted on its axis like Earth and has seasons lasting approximately seven years.
"We are heading towards Saturn equinox, when we'd expect maximum spoke activity, with higher frequency and darker spokes appearing over the next few years," said the OPAL program lead scientist, Amy Simon of NASA's Goddard Space Flight Centre in Greenbelt, Maryland.
This year, these ephemeral structures appear on both sides of the planet simultaneously as they spin around the giant world.
Although they look small compared with Saturn, their length and width can stretch longer than Earth's diameter!
"The leading theory is that spokes are tied to Saturn's powerful magnetic field, with some sort of solar interaction with the magnetic field that gives you the spokes," said Simon.
When it's near the equinox on Saturn, the planet and its rings are less tilted away from the Sun.
In this configuration, the solar wind may more strongly batter Saturn's immense magnetic field, enhancing spoke formation.
Planetary scientists think that electrostatic forces generated from this interaction levitate dust or ice above the ring to form the spokes, though after several decades no theory perfectly predicts the spokes. Continued Hubble observations may eventually help solve the mystery.

❖ Ringing in the holidays with ringed planet Uranus

Date: December 19, 2023
Source: NASA/Goddard Space Flight Centre

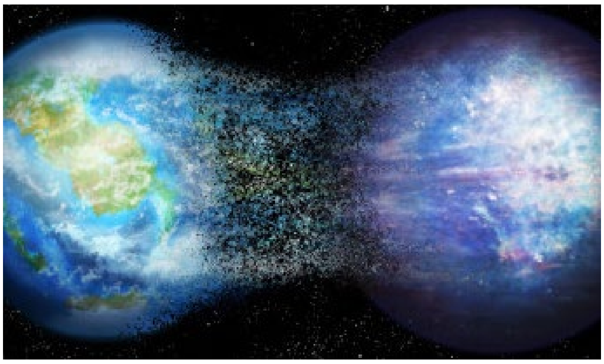
FILE - This image of Uranus from NIRCam (Near-Infrared Camera) on NASA’s James Webb Space Telescope exquisitely captures Uranus’s seasonal north polar cap and dim inner and outer rings. This Webb image also shows 9 of the planet’s 27 moons – clockwise **(NASA, ESA, CSA, STScI)**

NASA's James Webb Space Telescope recently trained its sights on unusual and enigmatic Uranus, an ice giant that spins on its side. Webb captured this dynamic world with rings, moons, storms, and other atmospheric features -- including a seasonal polar cap. The image expands upon a two-colour version released earlier this year, adding additional wavelength coverage for a more detailed look.
With its exquisite sensitivity, Webb captured Uranus' dim inner and outer rings, including the elusive Zeta ring -- the extremely faint and diffuse ring closest to the planet.

It also imaged many of the planet's 27 known moons, even seeing some small moons within the rings.
In visible wavelengths as seen by Voyager 2 in the 1980s, Uranus appeared as a placid, solid blue ball.
In infrared wavelengths, Webb is revealing a strange and dynamic ice world filled with exciting atmospheric features.
One of the most striking of these is the planet's seasonal north polar cloud cap.
Compared to the Webb image from earlier this year, some details of the cap are easier to see in these newer images.
These include the bright, white, inner cap and the dark lane in the bottom of the polar cap, toward the lower latitudes.
Several bright storms can also be seen near and below the southern border of the polar cap.
The number of these storms, and how frequently and where they appear in Uranus's atmosphere, might be due to a combination of seasonal and meteorological effects.
The polar cap appears to become more prominent when the planet's pole begins to point toward the Sun, as it approaches solstice and receives more sunlight.
Uranus reaches its next solstice in 2028, and astronomers are eager to watch any possible changes in the structure of these features.
Webb will help disentangle the seasonal and meteorological effects that influence Uranus's storms, which is critical to help astronomers understand the planet's complex atmosphere.
Because Uranus spins on its side at a tilt of about 98 degrees, it has the most extreme seasons in the solar system.
For nearly a quarter of each Uranian year, the Sun shines over one pole, plunging the other half of the planet into a dark, 21-year-long winter.
With Webb's unparalleled infrared resolution and sensitivity, astronomers now see Uranus and its unique features with groundbreaking new clarity.
These details, especially of the close-in Zeta ring, will be invaluable to planning any future missions to Uranus.
Uranus can also serve as a proxy for studying the nearly 2,000 similarly sized exoplanets that have been discovered in the last few decades. This "exoplanet in our backyard" can help astronomers understand how planets of this size work, what their meteorology is like, and how they formed. This can in turn help us understand our own solar system as a whole by placing it in a larger context.

- Exoplanets ‘climate -- it takes nothing to switch from habitable to hell

Simulation of entire runaway greenhouse effect, which can make a planet completely unhabitable
Date: December 18, 2023
Source: Université de Genève



Credits: Thibaut Roger/University of Geneva

The Earth is a wonderful blue and green dot covered with oceans and life, while Venus is a yellowish sterile sphere that is not only inhospitable but also sterile. However, the difference between the two bears to only a few degrees in temperature. A team of astronomers from the University of Geneva (UNIGE), with the support of the CNRS laboratories of Paris and Bordeaux, has achieved a world's first by managing to simulate the entirety of the runaway greenhouse process which can transform the climate of a planet from idyllic and perfect for life, to a place more than harsh and hostile. The scientists have also demonstrated that from initial stages of the process, the atmospheric structure and cloud coverage undergo significant changes, leading to an almost-unstoppable and very complicated to reverse runaway greenhouse effect. On Earth, a global average temperature rise of just a few tens of degrees, subsequent to a slight rise of the Sun's luminosity, would be sufficient to initiate this phenomenon and to make our planet inhabitable. These results are published in *Astronomy & Astrophysics*.
The idea of a runaway of the greenhouse effect is not new. In this scenario, a planet can evolve from a temperate state like on Earth to a true hell, with surface temperatures above 1000°C. The cause?
Water vapor, a natural greenhouse gas. Water vapor prevents the solar irradiation absorbed by Earth to be reemitted towards the void of space, as thermal radiation.

It traps heat a bit like a rescue blanket. A dash of greenhouse effect is useful -- without it, Earth would have an average temperature below the freezing point of water, looking like a ball covered with ice and hostile to life.
On the opposite, too much greenhouse effect increases the evaporation of oceans, and thus the amount of water vapor in the atmosphere.
"There is a critical threshold for this amount of water vapor, beyond which the planet cannot cool down anymore. From there, everything gets carried away until the oceans end up getting fully evaporated and the temperature reaches several hundred degrees," explains Guillaume Chaverot, former postdoctoral scholar in the Department of Astronomy at the UNIGE Faculty of Science and main author of the study.

World premiere

"Until now, other key studies in climatology have focused solely on either the temperate state before the runaway, or either the inhabitable state post-runaway," reveals Martin Turbet, researcher at CNRS laboratories of Paris and Bordeaux, and co-author of the study.
"It is the first time a team has studied the transition itself with a 3D global climate model, and has checked how the climate and the atmosphere evolve during that process."
One of the key points of the study describes the appearance of a very peculiar cloud pattern, increasing the runaway effect, and making the process irreversible.
"From the start of the transition, we can observe some very dense clouds developing in the high atmosphere. Actually, the latter does not display anymore the temperature inversion characteristic of the Earth atmosphere and separating its two main layers: the troposphere and the stratosphere. The structure of the atmosphere is deeply altered," points out Guillaume Chaverot.

Serious consequences for the search of life elsewhere

This discovery is a key feature for the study of climate on other planets, and in particular on exoplanets -- planets orbiting other stars than the Sun.
"By studying the climate on other planets, one of our strongest motivations is to determine their potential to host life," indicates Émeline Bolmont, assistant professor and director of the UNIGE Life in the Universe Centre (LUC), and co-author of the study.
The LUC leads state-of-the-art interdisciplinary research projects regarding the origins of life on Earth, and the quest for life elsewhere in our solar system and beyond, in exoplanetary systems.
"After the previous studies, we suspected already the existence of a water vapor threshold, but the appearance of this cloud pattern is a real surprise!" discloses Émeline Bolmont.
"We have also studied in parallel how this cloud pattern could create a specific signature, or "fingerprint", detectable when observing exoplanet atmospheres. The upcoming generation of instruments should be able to detect it," unveils Martin Turbet.
The team is also not aiming to stop there, Guillaume Chaverot having received a research grant to continue this study at the "Institut de Planétologie et d'Astrophysique de Grenoble" (IPAG). This new step of the research project will focus on the specific case of the Earth.

A planet Earth in a fragile equilibrium

With their new climate models, the scientists have calculated that a very small increase of the solar irradiation -- leading to an increase of the global Earth temperature, of only a few tens of degrees -- would be enough to trigger this irreversible runaway process on Earth and make our planet as inhospitable as Venus.
One of the current climate goals is to limit global warming on Earth, induced by greenhouse gases, to only 1.5 degrees by 2050.
One of the questions of Guillaume Chaverot's research grant is to determine if greenhouse gases can trigger the runaway process as a slight increase of the Sun luminosity might do. If so, the next question will be to determine if the threshold temperatures are the same for both processes.
The Earth is thus not so far from this apocalyptical scenario. "Assuming this runaway process would be started on Earth, an evaporation of only 10 meters of the oceans' surface would lead to a 1 bar increase of the atmospheric pressure at ground level. In just a few hundred years, we would reach a ground temperature of over 500°C. Later, we would even reach 273 bars of surface pressure and over 1 500°C, when all of the oceans would end up totally evaporated," concludes Guillaume Chaverot.

- Astronomers discover first population of binary stripped stars

New findings confirm existence of hot helium stars long-thought to be at the heart of hydrogen-poor supernovae and neutron star mergers

Date: December 15, 2023
Source: University of Toronto

Surveys conducted by NASA's Swift-UVOT telescope provide the most detailed overviews ever captured in ultraviolet light of the Large and Small Magellanic Clouds, the two closest major galaxies to our own. The researchers use this ultraviolet dataset to identify the candidate systems that they targeted for this paper. Credit: NASA/Swift/S. Immler (Goddard) and M. Siegel (Penn State)

Astronomers at the University of Toronto have discovered a population of massive stars that have been stripped of their hydrogen envelopes by their companions in binary systems. The findings, published today in *Science,* shed light on the hot helium stars that are believed to be the origins of hydrogen-poor core-collapse supernovae and neutron star mergers.

For over a decade, scientists have theorized that approximately one in three massive stars are stripped of their hydrogen envelope in binary systems. Yet, until now, only one possible candidate had been identified.

"This was such a big, glaring hole," says co-lead author Maria Drout, an Assistant Professor in the David A. Dunlap Department of Astronomy & Astrophysics and a Dunlap Institute for Astronomy & Astrophysics Associate at the University of Toronto.

"If it turned out that these stars are rare, then our whole theoretical framework for all these different phenomena is wrong, with implications for supernovae, gravitational waves, and the light from distant galaxies," Drout says. "This finding shows these stars really do exist."

"Going forward, we are going to be able to do much more detailed physics with these stars," Drout says. "For example, predictions for how many neutron star mergers we should see are dependent on the properties of these stars, such as how much material comes off of them in stellar winds. Now, for the first time, we'll be able to measure that, whereas people have been extrapolating it before."

Binary stripped stars have been previously evoked to explain why a third of core-collapse supernovae contain much less hydrogen than a typical explosion of a Red Supergiant star. Drout and her colleagues propose that these newly discovered stars will eventually explode as hydrogen-poor supernovae. These star systems are also thought to be necessary to form neutron star mergers, like those that emit gravitational waves detected from Earth by the LIGO experiment.

In fact, the researchers believe that a few objects in their current sample are stripped stars with neutron star or blackhole companions. These objects are at the stage immediately before they become double neutron star or neutron star plus blackhole systems that could eventually merge.

"Many stars are part of a cosmic dance with a partner, orbiting each other in a binary system. They're not solitary giants but part of dynamic duos, interacting and influencing each other throughout their lifetimes," says Bethany Ludwig, a PhD student in in the David A. Dunlap Department of Astronomy & Astrophysics at the University Toronto and the third author on this paper. "Our work sheds light on these fascinating relationships, revealing a universe that is far more interconnected and active than we previously imagined."

"Just as humans are social beings, stars too, especially the massive ones, are rarely alone," Ludwig says.

As stars evolve and expand to become red giants, the hydrogen at the outer edges of one can be stripped by the gravitational pull of its companion -- leaving a very hot helium core exposed. The process can take tens of thousands, or even hundreds of thousands, of years.

Stripped stars are difficult to find because much of the light they emit is outside of the visible light spectrum and can be obstructed by dust in the universe or outshone by their companion stars.

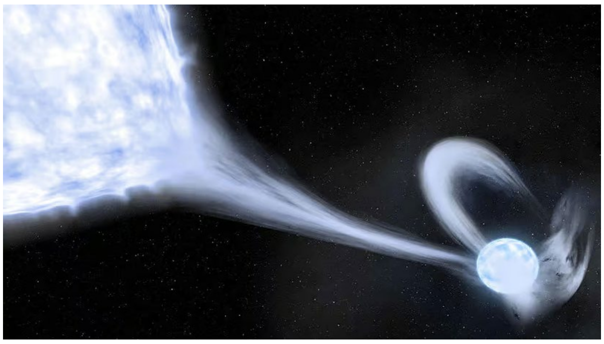
Drout and her collaborators began their search in 2016. Having studied hydrogen-poor supernovae during her PhD, Drout set out to find the stripped stars thought to be at the heart of them during a NASA Hubble Postdoctoral Fellowship at the Observatories of the Carnegie Institution for Science. She met fellow co-author Ylva Götberg, now

Assistant Professor at the Institute of Science and Technology Austria (ISTA), at a conference, who had recently built new theoretical models of what these stars should look like.
Drout, Götberg, and their collaborators designed a new survey to look in the ultraviolet part of the spectrum where extremely hot stars emit most of their light. While invisible to the naked eye, ultraviolet light can be detected by specialized instruments and telescopes.
Using data from the Swift Ultra-Violet/Optical Telescope, the researchers collected brightnesses for millions of stars in the Large and Small Magellanic Clouds, two of the closest galaxies to Earth. Ludwig developed the first wide-field UV catalogue of the Magellanic Clouds and used UV photometry to detect systems with unusual UV emissions, signalling the possible presence of a stripped star.
They carried out a pilot study of 25 objects, obtaining optical spectroscopy with the Magellan Telescopes at Las Campanas Observatory between 2018 and 2022. They used these observations to demonstrate that the stars were hot, small, hydrogen-poor, and in binary systems -- all consistent with their model predictions.
Currently, the researchers are continuing to study the stars identified in this paper and expanding their search to find more. They will be looking both within nearby galaxies and within our own Milky Way with approved programs on the Hubble Space Telescope, the Chandra X-Ray Telescope, the Magellan Telescopes, and the Anglo-Australian Telescope. As part of this publication, all theoretical models and data used to identify these stars have been made public and available to other scientists.
Collaborating institutions include the University of Toronto, the Observatories of the Carnegie Institution for Science, Max-Planck-Institut für Astrophysik, Anton Pannekoek Institute for Astronomy, Dunlap Institute for Astronomy & Astrophysics, and Steward Observatory.

- ❖ Reaching for the (invisible) stars

Uncovering the missing precursors of hydrogen-poor supernovae

Date: December 15, 2023
Source: Institute of Science and Technology Austria



Visualization of a binary star experiencing mass transfer. Credit: © Ylva Götberg.

Supernovae-stellar explosions as bright as an entire galaxy-have fascinated us since time immemorial. Yet, there are more hydrogen-poor supernovae than astrophysicists can explain. Now, a new Assistant Professor at the Institute of Science and Technology Austria (ISTA) has played a pivotal role in identifying the missing precursor star population. The results, now published in *Science*, go back to a conversation the involved professors had many years ago as junior scientists.

Some stars do not simply die down, but explode in a stellar blast that could outshine entire galaxies. These cosmic phenomena, called supernovae, spread light, elements, energy, and radiation in space and send galactic shock waves that could compress gas clouds and generate new stars. In other words, supernovae shape our universe. Among these, hydrogen-poor supernovae from exploding massive stars have long puzzled astrophysicists. The reason: scientists have not been able to put their finger on their precursor stars. It is almost as if these supernovae appeared out of nowhere.

"There are many more hydrogen-poor supernovae than our current models can explain. Either we can't detect the stars that mature on this path, or we must revise all our models," says ISTA Assistant Professor Ylva Götberg. She pioneered this work together with Maria Drout, an Associated Faculty Member of the Dunlap Institute for Astronomy & Astrophysics, University of Toronto, Canada. "Single stars would typically explode as hydrogen-rich supernovae. Being hydrogen-poor indicates that the precursor star must have lost its thick hydrogen-rich envelope. This happens naturally in a third of all massive stars through envelope stripping by a binary companion star," says Götberg. Now, Götberg and Drout combined their areas of expertise in theoretical modelling and observation to hunt down the missing stars. Their quest is successful: they document a first-of-its-kind star population that finally bridges a large knowledge gap and sheds light on the origin of hydrogen-poor supernovae.

Binary stars and envelope stripping

The stars that Götberg and Drout search for go in pairs: interlocked in a binary star system. Some binary systems are well-known to us Earthlings: these include the brightest star in our night sky, Sirius A, and its faint companion star Sirius B. The Sirius binary system is located only 8.6 light-years away from Earth-a stone's throw in cosmic terms. This explains Sirius A's observed brightness in our night sky.

Astrophysicists expect the missing stars to be initially formed from massive binary systems. In a binary system, the stars would orbit around one another until the more massive star's thick, hydrogen-rich envelope expands. Eventually, the expanding envelope experiences a stronger gravitational pull to the companion star than to its own core. This causes a transfer of mass to begin, which eventually leads the entire hydrogen-rich envelope to be stripped off, leaving the hot and compact helium core exposed-more than 10 times hotter than the Sun's surface. This is precisely the type of stars that Götberg and Drout are looking for. "Intermediate mass helium stars stripped through binary interaction are predicted to play important roles in astrophysics. Yet, they were not observed until now," says Götberg. In fact, there is an important mass gap between the known classes of helium stars: the more massive Wolf-Rayet (WR) stars have more than 10 times the Sun's mass, and the low-mass subdwarf stars could have around half the Sun's mass. However, models have predicted the precursors of hydrogen-poor supernovae to lie between 2 and 8 solar masses following stripping.

Not just a needle in the haystack

Before Götberg and Drout's study, only one star was found to fulfil the expected mass and composition criteria and was called "Quasi-WR" (or "Almost Wolf-Rayet"). "Yet, the stars that follow this path have such a long lifetime that many must be scattered all over the observable universe," says Götberg. Did the scientists simply not "see" them? Thus, Götberg and Drout drew on their complementary expertise. With the help of UV photometry and optical spectroscopy, they identified a population of 25 stars that are consistent with the expectations for intermediate-mass helium stars. The stars are located in two well-studied neighbouring galaxies, the Large and the Small Magellanic Clouds. "We showed that these stars were bluer than the stellar birth line, the bluest phase in a single star's lifetime. Single stars mature by evolving towards the redder region of the spectrum. A star only shifts in the opposite direction if its outer layers are removed-something that is expected to be common in interacting binary stars and rare among single massive stars," explains Götberg.

The scientists then verified their candidate star population using optical spectroscopy: they showed that the stars had strong spectral signatures of ionized helium. "Strong ionized helium lines tell us two important things: first, they confirm that the stars' outermost layers are dominated by helium and, second, that their surface is very hot. This is what happens to stars left as an exposed, compact, helium-rich core following stripping," says Götberg. Yet, both stars in a binary system contribute to the observed spectra. Thus, this technique allowed the researchers to classify their candidate population depending on which star contributed the most to the spectrum. "This work allowed us to find the missing population of intermediate-mass, stripped helium stars, the predicted progenitors of hydrogen-poor supernovae. These stars have always been there and there are probably many more out there. We must simply come up with ways to find them," says Götberg. "Our work may be one of the first attempts, but there should be other ways possible."

From graduate students at a conference to group leaders

The idea behind this project sparked in a discussion following a talk by Götberg at a conference that she and Drout attended during their graduate studies. Both scientists, then Early Career Researchers reaching for the stars, are now group leaders in their field. Götberg joined ISTA in September following her research at the Carnegie Observatories in Pasadena, California, as a NASA Hubble postdoctoral fellow. At ISTA, Götberg joins the Institute's growing ranks of young group leaders in astrophysics and leads her own group focused on studying the binary interactions of stars.

This work, led by Maria R. Drout (Dunlap Institute for Astronomy & Astrophysics, University of Toronto, Canada) and Ylva Götberg (Institute of Science and Technology Austria, ISTA), was done in collaboration with The Observatories of the Carnegie Institution for Science (Pasadena, USA), and the Max Planck Institute for Astrophysics (Garching, Germany), among others.