South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk Peter Bull MBE FRAS "A Window Through Your Universe": An amazing summary of topics you'll be aware of but perhaps never seen the relationship between them. The talk will give the salient facts in an easily understood form: the Big Bang, space, time, matter and energy encompassing forces, constants, quantum theory, special relativity, general relativity, star life and death, galaxies, wormholes and string theory, the demise of the Universe!

Please support a raffle we are organizing this month

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- Could this copycat black hole be a new type of star?

Date: April 18, 2023
Source: Johns Hopkins University

Credit: Pierre Heidmann / Johns Hopkins University

Though the mysterious object is a hypothetical mathematical construction, new simulations by Johns Hopkins researchers suggest there could be other celestial bodies in space hiding from even the best telescopes on Earth. The findings are set to publish in *Physical Review D.*

"We were very surprised," said Pierre Heidmann, a Johns Hopkins University physicist who led the study. "The object looks identical to a black hole, but there's light coming out from its dark spot."

The detection of gravitational waves in 2015 rocked the world of astrophysics because it confirmed the existence of black holes.

Inspired by those findings, the Johns Hopkins team set out to explore the possibility of other objects that could produce similar gravitational effects but that could be passing as black holes when observed with ultraprecise sensors on Earth, said co-author and Johns Hopkins physicist Ibrahima Bah. "How would you tell when you don't have a black hole? We don't have a good way to test that," Bah said. "Studying hypothetical objects like topological solitons will help us figure that out as well."

The new simulations realistically depict an object the Johns Hopkins team calls a topological soliton. The simulations show an object looking like a blurry photo of a black hole from afar but like something else entirely up close.

The object is hypothetical at this stage. But the fact that the team could construct it using mathematical equations and show what it looks like with simulations suggests there could be other types of celestial bodies in space hiding from even the best telescopes on Earth.

The findings show how the topological soliton distorts space exactly as a black hole does -- but behaves unlike a black hole as it scrambles and releases weak light rays that would not escape the strong gravitational force of a true hole.

"Light is strongly bent, but instead of being absorbed like it would in a black hole, it scatters in funky motions until at one point it comes back to you in a chaotic manner," Heidmann said. "You don't see a dark spot. You see a lot of blur, which means light is orbiting like crazy around this weird object."

A black hole's gravitational field is so intense that light can orbit around it at a certain distance from its centre, in the same way that Earth orbits the sun. This distance determines

the edge of the hole's "shadow," so that any incoming light will fatally hit the region that scientists call the "event horizon." There, nothing can escape -- not even light.
The Hopkins team simulated several scenarios using pictures of outer space as if they had been captured with a camera, placing a black hole and the topological soliton in front of the lens. The results produced distorted pictures because of the gravitational effects of the massive bodies.
"These are the first simulations of Astro physically relevant string theory objects, since we can actually characterize the differences between a topological soliton and a black hole as if an observer was seeing them in the sky," Heidmann said.
Motivated by various results from string theory, Bah and Heidmann discovered ways to construct topological solitons using Einstein's theory of general relativity in 2021. While the solitons are not predictions of new objects, they serve as the best models of what new quantum gravity objects could look like compared to black holes.
Scientists have previously created models of boson stars, gravastars, and other hypothetical objects that could exert similar gravitational effects with exotic forms of matter. But the new research accounts for pillar theories of the inner workings of the universe that other models don't. It uses string theory that reconciles quantum mechanics and Einstein's theory of gravity, the researchers said.
"It's the start of a wonderful research program," Bah said. "We hope in the future to be able to genuinely propose new types of ultracompact stars consisting of new kinds of matter from quantum gravity."
The team includes Johns Hopkins physicist Emanuele Berti. The topological soliton in the simulations was first constructed in research published in 2022 by Bah's group.

❖ Metal-poor stars are more life-friendly

Date: April 18, 2023
Source: Max-Planck-Gesellschaft

Stars that contain comparatively large amounts of heavy elements provide less favourable conditions for the emergence of complex life than metal-poor stars, as scientists from the Max Planck Institutes for Solar System Research and for Chemistry as well as from the University of Göttingen have now found. The team showed how the metallicity of a star is connected to the ability of its planets to surround themselves with a protective ozone layer. Crucial to this is the intensity of the ultraviolet light that the star emits into space, in different wavelength ranges. The study provides scientists searching the sky with space telescopes for habitable star systems with important clues as to where this endeavour could be particularly promising. It also suggests a startling conclusion: as the universe ages, it becomes increasingly unfriendly to the emergence of complex life on new planets.
In the search for habitable or even inhabited planets orbiting distant stars, researchers have in the past years increasingly focused on the gas envelopes of these worlds. Do observational data show evidence of an atmosphere? Does it perhaps even contain gases such as oxygen or methane, which on Earth are produced almost exclusively as metabolic products of lifeforms? In the next years, such observations will be pushed to new limits: Nasa's James Webb Telescope will make it possible to not only characterize the atmospheres of large gas giants like Super-Neptune's, but also to analyse for the first time the much fainter spectrographic signals from rocky planet atmospheres.
With the help of numerical simulations, the current study, which was published in Nature Communications today, now turns to the ozone content of exoplanet atmospheres. As on Earth, this compound of three oxygen atoms can protect the planet's surface (and life forms residing on it) from cell-damaging ultraviolet (UV) radiation. A protective layer of ozone is thus an important prerequisite for the emergence of complex life. "We wanted to understand what properties a star must have in order for its planets to form a protective ozone layer," Anna Shapiro, scientist at the Max Planck Institute for Solar System Research and first author of the current study, explains the basic idea.
As often in science, this idea was triggered by an earlier finding. Three years ago, researchers led by the Max Planck Institute for Solar System Research had compared the Sun's brightness variations with those of

hundreds of Sun-like stars. The result: the intensity of the visible light from many of these stars fluctuates much more strongly than in the case of the Sun. "We saw huge peaks in intensity," says Alexander Shapiro, who was involved in both the analyses from three years ago and the current study. "It is therefore quite possible, that the Sun, too, is capable of such spikes in intensity. In that case, also the intensity of the ultraviolet light would increase dramatically," he adds. "So naturally we wondered, what this would mean for life on Earth and what the situation is like in other star systems," says Sami Solanki, director at the Max Planck Institute for Solar System Research and co-author of both studies.

Dual role of UV radiation

At the surface of about half of all stars around which exoplanets have been shown to orbit, temperatures range from about 5,000 to about 6,000 degrees Celsius. In their calculations, the researchers therefore turned to this subgroup. With a surface temperature of approximately 5500 degrees Celsius, the Sun is also one of them. "In the Earth's atmospheric chemistry, ultraviolet radiation from the Sun plays a dual role," explains Anna Shapiro, whose past research interest focused on the influence of solar radiation on Earth's atmosphere. In reactions with individual oxygen atoms and oxygen molecules, ozone can both be created and destroyed. While long-wave UV-B radiation destroys ozone, short-wave UV-C radiation helps create protective ozone in the middle atmosphere. "It was therefore reasonable to assume that ultraviolet light may have a similarly complex influence on exoplanet atmospheres as well," the astronomer adds. The precise wavelengths are crucial.

The researchers therefore calculated exactly which wavelengths make up the ultraviolet light emitted by the stars. For the first time, they also considered the influence of metallicity. This property describes the ratio of hydrogen to heavier elements (simplistically and somewhat misleadingly called "metals" by astrophysicists) in the building material of the star. In the case of the Sun, there are more than 31000 hydrogen atoms for every iron atom. The study also considered stars with lower and higher iron content.

Simulated interactions of UV radiation with gases

In a second step, the team investigated how the calculated UV radiation would affect the atmospheres of planets orbiting at a life-friendly distance around these stars. Life-friendly distances are those that allow moderate temperatures -- neither too hot nor too cold for liquid water -- at the planet's surface. For such worlds, the team simulated on the computer exactly which processes the parent star's characteristic UV light sets in motion in the planet's atmosphere.

To compute the composition of planetary atmospheres the researchers used a chemistry-climate model that simulates the processes that control oxygen, ozone, and many other gases, and their interactions with ultraviolet light from stars, at very high spectral resolution. This model allowed the investigation of a wide variety of conditions on exoplanets and comparison with the history of the Earth's atmosphere in the last half billion years. During this period the high atmospheric oxygen content and the ozone layer were established that allowed the evolution of life on land on our planet. "It is feasible that the history of the Earth and its atmosphere holds clues about the evolution of life that may also apply to exoplanets" says Jos Lelieveld, Managing Director of the Max Planck Institute for Chemistry, who was involved in the study.

Promising candidates

The results of the simulations were surprising for the scientists. Overall, metal-poor stars emit more UV radiation than their metal-rich counterparts. But the ratio of ozone-generating UV-C radiation to ozone-destroying UV-B radiation also depends critically on metallicity: in metal-poor stars, UV-C radiation predominates, allowing a dense ozone layer to form. For metal-rich stars, with their predominant UV-B radiation, this protective envelope is much sparser. "Contrary to expectations, metal-poor stars should thus provide more favourable conditions for the emergence of life," Anna Shapiro concludes. This finding could be helpful for future space missions such as Esa's Plato mission, which will comb through a vast array of stars for signs of habitable exoplanets. With 26 telescopes on board, the eponymous probe will be launched into space in 2026 and will focus its attention primarily on Earth-like planets orbiting Sun-like stars at life-friendly distances. The mission's data centre is currently being set up at the Max

Planck Institute for Solar System Research. "Our current study gives us valuable clues as to which stars Plato should pay special attention to," says Laurent Gizon, Managing Director at the Institute and co-author of the current study.

Paradoxical conclusion

Moreover, the study yields an almost paradoxical conclusion: as the universe ages, it is likely to become increasingly hostile to life. Metals and other heavy elements are formed inside stars at the end of their several-billion-year lifetimes and -- depending on the mass of the star -- are released into space as stellar wind or in a supernova explosion: the building material for the next generation of stars. "Each newly forming star therefore has more metal-rich building material available than its predecessors. Stars in the universe are becoming more metal-rich with each generation," says Anna Shapiro. According to the new study, the probability that star systems will produce life thus also decreases as the universe ages. However, the search for life is not hopeless. After all, many host stars of exoplanets have a similar age as the Sun. And this star is indeed known to harbour complex and interesting lifeforms on at least one of its planets.

- Exoplanet discoveries inform new model that could explain the origin of some of Earth's signature features, such as its abundance of water

Date: April 12, 2023
Source: Carnegie Institution for Science

Our planet's water could have originated from interactions between the hydrogen-rich atmospheres and magma oceans of the planetary embryos that comprised Earth's formative years, according to new work from Carnegie Science's Anat Shahar and UCLA's Edward Young and Hilke Schlichting. Their findings, which could explain the origins of Earth's signature features, are published in *Nature*.

For decades, what researchers knew about planet formation was based primarily on our own Solar System. Although there are some active debates about the formation of gas giants like Jupiter and Saturn, it is widely agreed upon that Earth and the other rocky planets accreted from the disk of dust and gas that surrounded our Sun in its youth.

As increasingly larger objects crashed into each other, the baby planetesimals that eventually formed Earth grew both larger and hotter, melting into a vast magma ocean due to the heat of collisions and radioactive elements. Over time, as the planet cooled, the densest material sank inward, separating Earth into three distinct layers -- the metallic core, and the rocky, silicate mantle and crust.

However, the explosion of exoplanet research over the past decade informed a new approach to modelling the Earth's embryonic state.

"Exoplanet discoveries have given us a much greater appreciation of how common it is for just-formed planets to be surrounded by atmospheres that are rich in molecular hydrogen, H_2, during their first several million years of growth," Shahar explained. "Eventually these hydrogen envelopes dissipate, but they leave their fingerprints on the young planet's composition."

Using this information, the researchers developed new models for Earth's formation and evolution to see if our home planet's distinct chemical traits could be replicated.

Using a newly developed model, the Carnegie and UCLA researchers were able to demonstrate that early in Earth's existence, interactions between the magma ocean and a molecular hydrogen proto-atmosphere could have given rise to some of Earth's signature features, such as its abundance of water and its overall oxidized state.

The researchers used mathematical modelling to explore the exchange of materials between molecular hydrogen atmospheres and magma oceans by looking at 25 different compounds and 18 different types of reactions -- complex enough to yield valuable data about Earth's possible formative history, but simple enough to interpret fully.

Interactions between the magma ocean and the atmosphere in their simulated baby Earth resulted in the movement of large masses of hydrogen into the metallic core, the oxidation of the mantle, and the production of large quantities of water.

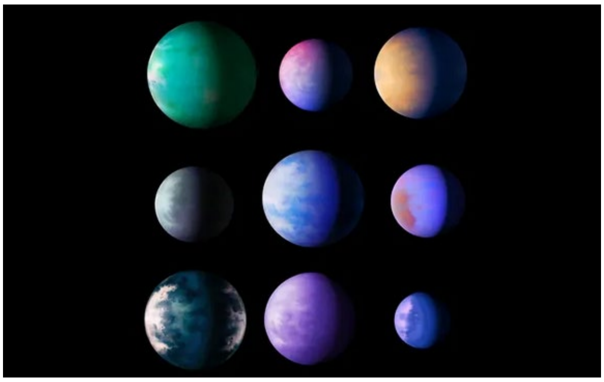
Even if all of the rocky material that collided to form the growing planet was completely dry, these interactions between the molecular hydrogen atmosphere and the magma ocean would generate copious amounts of water, the researchers revealed. Other water sources are possible, they say, but not necessary to explain Earth's current state.

"This is just one possible explanation for our planet's evolution, but one that would establish an important link between Earth's formation history and the most common

exoplanets that have been discovered orbiting distant stars, which are called Super-Earths and sub-Neptune's," Shahar concluded.
This project was part of the interdisciplinary, multi-institution AEThER project, initiated and led by Shahar, which seeks to reveal the chemical makeup of the Milky Way galaxy's most common planets -- Super-Earths and sub-Neptune's -- and to develop a framework for detecting signatures of life on distant worlds. Funded by the Alfred P. Sloan Foundation, this effort was developed to understand how the formation and evolution of these planets shape their atmospheres. This could -- in turn -- enable scientists to differentiate true biosignatures, which could only be produced by the presence of life, from atmospheric molecules of non-biological origin.
"Increasingly powerful telescopes are enabling astronomers to understand the compositions of exoplanet atmospheres in never-before-seen detail," Shahar said. "AEThER's work will inform their observations with experimental and modelling data that, we hope, will lead to a fool proof method for detecting signs of life on other worlds."

- Playing hide and seek with planets

Date: April 14, 2023
Source: National Institutes of Natural Sciences

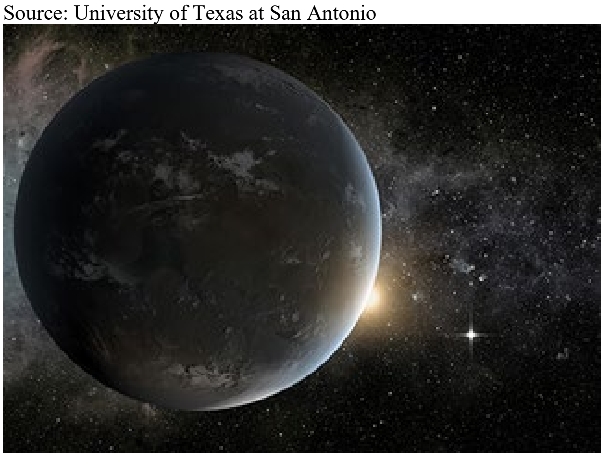


iStock, Nazarii Neshcherenskyi

An international team of astronomers announced the first exoplanet discovered through a combined approach of direct imaging and precision measurements of a star's motion on the sky. This new method promises to improve the efficiency of exoplanet searches, paving the way for the discovery of an Earth twin.
To discover exoplanets, planets which orbit stars other than the Sun, by imaging astronomers have up until now used "blind surveys": stars are selected for imaging consider factors such as age and distance but are otherwise unbiased. However, blind surveys find planets very infrequently. Knowing where to look would help increase detection rates.
An international research team led by Subaru Telescope, the University of Tokyo, the University of Texas-San Antonio, and the Astrobiology Centre of Japan, searched for hints of unknown planets in the data from the European Space Agency's Gaia mission and its predecessor, Hipparcos. The team identified a star, HIP 99770 located 133 light-years away in the constellation Cygnus, whose motion suggests that an unseen planet is gravitationally pulling on it. Direct imaging observations with the Subaru Telescope detected the planet, HIP 99770 b.
The newly discovered planet is 14-16 times more massive than Jupiter. Its orbit is just over 3 times further from its star than Jupiter is from the Sun. The planet is 10 times hotter than Jupiter, with signs of water and carbon monoxide in its atmosphere.
A decade from now, astronomers hope to image a potentially-habitable planet with a size and temperature like the Earth using observatories like the Thirty Meter Telescope (TMT). Compared with HIP 99770 b, this Earth twin will be smaller and closer to its star, traits that will make it harder to detect. But with precise motion measurements, researchers will know where to look in this game of planetary hide and seek.

- New exoplanet discovered

Date: April 13, 2023
Source: University of Texas at San Antonio

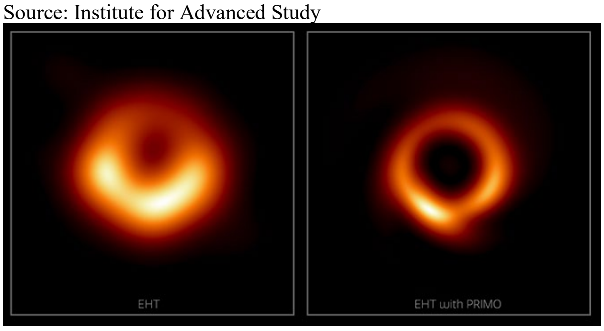


An international research team led by UTSA Associate Professor of Astrophysics Thayne Currie has made a breakthrough in accelerating the search for new planets.
In a paper slated for publication April 14 in *Science*, Currie reports the first exoplanet jointly discovered through direct imaging and precision astrometry, a new indirect method that identifies a planet by measuring the

position of the star it orbits. Data from the Subaru Telescope in Hawai`i and space telescopes from the European Space Agency (ESA) were integral to the team's discovery.
An exoplanet -- also called an extrasolar planet -- is a planet outside a solar system that orbits another star. With direct imaging, astronomers can see an exoplanet's light in a telescope and study its atmosphere. However, only about 20 have been directly imaged over the past 15 years.
By contrast, indirect planet detection methods determine a planet's existence through its effect on the star it orbits. This approach can provide detailed measurements of the planet's mass and orbit.
Combining direct and indirect methods to examine a planet's position provides a more complete understanding of an exoplanet, Current says.
"Indirect planet detection methods are responsible for most exoplanet discoveries thus far. Using one of these methods, precision astrometry, told us where to look to try to image planets. And, as we found out, we can now see planets a lot easier," said Currie.
The newly discovered exoplanet, called HIP 99770 b, is about 14 to 16 times the mass of Jupiter and orbits a star that is nearly twice as massive as the Sun. The planetary system also shares similarities with the outer regions of our solar system. HIP 99770 b receives about as much light as Jupiter, our solar system's most massive planet, receives from the Sun. Its host star is surrounded by icy debris left over from planet formation, similar to our solar system's Kuiper belt, the ring of icy objects observed around the Sun.
Currie and team used the Hipparcos-Gaia Catalogue of Accelerations to advance their discovery of HIP 99770 b. The catalogue consists of data from ESA's Gaia mission and Hipparcos, Gaia's predecessor, providing a 25-year record of accurate star positions and motions. It revealed that the star HIP 99770 is likely being accelerated by the gravitational pull of an unseen planet.
The team then used the Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) instrument, which is permanently installed at the focus of the Subaru Telescope in Hawai`i, to image and confirm the existence of HIP 99770 b.
The discovery of HIP 99770 b is significant, because it opens a new avenue for scientists to discover and characterize exoplanets more comprehensively than ever before, Currie said, shedding light on the diversity and evolution of planetary systems. Using indirect methods to guide efforts to image planets may also someday lead scientists closer to the first images of other Earths.
"This is the first of many discoveries that we expect to have. We are in a new era of studying extrasolar planets," Currie said.

- A sharper look at the M87 black hole

Machine learning reconstructs new image from EHT data
Date: April 13, 2023
Source: Institute for Advanced Study



The original Event Horizon Telescope image of the supermassive black hole at the heart of galaxy M87 (left) was the first to capture the shadow of a black hole’s event horizon. Researchers have reconstructed that image using machine learning to sharpen details (right). Image: L. Medeiros (Institute for Advanced Study), D. Psaltis (Georgia Tech), T. Lauer (NSF’s NOIRLab), and F. Ozel (Georgia Tech)

The iconic image of the supermassive black hole at the centre of M87 -- sometimes referred to as the "fuzzy, orange donut" -- has gotten its first official makeover with the help of machine learning. The new image further exposes a central region that is larger and darker, surrounded by the bright accreting gas shaped like a "skinny donut." The team used the data obtained by the Event Horizon Telescope (EHT) collaboration in 2017 and achieved, for the first time, the full resolution of the array.
In 2017, the EHT collaboration used a network of seven pre-existing telescopes around the world to gather data on M87, creating an "Earth-sized telescope." However, since it is infeasible to cover the Earth's entire surface with telescopes, gaps arise in the data -- like missing pieces in a jigsaw puzzle.
"With our new machine learning technique, PRIMO, we were able to achieve the maximum resolution of the current array," says lead author Lia Medeiros of the Institute for Advanced Study. "Since we cannot study black holes up-close, the detail of an image plays a critical role in our ability to understand its behaviour. The width of the ring in the image is now smaller by about a

factor of two, which will be a powerful constraint for our theoretical models and tests of gravity."

PRIMO, which stands for principal-component interferometric modelling, was developed by EHT members Lia Medeiros (Institute for Advanced Study), Dimitrios Psaltis (Georgia Tech), Tod Lauer (NOIRLab), and Feryal Özel (Georgia Tech). Their publication, "The Image of the M87 Black Hole Reconstructed with PRIMO," is now available in *The Astrophysical Journal Letters.*

"PRIMO is a new approach to the difficult task of constructing images from EHT observations," said Lauer. "It provides a way to compensate for the missing information about the object being observed, which is required to generate the image that would have been seen using a single gigantic radio telescope the size of the Earth."

PRIMO relies on dictionary learning, a branch of machine learning which enables computers to generate rules based on large sets of training material. For example, if a computer is fed a series of different banana images -- with sufficient training -- it may be able to determine if an unknown image is or is not a banana. Beyond this simple case, the versatility of machine learning has been demonstrated in numerous ways: from creating Renaissance-style works of art to completing the unfinished work of Beethoven. So how might machines help scientists to render a black hole image? The research team has answered this very question.

With PRIMO, computers analysed over 30,000 high-fidelity simulated images of black holes accreting gas. The ensemble of simulations covered a wide range of models for how the black hole accretes matter, looking for common patterns in the structure of the images. The various patterns of structure were sorted by how commonly they occurred in the simulations, and were then blended to provide a highly accurate representation of the EHT observations, simultaneously providing a high fidelity estimate of the missing structure of the images. A paper pertaining to the algorithm itself was published in *The Astrophysical Journal* on February 3, 2023.

"We are using physics to fill in regions of missing data in a way that has never been done before by using machine learning," added Medeiros. "This could have important implications for interferometry, which plays a role in fields from exo-planets to medicine."

The team confirmed that the newly rendered image is consistent with the EHT data and with theoretical expectations, including the bright ring of emission expected to be produced by hot gas falling into the black hole. Generating an image required assuming an appropriate form of the missing information, and PRIMO did this by building on the 2019 discovery that the M87 black hole in broad detail looked as predicted.

"Approximately four years after the first horizon-scale image of a black hole was unveiled by EHT in 2019, we have marked another milestone, producing an image that utilizes the full resolution of the array for the first time," stated Psaltis. "The new machine learning techniques that we have developed provide a golden opportunity for our collective work to understand black hole physics."

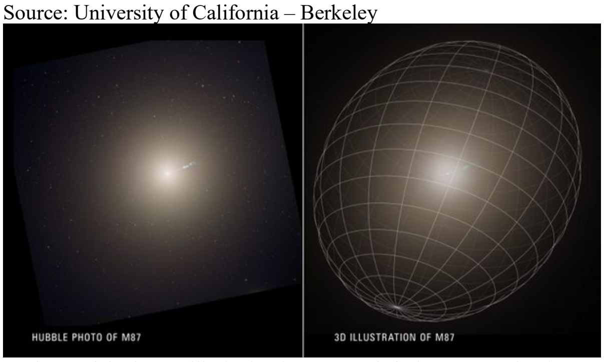
The new image should lead to more accurate determinations of the mass of the M87 black hole and the physical parameters that determine its present appearance. The data also provides an opportunity for researchers to place greater constraints on alternatives to the event horizon (based on the darker central brightness depression) and perform more robust tests of gravity (based on the narrower ring size). PRIMO can also be applied to additional EHT observations, including those of Sgr A*, the central black hole in our own Milky Way galaxy.

M87 is a massive, relatively nearby, galaxy in the Virgo cluster of galaxies. Over a century ago, a mysterious jet of hot plasma was observed to emanate from its centre. Beginning in the 1950s, the then new technique of radio astronomy showed the galaxy to have a compact bright radio source at its centre. During the 1960s, M87 had been suspected to have a massive black hole at its centre powering this activity. Measurements made from ground-based telescopes starting in the 1970s, and later the Hubble Space Telescope starting in the 1990s, provided strong support that M87 indeed harboured a black hole weighing several billion times the mass of the Sun based on observations of the high velocities of stars and gas orbiting its centre. The 2017 EHT observations of M87 were obtained over several days from several different radio telescopes linked together at the same time to obtain the highest possible

resolution. The now iconic "orange donut" picture of the M87 black hole, released in 2019, reflected the first attempt to produce an image from these observations.
"The 2019 image was just the beginning," stated Medeiros. "If a picture is worth a thousand words, the data underlying that image have many more stories to tell. PRIMO will continue to be a critical tool in extracting such insights."
Development of the PRIMO algorithm was enabled through the support of the National Science Foundation Astronomy and Astrophysics Postdoctoral Fellowship.

- M87 in 3D: New view of galaxy helps pin down mass of the black hole at its core

Mapping stellar velocities around giant elliptical galaxy reveals its asymmetric structure
Date: April 13, 2023
Source: University of California – Berkeley



A photo of the huge elliptical galaxy M87 [left] is compared to its three-dimensional shape as gleaned from meticulous observations made with the Hubble and Keck telescopes [right]. Because the galaxy is too far away for astronomers to employ stereoscopic vision, they instead followed the motion of stars around the centre of M87, like bees around a hive. This created a three-dimensional view of how stars are distributed within the galaxy. Credit: NASA, ESA, Joseph Olmsted (STScI), Frank Summers (STScI), Chung-Pei Ma (UC Berkeley)

Seen from Earth, the giant elliptical galaxy M87 is just a two-dimensional blob, though one that appears perfectly symmetrical and thus a favoured target of amateur astronomers.

Yet, a new, highly detailed analysis of the motion of stars around its central supermassive black hole — the first black hole to be imaged by the Event Horizon Telescope (EHT) in 2019 — reveals that it's not as perfect as it looks.

In fact, M87 is highly asymmetrical, like a russet potato. The galaxy's shortest axis is about three-fourths (72.2%) the length of its long axis, while the intermediate axis is about seven-eighths (84.5%) that of the long axis.

Knowing this, University of California, Berkeley, astronomers were able to determine the mass of the supermassive black hole at the galaxy's core to a high precision, estimating it at 5.37 billion times the mass of the sun. By comparison, our own Milky Way has at its centre a massive black hole only 4 million times the mass of the sun.

They also were able to measure the rotation of the galaxy, which is a relatively sedate 25 kilometres per second. Interestingly, it is not rotating around any of the galaxy's major axes, but instead about an axis that is 40 degrees away from the long axis of its 2D image as observed by the Hubble Space Telescope.

The stereo reconstruction of the M87 galaxy and the more precise figure for the mass of the central black hole could help astrophysicists learn about a characteristic of the black hole they've had no way to determine before for any black hole: its spin.

"Now that we know the direction of the net rotation of stars in M87 and have an updated mass of the black hole, we can combine this information with the amazing data from the EHT team to constrain the spin," said Chung-Pei Ma, a UC Berkeley professor of astronomy and of physics who led the research. "This may point toward a certain direction and range of spin for the black hole, which would be remarkable. We are working on this."

Further analyses to determine the true shape of giant elliptical galaxies — the galaxies with the largest black holes at their cores — will help astronomers understand better how large galaxies and large black holes form and could help astronomers better interpret gravitational wave signals. Ma leads a long-term study of supermassive black holes that is dubbed MASSIVE.

The results were published online March 15 in *The Astrophysical Journal Letters* (*ApJ Letters*).

Determining a galaxy's 3D shape

While spiral galaxies tend to be small, rotate quickly and have a well-recognized pancake shape, giant elliptical galaxies rotate slowly and have a blobby appearance, their 3D shape difficult to discern. Like M87, the largest galaxy in the massive Virgo Cluster of galaxies, giant elliptical galaxies have grown from the merger of many other galaxies. That's likely the reason M87's central black hole is so large — it assimilated the central black holes of all the galaxies it swallowed. In all, the galaxy contains about 100 billion stars, 10 times larger than the Milky Way.

Ma, UC Berkeley graduate student and lead author Emily Liepold, and Jonelle Walsh at Texas A&M University in College Station were able to determine the 3D shape of M87 thanks to a relatively new precision instrument mounted on the Keck II Telescope, one of the twin 10-meter Keck telescopes atop Mauna Kea, a volcano in Hawai'i. Called the Keck Cosmic Web Imager (KCWI), the integral field spectrometer allowed Ma and her team to measure the spectra of stars in the centre of the galaxy.

They pointed the telescope at 62 adjacent locations in the galaxy, completely covering a region about 70,000 light-years across, and recorded the spectra of stars within that region. The observations span the central region — about 3,000 light-years across — where gravity is largely dominated by the supermassive black hole, as well as the outer part dominated by dark matter. Though the telescope cannot resolve individual stars — M87 lies about 53 million light- years from Earth — the spectra can reveal the range of velocities within each pixel of each image, enough information to calculate the gravitational mass they're orbiting.

"It's sort of like looking at a swarm of 100 billion bees that are going around in their own happy orbits," said Ma, the Judy Chandler Webb Professor in the Physical Sciences. "Though we are looking at them from a distance and can't discern individual bees, we are getting very detailed information about their collective velocities. It's really the superb sensitivity of this spectrograph that allowed us to map out M87 so comprehensively."

This is the first time KCWI has been used to reconstruct the geometry of a distant galaxy, and M87 is one of only a handful of giant elliptical galaxies whose 3D structure has been determined. Ma's team had previously determined the 3D structure of two other giant elliptical galaxies, NGC 1453 and NGC 2693, both harbouring smaller black holes than M87.

The researchers took the data obtained during four nights of Keck observations between 2020 and 2022, along with earlier photometric data for M87 from NASA's Hubble Space Telescope, and compared them to computer model predictions of how stars move around the centre of a triaxial galaxy. The best fit to the data — axial ratios of 1 to 0.84 to 0.72 — then allowed them to calculate the black hole mass.

"The Keck data are so good that we can measure the intrinsic shape of M87 along with the black hole at the same time," Ma said. "We made the first measurement of the actual 3D shape of the galaxy. And since we allowed the swarm of bees to have a more general shape than just a sphere or disk, we have a more robust dynamical measurement of the mass of the central black hole that is governing the bees' orbiting velocities."

The authors dedicated their manuscript to the late astronomer Wallace "Wal" Sargent, who first suggested that a supermassive black hole lurked at the centre of M87 and calculated its mass to be about 5 billion solar masses.

"His number is a twiddle with our error bars, which is very interesting to see after decades of work," said Ma, who credits Sargent with being a mentor when she was a postdoctoral fellow at the California Institute of Technology.

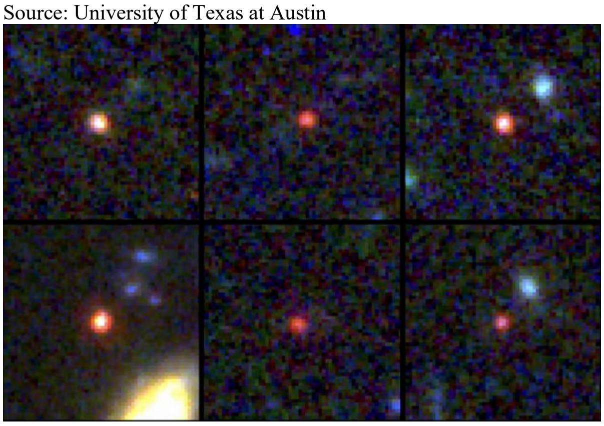
The previous estimate of the mass of the supermassive black hole in M87, published in 2011, was based on a similar analysis of the dynamical movement of stars around the black hole, though that study assumed the galaxy was axisymmetric. The number, 6.14 billion solar masses, is within error bars of the new, more precise estimate. When imaging the black hole four years ago, the EHT scientists estimated the black hole mass to be 6.5 billion solar masses, 21% higher than the new number.

Interestingly, the dark matter within the volume of the galaxy they analysed is much higher than that of the black hole — about 388 billion solar masses, or 67% of the entire mass of M87. Though the identity of dark matter is still a mystery, it makes up about 85% of the mass of the universe.

Jonelle Walsh is with the George P. and Cynthia Woods Mitchell Institute for Fundamental Physics and Astronomy at Texas A&M. The work was funded by the National Science Foundation (AST-1817100, AST-2206307), the Heising-Simons Foundation and the Miller Institute for Basic Research in Science.

- James Webb Space Telescope images challenge theories of how universe evolved

Date: April 13, 2023
Source: University of Texas at Austin



Images of six massive galaxy candidates, seen 500-800 million years after the Big Bang. Image credit: I. Labbe/NASA/ESA/CSA.

The James Webb Space Telescope (JWST) appears to be finding multiple galaxies that grew too massive too soon after the Big Bang, if the standard model of cosmology is to be believed.

In a study published in *Nature Astronomy*, Mike Boylan-Kolchin, an associate professor of astronomy at The University of Texas at Austin, finds that six of the earliest and most massive galaxy candidates observed by JWST so far stand to contradict the prevailing thinking in cosmology. That's because other researchers estimate that each galaxy is seen from between 500 and 700 million years after the Big Bang, yet measures more than 10 billion times as massive as our sun. One of the galaxies even appears to be more massive than the Milky Way, despite that our own galaxy had billions of more years to form and grow.

"If the masses are right, then we are in uncharted territory," Boylan-Kolchin said. "We'll require something very new about galaxy formation or a modification to cosmology. One of the most extreme possibilities is that the universe was expanding faster shortly after the Big Bang than we predict, which might require new forces and particles."

For galaxies to form so fast at such a size, they also would need to be converting nearly 100% of their available gas into stars.

"We typically see a maximum of 10% of gas converted into stars," Boylan-Kolchin said. "So, while 100% conversion of gas into stars is technically right at the edge of what is theoretically possible, it's really the case that this would require something to be very different from what we expect."

For all of the breathless excitement it evokes, JWST has presented astronomers with an unsettling dilemma. If the masses and time since the Big Bang are confirmed for these galaxies, fundamental changes to the reigning model of cosmology -- what's called the dark energy + cold dark matter (ΛCDM) paradigm, which has guided cosmology since the late 1990s -- could be needed. If there are other, faster ways to form galaxies than ΛCDM allows, or if more matter actually was available for forming stars and galaxies in the early universe than was previously understood, astronomers would need to shift their prevailing thinking.

The six galaxies' times and masses are initial estimates and will need follow-up confirmation with spectroscopy -- a method that splits the light into a spectrum and analyses the brightness of different colours. Such analysis might suggest that central supermassive black holes, which could heat up the surrounding gas, may be making the galaxies brighter so that they look more massive than they really are. Or perhaps the galaxies are actually seen at a time much later than originally estimated due to dust that causes the colour of the light from the galaxy to shift redder, giving the illusion of being more lightyears away and, thus, further back in time.

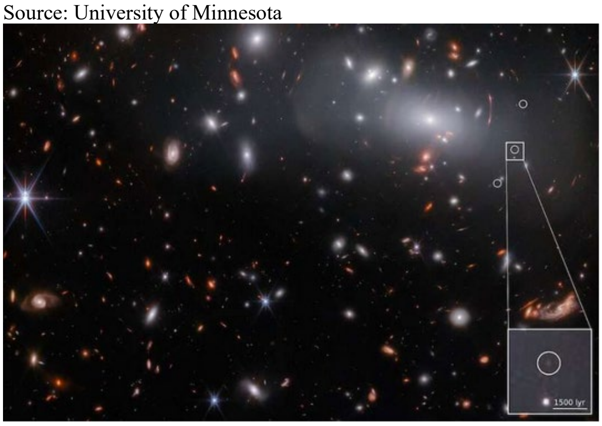
The galaxy data came from the Cosmic Evolution Early Release Science Survey (CEERS), a multi-institution JWST initiative led by UT Austin astronomer Steven Finkelstein.

Another ongoing collaborative JWST project, COSMOS-Web, co-led by UT Austin's Caitlin Casey, may be involved with spectroscopy and shedding more light on the findings to help resolve the dilemma. COSMOS-Web is covering an area roughly 50 times larger than CEERS and is expected to discover thousands of galaxies.

"It will be ideal for discovering the rarest, most massive galaxies at early times, which will tell us how the biggest galaxies and black holes in the early universe arose so quickly," Boylan-Kolchin said.
The initial discovery and estimates of the six galaxy candidates' masses and redshifts were published in *Nature* in February by a team led by Swinburne University of Technology in Australia.
This research is supported by the National Science Foundation and NASA.

- Researchers discover tiny galaxy with big star power using James Webb telescope

Galaxy is the smallest ever discovered at this distance -- around 500 million years after the Big Bang
Date: April 13, 2023
Source: University of Minnesota



A University of Minnesota Twin Cities-led team looked more than 13 billion years into the past to discover a unique, minuscule galaxy that could help astronomers learn more about galaxies that were present shortly after the Big Bang. Credit: ESA/Webb, NASA & CSA, P. Kelly

Using first-of-their-kind observations from the James Webb Space Telescope, a University of Minnesota Twin Cities-led team looked more than 13 billion years into the past to discover a unique, minuscule galaxy that generated new stars at an extremely high rate for its size. The galaxy is one of the smallest ever discovered at this distance—around 500 million years after the Big Bang—and could help astronomers learn more about galaxies that were present shortly after the Universe came into existence.
The paper is published in *Science*, one of the world's top peer-reviewed academic journals. The University of Minnesota researchers were one of the first teams to study a distant galaxy using the James Webb Space Telescope, and their findings will be among the first ever published.
“This galaxy is far beyond the reach of all telescopes except the James Webb, and these first-of-their-kind observations of the distant galaxy are spectacular,” said Patrick Kelly, senior author of the paper and an assistant professor in the University of Minnesota School of Physics and Astronomy. “Here, we’re able to see most of the way back to the Big Bang, and we've never looked at galaxies when the universe was this young in this level of detail. The galaxy’s volume is roughly a millionth of the Milky Way’s, but we can see that it’s still forming the same numbers of stars each year.”
The James Webb telescope can observe a wide enough field to image an entire galaxy cluster at once. The researchers were able to find and study this new, tiny galaxy because of a phenomenon called gravitational lensing—where mass, such as that in a galaxy or galaxy cluster, bends and magnifies light. A galaxy cluster lens caused this small background galaxy to appear 20 times brighter than it would if the cluster were not magnifying its light.
The researchers then used spectroscopy to measure how far away the galaxy was, in addition to some of its physical and chemical properties. Studying galaxies that were present when the Universe was this much younger can help scientists get closer to answering a huge question in astronomy regarding how the Universe became re-ionized.
“The galaxies that existed when the Universe was in its infancy are very different from what we see in the nearby Universe now,” explained Hayley Williams, first author on the paper and a Ph.D. student at the Minnesota Institute for Astrophysics. “This discovery can help us learn more about the characteristics of those first galaxies, how they differ from nearby galaxies, and how the earlier galaxies formed.”
The James Webb telescope can collect about 10 times as much light as the Hubble Space Telescope and is much more sensitive at redder, longer wavelengths in the infrared spectrum. This allows scientists to access an entirely new window of data, the researchers said.
“The James Webb Space Telescope has this amazing capability to see extremely far into the universe,” Williams said. “This is one of the most exciting things about this paper. We're seeing things that previous telescopes would have ever been able to capture. It’s

basically getting a snapshot of our universe in the first 500 million years of its life."

The research was supported by the National Science Foundation and NASA through the Space Telescope Science Institute, with additional funding from the United States-Israel Binational Science Foundation and the Spanish State Research Agency.

In addition to Williams and Kelly, the research team included University of Minnesota School of Physics and Astronomy postdoctoral researcher Wenlei Chen, Professor Claudia Scarlata, Ph.D. student Yu-Heng Lin, and graduate student Noah Rogers; University of Copenhagen researchers Gabriel Brammer, Jens Hjorth, and Danial Langeroodi; Ben-Gurion University of the Negev Associate Professor Adi Zitrin; University of California Los Angeles faculty member Tomasso Treu; Space Telescope Science Institute researchers Anton Koekemoer, Lou Strolger, and Justin Pierel; Chiba University faculty member Masamune Oguri; University of Cantebria researcher Jose Diego; Astronomical Observatory of Trieste researcher Mario Nonino; University of the Basque Country Professor Tom Broadhurst; University of La Laguna researchers Ismael Perez-Fournon and Frederick Poidevin; University of California Santa Cruz Assistant Professor Ryan Foley; Rutgers University Professor Saurabh Jha; University of California Berkeley Professor Alexei Filippenko; and University of Tokyo postdoctoral researcher Lilan Yang.

- Humans need Earth-like ecosystem for deep-space living

Date: April 12, 2023
Source: Cornell University

Even on future cosmic outposts like Mars, depicted in this artistic rendering, humans must consider closely replicating natural conditions found on Earth, according to a new theory called Pancosmorio.

Can humans endure long-term living in deep space? The answer is a lukewarm maybe, according to a new theory describing the complexity of maintaining gravity and oxygen, obtaining water, developing agriculture and handling waste far from Earth.

Dubbed the Pancosmorio theory -- a word coined to mean "all world limit" -- it was described in a paper published in Frontiers in Astronomy and Space Sciences.

"For humans to sustain themselves and all of their technology, infrastructure and society in space, they need a self-restoring, Earth-like, natural ecosystem to back them up," said co-author Morgan Irons, a doctoral student conducting research with Johannes Lehmann, professor in the School of Integrative Plant Science at Cornell University. Her work focuses on soil organic carbon persistence under Earth's gravity and varying gravity conditions. "Without these kinds of systems, the mission fails."

The first key is gravity, which Earth life needs to function properly, said co-author Lee Irons, Morgan Irons' father and executive director of the Norfolk Institute, a group that aims to solve problems of human resilience on Earth and in space.

"Gravity induces a gradient in the fluid pressure within the body of the living thing to which the autonomic functions of the life form are attuned," he said. "An example of gravity imbalance would be the negative affect on the eyesight of humans in Earth orbit, where they don't experience the weight necessary to induce the pressure gradient."

Morgan Irons said that it would be unwise to spend billions of dollars to set up a space settlement only to see it fail, because even with all other systems in place, you need gravity.

Humans and all Earth life have evolved within the context of 1G of gravity. "Our bodies, our natural ecosystems, all the energy movement and the way we utilize energy is all fundamentally based upon 1G of gravity being present," she said. "There is just no other place in space where there is 1G of gravity; that just doesn't exist anywhere else in our solar system. That's one of the first problems we must solve."

Oxygen is another key factor. Earth's ecosystem generates oxygen for humans and other life forms. If a technologically advanced primary and a back-up system failed to provide oxygen for the moon base, for example, it would mean instant doom for the astronauts. "A reserve exists everywhere in Earth's nature," Lee Irons said. "Think of the hundreds of thousands of species of plants that generate oxygen. That's the kind of system reserve we need to replicate to be truly sustainable."

Such an ecological system of an outpost would need an enormous amount energy from the sun. The more distant planets and moons from the sun in our own solar system get decreased amounts of energy.

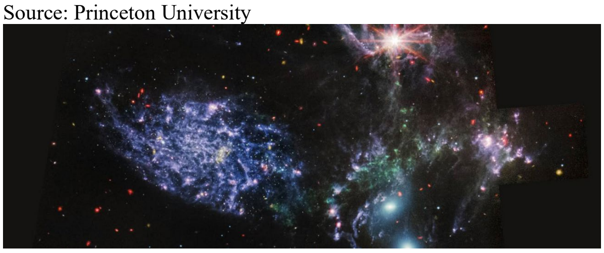
"You'll need a lot of energy," Lee Irons said. "Otherwise powering the ecological system of an outpost will be like trying to run your car on a cell phone battery or probably even worse, trying to run your entire house and household on a cell phone battery."

- ❖ New findings that map the universe's cosmic growth support Einstein's theory of gravity

Significant breakthrough in understanding the evolution of the universe

Date: April 11, 2023

Source: Princeton University



For millennia, humans have been fascinated by the mysteries of the cosmos.

Unlike ancient philosophers imagining the universe's origins, modern cosmologists use quantitative tools to gain insights into the universe's evolution and structure. Modern cosmology dates back to the early 20th century, with the development of Albert Einstein's theory of general relativity.

Now, researchers from the Atacama Cosmology Telescope (ACT) collaboration have created a ground-breaking new image that reveals the most detailed map of dark matter distributed across a quarter of the entire sky, extending deep into the cosmos. What's more, it confirms Einstein's theory of how massive structures grow and bend light, over the entire 14-billion-year life span of the universe.

"We have mapped the invisible dark matter across the sky to the largest distances, and clearly see features of this invisible world that are hundreds of millions of light-years across, says Blake Sherwin, professor of cosmology at the University of Cambridge, where he leads a group of ACT researchers. "It looks just as our theories predict."

Despite making up 85% of the universe and influencing its evolution, dark matter has been hard to detect because it doesn't interact with light or other forms of electromagnetic radiation. As far as we know dark matter only interacts with gravity.

To track it down, the more than 160 collaborators who have built and gathered data from the National Science Foundation's Atacama Cosmology Telescope in the high Chilean Andes observe light emanating following the dawn of the universe's formation, the Big Bang -- when the universe was only 380,000 years old. Cosmologists often refer to this diffuse light that fills our entire universe as the "baby picture of the universe," but formally, it is known as the cosmic microwave background radiation (CMB).

The team tracks how the gravitational pull of large, heavy structures including dark matter warps the CMB on its 14-billion-year journey to us, like how a magnifying glass bends light as it passes through its lens.

"We've made a new mass map using distortions of light left over from the Big Bang," says Mathew Madhavacheril, assistant professor in the Department of Physics and Astronomy at the University of Pennsylvania. "Remarkably, it provides measurements that show that both the 'lumpiness' of the universe, and the rate at which it is growing after 14 billion years of evolution, are just what you'd expect from our standard model of cosmology based on Einstein's theory of gravity."

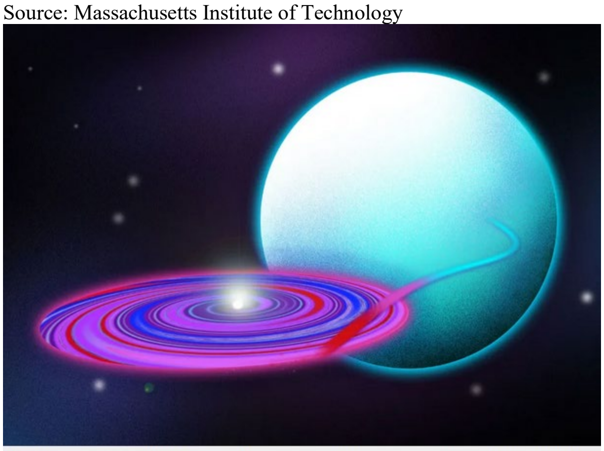
Sherwin adds, "our results also provide new insights into an ongoing debate some have called 'The Crisis in Cosmology,' "explaining that this crisis stems from recent measurements that use a different background light, one emitted from stars in galaxies rather than the CMB. These have produced results that suggest the dark matter was not lumpy enough under the standard model of cosmology and led to concerns that the model may be broken. However, the team's latest results from ACT were able to precisely assess that the vast lumps seen in this image are the exact right size.

"When I first saw them, our measurements were in such good agreement with the underlying theory that it took me a moment to process the results," says Cambridge Ph.D. student Frank Qu, part of the research team. "It will be interesting to see how this possible discrepancy between different measurements will be resolved."

"The CMB lensing data rivals more conventional surveys of the visible light from galaxies in their ability to trace the sum of what is out there," says Suzanne Staggs, director of ACT and Henry DeWolf Smyth Professor of Physics at Princeton University. "Together, the CMB lensing and the best optical surveys are clarifying the evolution of all the mass in the universe."
"When we proposed this experiment in 2003, we had no idea the full extent of information that could be extracted from our telescope," says Mark Devlin, the Reese Flower Professor of Astronomy at the University of Pennsylvania and the deputy director of ACT. "We owe this to the cleverness of the theorists, the many people who built new instruments to make our telescope more sensitive, and the new analysis techniques our team came up with."
ACT, which operated for 15 years, was decommissioned in September 2022. Nevertheless, more papers presenting results from the final set of observations are expected to be submitted soon, and the Simons Observatory will conduct future observations at the same site, with a new telescope slated to begin operations in 2024. This new instrument will be capable of mapping the sky almost 10 times faster than ACT.

- Scientists map gusty winds in a far-off neutron star system

The 2D map of this 'disk wind' may reveal clues to galaxy formation.
Date: April 10, 2023
Source: Massachusetts Institute of Technology



MIT astronomers mapped the "disk winds" associated with the accretion disk around Hercules X-1, a system in which a neutron star is drawing material away from a sun-like star, represented as the teal sphere. Credit: Jose-Luis Olivares, MIT. Based on an image of Hercules X-1 by D. Klochkov, European Space Agency.

An accretion disk is a colossal whirlpool of gas and dust that gathers around a black hole or a neutron star like cotton candy as it pulls in material from a nearby star. As the disk spins, it whips up powerful winds that push and pull on the sprawling, rotating plasma. These massive outflows can affect the surroundings of black holes by heating and blowing away the gas and dust around them. At immense scales, "disk winds" can offer clues to how supermassive black holes shape entire galaxies. Astronomers have observed signs of disk winds in many systems, including accreting black holes and neutron stars. But to date, they've only ever glimpsed a very narrow view of this phenomenon.
Now, MIT astronomers have observed a wider swath of winds, in Hercules X-1, a system in which a neutron star is drawing material away from a sun-like star. This neutron star's accretion disk is unique in that it wobbles, or "processes," as it rotates. By taking advantage of this wobble, the astronomers have captured varying perspectives of the rotating disk and created a two-dimensional map of its winds, for the first time.
The new map reveals the wind's vertical shape and structure, as well as its velocity -- around hundreds of kilometres per second, or about a million miles per hour, which is on the milder end of what accretion disks can spin up.
If astronomers can spot more wobbling systems in the future, the team's mapping technique could help determine how disk winds influence the formation and evolution of stellar systems, and even entire galaxies.
"In the future, we could map disk winds in a range of objects and determine how wind properties change, for instance, with the mass of a black hole, or with how much material it is accreting," says Peter Kosec, a postdoc in MIT's Kavli Institute for Astrophysics and Space Research. "That will help determine how black holes and neutron stars influence our universe."
Kosec is the lead author of a study appearing in *Nature Astronomy*. His MIT co-authors include Erin Kara, Daniele Rogantini, and Claude Canizares, along with collaborators from multiple institutions, including the Institute of Astronomy in Cambridge, U.K.

Fixed sight

Disk winds have most often been observed in X-ray binaries -- systems in which a black hole or a neutron star is pulling material from a less dense object and generating a white-hot disk of inspiraling matter, along with outflowing wind. Exactly how winds are launched from these systems is unclear. Some theories propose that magnetic fields could shred the disk and expel some of the material outward as wind. Others posit that the neutron

star's radiation could heat and evaporate the disk's surface in white-hot gusts.
Clues to a wind's origins may be deduced from its structure, but the shape and extent of disk winds has been difficult to resolve. Most binaries produce accretion disks that are relatively even in shape, like thin donuts of gas that spins in a single plane. Astronomers who study these disks from far-off satellites or telescopes can only observe the effects of disk winds within a fixed and narrow range, relative to their rotating disk. Any wind that astronomers manage to detect is therefore a small sliver of its larger structure.
"We can only probe the wind properties at a single point, and we're completely blind to everything around that point," Kosec notes.
In 2020, he and his colleagues realized that one binary system could offer a wider view of disk winds. Hercules X-1 has stood out from most known X-ray binaries for its warped accretion disk, which wobbles as it rotates around the system's central neutron star.
"The disk is really wobbling over time every 35 days, and the winds are originating somewhere in the disk and crossing our line of sight at different heights above the disk with time," Kosec explains. "That's a very unique property of this system which allows us to better understand its vertical wind properties."

A warped wobble

In the new study, the researchers observed Hercules X-1 using two X-ray telescopes -- the European Space Agency's XMM Newton and NASA's Chandra Observatory.
"What we measure is an X-ray spectrum, which means the amount of X-ray photons that arrive at our detectors, versus their energy. We measure the absorption lines, or the lack of X-ray light at very specific energies," Kosec says. "From the ratio of how strong the different lines are, we can determine the temperature, velocity, and the amount of plasma within the disk wind."
With Hercules X-1's warped disk, astronomers were able to see the line of the disk moving up and down as it wobbled and rotated, similar to the way a warped record appears to oscillate when seen from edge-on. The effect was such that the researchers could observe signs of disk winds at changing heights with respect to the disk, rather than at a single, fixed height above a uniformly rotating disk.
By measuring X-ray emissions and the absorption lines as the disk wobbled and rotated over time, the researchers could scan properties such as the temperature and density of winds at various heights with respect to its disk and construct a two-dimensional map of the wind's vertical structure.
"What we see is that the wind rises from the disk, at an angle of about 12 degrees with respect to the disk as it expands in space," Kosec says. "It's also getting colder and clumpier, and weaker at greater heights above the disk."
The team plans to compare their observations with theoretical simulations of various wind-launching mechanisms, to see which could best explain the wind's origins. Further out, they hope to discover more warped and wobbling systems, and map their disk wind structures. Then, scientists could have a broader view of disk winds, and how such outflows influence their surroundings -- particularly at much larger scales.
"How do supermassive black holes affect the shape and structure of galaxies?" poses Erin Kara, the Class of 1958 Career Development Assistant Professor of Physics at MIT. "One of the leading hypotheses is that disk winds, launched from a black hole, can affect how galaxies look. Now we can get a more detailed picture of how these winds are launched, and what they look like."
This research was supported in part by NASA.

- ❖ Navigating the cosmos with CHARA Array

Date: April 10, 2023
Source: Georgia State University

Plans are underway to add a seventh movable telescope to Georgia State University's Centre for High Angular Resolution Astronomy -- known as the CHARA Array -- that would increase the resolution, or the ability to see small objects, by a factor of three.
Located at Mount Wilson Observatory in Southern California and operated by Georgia State, the new telescope will be connected using fibre optics to transport the starlight, a technique that will serve as a pathfinder for future expansion of the Array. The update comes after a group of international scientists gathered in Atlanta to take part in the 2023 CHARA Science Meeting to share the latest developments in high-resolution astronomical imaging using the CHARA Array.

"Adding a seventh moveable telescope to the Array represents a great leap forward in stellar astronomy," says Doug Gies, Regents' Professor of Physics and Astronomy and director of the centre. "Collaboration is truly fundamental for an undertaking like the CHARA Array. With scientists all over the world using our telescopes, this annual gathering is an important forum for us to share our latest discoveries."

The CHARA Array combines the light from six optical telescopes spread across the mountaintop to image stars with a spatial resolution equivalent to a single telescope 331 meters (over 1000 ft) in diameter. The visible and infrared observatory offers astronomers the opportunity to capture images of space with better resolution than any other telescope in the world.

More than 40 members of the CHARA Consortium, which represents 10 institutions around the world, took part in the annual review of the latest scientific and technical progress.

Scientists gathered at Georgia State University in March 2023 for the CHARA Science Meeting and Imaging Workshop. CHARA features a new suite of instruments built by partner institutions at the University of Michigan, University of Exeter, and Observatoire de la Côte d'Azur in France. This next generation of instrumentation provides unprecedented capabilities to image the surfaces of stars and their circumstellar environments at a variety of different wavelengths from the near-infrared to the visible part of the spectrum. Georgia State University is also building a new instrument that will increase the sensitivity of the CHARA Array to measure light 30 times fainter than possible now. This improvement will help astronomers probe the gas clouds swirling around supermassive black holes in very distant active galaxies.

With funding from the National Science Foundation (NSF), CHARA has expanded its user base over the last six years by offering open access time to the global community of astronomers through a competitive proposal process offered through the National Optical-Infrared Astronomy Research Laboratory. In addition to over 60 active observers at Georgia State University and partner institutions, the open-access program has received applications from over 350 visiting astronomers around the world.

"Expanding the user community brings new opportunities for innovative science projects that broaden the impact and productivity of the CHARA Array," says Gail Schaefer, Director of the CHARA Array.

At the recent meeting, members presented some science highlights and findings from the CHARA Array.

- Georgia State graduate student Katherine Shepard presented results on a sample of evolved massive binary star systems surrounded by outflowing disks. The disks in these fascinating systems form as one star in the system grows in size as it evolves and material from that star is transferred to the companion. Some of the mass escapes into a disk that surrounds the system. Katherine is using the CHARA Array to resolve the structure of these disks and search for interactions between the disk and the inner binary system.
- Noura Ibrahim, a graduate student from the University of Michigan, imaged the ring-like structure of a circumstellar disk around the young star V1295 Aquila. Two images taken one month apart show a bright spot in the ring that rotates between the two epochs. This variation could be caused by a stellar companion, an exoplanet in formation, or asymmetries in the density distribution.
- Visiting astronomer Willie Torres at the Harvard-Smithsonian Centre for Astrophysics mapped the orbits in the Castor multiple star system. The system consists of Castor A and B that revolve around each other every 450 years, and each component in turn are short-period binary systems with periods of a few days. They are joined by a more distant component Castor C, which is also a binary. Torres used the CHARA Array to resolve the close, faint companions in Castor A and B for the first time. He combined these observations with historical observations spanning the past three centuries to map the orbits of the stars in the Castor system and measure their stellar masses with a precision better than 1%. The CHARA observations were also used to measure the radii of

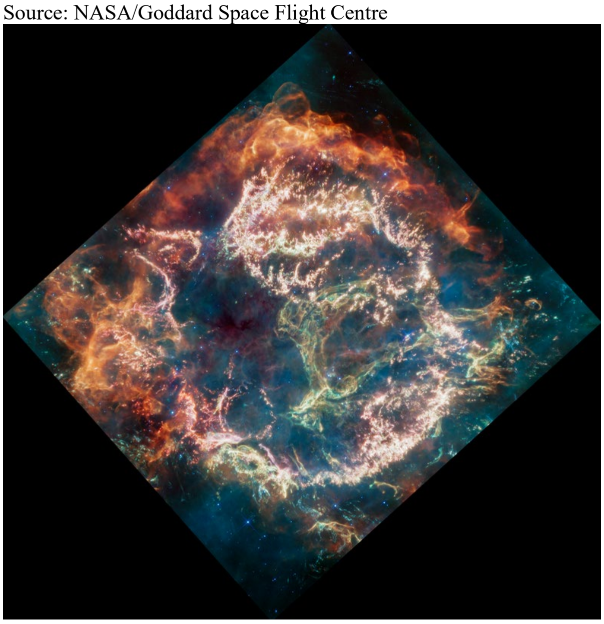
the two brightest stars to infer an age for the system of 290 million years.

- Rachael Roettenbacher, a Postdoctoral Associate from the University of Michigan, presented recent work on mapping star spots over a rotation cycle for the sun-like star Epsilon Eridani, which is orbited by an exoplanet. The star spot images, in combination with data from other telescopes, were used to develop a technique to distinguish between small changes in the stellar spectrum caused by star spots and those caused the orbiting planet. These techniques will improve the detection of planets around other stars.

The annual meeting was followed by a workshop on imaging and modelling of interferometric observations. Participants were given an overview of modelling and imaging software packages available to analyse data from stellar interferometers (arrays of telescopes that combine light together), and the workshop included interactive hands-on sessions where participants used the software tools to analyse data. Participants also brought their own data for review in order to get the most from observations made with the CHARA Array.

- ❖ Webb reveals never-before-seen details in Cassiopeia A

Date: April 7, 2023
Source: NASA/Goddard Space Flight Centre



Cassiopeia A (Cas A) is a supernova remnant located about 11,000 light-years from Earth in the constellation Cassiopeia. It spans approximately 10 light-years. This new image uses data from Webb’s Mid-Infrared Instrument (MIRI) to reveal Cas A in a new light. Credits: NASA, ESA, CSA, D. Milisavljevic (Purdue), T. Temim (Princeton), I. De Looze (Ghent University). Image Processing: J. DePasquale (STScI).
[Download the full-resolution version from the Space Telescope Science Institute.]

The explosion of a star is a dramatic event, but the remains the star leaves behind can be even more dramatic. A new mid-infrared image from NASA's James Webb Space Telescope provides one stunning example. It shows the supernova remnant Cassiopeia A (Cas A), created by a stellar explosion seen from Earth 340 years ago. Cas A is the youngest known remnant from an exploding, massive star in our galaxy, which makes it a unique opportunity to learn more about how such supernovae occur.

"Cas A represents our best opportunity to look at the debris field of an exploded star and run a kind of stellar autopsy to understand what type of star was there beforehand and how that star exploded," said Danny Milisavljevic of Purdue University in West Lafayette, Indiana, principal investigator of the Webb program that captured these observations.

"Compared to previous infrared images, we see incredible detail that we haven't been able to access before," added Tea Temim of Princeton University in Princeton, New Jersey, a co-investigator on the program.

Cassiopeia A is a prototypical supernova remnant that has been widely studied by a number of ground-based and space-based observatories, including NASA's Chandra X-ray Observatory. The multi-wavelength observations can be combined to provide scientists with a more comprehensive understanding of the remnant.

Dissecting the Image

The striking colours of the new Cas A image, in which infrared light is translated into visible-light wavelengths, hold a wealth of scientific information the team is just beginning to tease out. On the bubble's exterior, particularly at the top and left, lie curtains of material appearing orange and red due to emission from warm dust. This marks where ejected material from the exploded star is ramming into surrounding circumstellar gas and dust.

Interior to this outer shell lie mottled filaments of bright pink studded with clumps and knots. This represents material from the star itself, which is shining due to a mix of various heavy elements, such as oxygen, argon, and neon, as well as dust emission.

"We're still trying to disentangle all these sources of emission," said Ilse De Looze of Ghent University in Belgium, another co-investigator on the program.

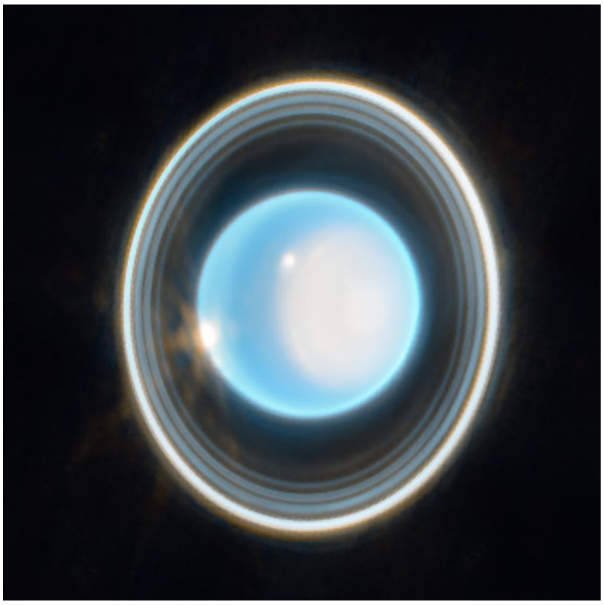
The stellar material can also be seen as fainter wisps near the cavity's interior.
Perhaps most prominently, a loop represented in green extends across the right side of the central cavity. "We've nicknamed it the Green Monster in honour of Fenway Park in Boston. If you look closely, you'll notice that it's pockmarked with what look like mini-bubbles," said Milisavljevic. "The shape and complexity are unexpected and challenging to understand."

Origins of Cosmic Dust -- and Us

Among the science questions that Cas A may help answer is: Where does cosmic dust come from? Observations have found that even very young galaxies in the early universe are suffused with massive quantities of dust. It's difficult to explain the origins of this dust without invoking supernovae, which spew large quantities of heavy elements (the building blocks of dust) across space.
However, existing observations of supernovae have been unable to conclusively explain the amount of dust we see in those early galaxies. By studying Cas A with Webb, astronomers hope to gain a better understanding of its dust content, which can help inform our understanding of where the building blocks of planets and ourselves are created.
"In Cas A, we can spatially resolve regions that have different gas compositions and look at what types of dust were formed in those regions," explained Temim.
Supernovae like the one that formed Cas A are crucial for life as we know it. They spread elements like the calcium we find in our bones and the iron in our blood across interstellar space, seeding new generations of stars and planets.
"By understanding the process of exploding stars, we're reading our own origin story," said Milisavljevic. "I'm going to spend the rest of my career trying to understand what's in this data set."
The Cas A remnant spans about 10 light-years and is located 11,000 light-years away in the constellation Cassiopeia.

- NASA's Webb scores another ringed world with new image of Uranus

Date: April 6, 2023
Source: NASA/Goddard Space Flight Centre



This zoomed-in image of Uranus, captured by Webb's Near-Infrared Camera (NIRCam) Feb. 6, 2023, reveals stunning views of the planet's rings. The planet displays a blue hue in this representative-colour image, made by combining data from two filters (F140M, F300M) at 1.4 and 3.0 microns, which are shown here as blue and orange, respectively
Credits: NASA, ESA, CSA, STScI. Image processing: J. DePasquale (STScI)
Download the full-resolution version from the Space Telescope Science Institute.

Following in the footsteps of the Neptune image released in 2022, NASA's James Webb Space Telescope has taken a stunning image of the solar system's other ice giant, the planet Uranus. The new image features dramatic rings as well as bright features in the planet's atmosphere. The Webb data demonstrates the observatory's unprecedented sensitivity for the faintest dusty rings, which have only ever been imaged by two other facilities: the Voyager 2 spacecraft as it flew past the planet in 1986, and the Keck Observatory with advanced adaptive optics.
The seventh planet from the Sun, Uranus is unique: It rotates on its side, at roughly a 90-degree angle from the plane of its orbit. This causes extreme seasons since the planet's poles experience many years of constant sunlight followed by an equal number of years of complete darkness. (Uranus takes 84 years to orbit the Sun.) Currently, it is late spring for the northern pole, which is visible here; Uranus' northern summer will be in 2028. In contrast, when Voyager 2 visited Uranus, it was summer at the south pole. The south pole is now on the 'dark side' of the planet, out of view and facing the darkness of space.
This infrared image from Webb's Near-Infrared Camera (NIRCam) combines data from two filters at 1.4 and 3.0 microns, which are shown here in blue and orange,

respectively. The planet displays a blue hue in the resulting representative-colour image. When Voyager 2 looked at Uranus, its camera showed an almost featureless blue-green ball in visible wavelengths. With the infrared wavelengths and extra sensitivity of Webb we see more detail, showing how dynamic the atmosphere of Uranus really is.

On the right side of the planet there's an area of brightening at the pole facing the Sun, known as a polar cap. This polar cap is unique to Uranus -- it seems to appear when the pole enters direct sunlight in the summer and vanish in the fall; these Webb data will help scientists understand the currently mysterious mechanism. Webb revealed a surprising aspect of the polar cap: a subtle enhanced brightening at the centre of the cap. The sensitivity and longer wavelengths of Webb's NIRCam may be why we can see this enhanced Uranus polar feature when it has not been seen as clearly with other powerful telescopes like the Hubble Space Telescope and Keck Observatory.

At the edge of the polar cap lies a bright cloud as well as a few fainter extended features just beyond the cap's edge, and a second very bright cloud is seen at the planet's left limb. Such clouds are typical for Uranus in infrared wavelengths, and likely are connected to storm activity.

This planet is characterized as an ice giant due to the chemical make-up of its interior. Most of its mass is thought to be a hot, dense fluid of "icy" materials -- water, methane, and ammonia -- above a small rocky core.

Uranus has 13 known rings and 11 of them are visible in this Webb image. Some of these rings are so bright with Webb that when they are close together, they appear to merge into a larger ring. Nine are classed as the main rings of the planet, and two are the fainter dusty rings (such as the diffuse zeta ring closest to the planet) that weren't discovered until the 1986 flyby by Voyager 2. Scientists expect that future Webb images of Uranus will reveal the two faint outer rings that were discovered with Hubble during the 2007 ring-plane crossing.

Webb also captured many of Uranus' 27 known moons (most of which are too small and faint to be seen here); the six brightest are identified in the wide-view image. This was only a short, 12-minute exposure image of Uranus with just two filters. It is just the tip of the iceberg of what Webb can do when observing this mysterious planet. In 2022, the National Academies of Sciences, Engineering, and Medicine identified Uranus science as a priority in its 2023-2033 Planetary Science and Astrobiology decadal survey. Additional studies of Uranus are happening now, and more are planned in Webb's first year of science operations.